A research trajectory driven by scaling out: from a detailed farm model (SEDIVER) to a participatory board game (Forage Rummy)

Guillaume Martin

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FSD5 Proceedings

FSD Agricultural systems by design

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"Multi-functional **farming systems** in a **changing world**"

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FOREWORD

Eight years after the launching of the FSD (Farming Systems Design) initiative in Catania (2007), the European Society for Agronomy (http://www.european-agronomy.org) has been mandated to organize its fifth symposium with the specific objective to strengthen the interdisciplinary and methodological focus of FSD. The overall objective is to promote research and capacity building on methodologies for the analysis and design of Agricultural Systems on a worldwide level. The research focus of this FSD community is the farm system level, the interactions and feedbacks at lower and higher levels of integration and the tools and methods required for understanding and implementing multi-functional farming systems expressing good trade-offs between agricultural production and ecosystems services. In a time when challenges for farming systems are increasingly defined by other systems operating at higher scales (food security, climate change, natural resource conservation, poverty alleviation….) it is important to keep an active scientific community sustaining innovation and capacity building on farming systems and their interfaces with those embedding systems and global issues.

These proceedings are aimed to serve as a compendium of the on going research in the FSD domain when considered worldwide and across the various sectors of agriculture (including fish-based systems). They include all the presentations (orals and posters) selected by the Scientific Committee of the 5th Farming Systems Design conference held in Montpellier (France) from September 7 to 9, 2015 (http://fsd5.european-agronomy.org/). A part of these communication have also been selected to compose special issues of major journals in the domain (Agricultural Systems and European Journal of Agronomy) and others will give raise to individual submissions in other journals.

The major achievements and challenges of the FSD approach are browsed through the 6 short sessions of the symposium "Farming Systems Design in Action: Methods, Achievements and Challenges" and are further developed and illustrated in the thematic sessions covering:

- *The grounds of the FSD approach* in quantitative analysis of crops (session T1. Assessing performances and services of cropping systems) and farms (T2. Assessing performances and services of farming systems).
- *The research frontiers on methodologies* for systems experiments at field level (W3. Cropping systems design: what can we do with field experiments and expert knowledge?), support of transition pathways at farm level (W4. Farms in transition), integrated analysis (T7. Scaling up from farm to landscape and multiscale scenario analysis of agricultural systems) and design (T8. Co-design and co-innovation with farmers and stakeholders) of agricultural systems.
- *A specific focus on crop models* (T3. Crop modelling and yield gap analysis for agricultural systems analysis and design) *and farm models* (T4. What's new with bio-economic models for the analysis and design of agricultural systems?) and the way they can be developed and used to sustain system's analysis and design.
- *Three typical challenges* on which the multi-scale and multi-domain FSD approach is likely to bring significant breakthrough: T5. Designing Climate Smart Agricultural Systems; T6. Designing sustainable agricultural systems with legumes; W6. Pathways for sustainable intensification of African agriculture?
- *Applications of the FSD approach to specific types of farming systems*: W1. Animal-based systems and crop-livestock interactions at farm and territory level; W7. Aquaculture systems, W2. Annual crops based systems; W5. Silvo-arable and silvo-pastoral systems.

Prof. Jacques Wery

(FSD5 Chair and ESA Executive Secretary)

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Co-chair: Marie Gosme, INRA

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Co-chairs: Philippe Lecomte, CIRAD & Liang Weili, Hebei Agricultural University

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Chair: Patrick Dugan, WorldFish Center
Co-chair: Lionel Dabbadie, CIRAD

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Andrew Thorne-Lyman, Sven Genschick, Michael J. Phillips, Shakuntala H. Thilsted & Patrick Dugan

Plenary symposium
"Farming Systems Design in Action: Methods, Achievements and Challenges"

Systems Analysis for management and design in Agriculture: can we do it with only two concepts ?

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1 Challenge

In many countries of the world, systems analysis is seen as a major driver of innovation and sustainability improvement in agriculture by research institutions, by development agencies but also by private companies and advisory services. On one side the transition towards productive and resource efficient systems (agroecology, sustainable intensification…) requires more knowledge and management of ecological processes. This implies to focuss on interactions and emerging properties, two key components of a system's analysis, rather than on relationships between input and output of a black box. On the other side the performances and sustainability of the farming systems are increasingly defined by other systems (food system, climate change, resources conservation, poverty alleviation, sustainable development…). This implies to work on the three other components of a system's analysis that are limits, environment and flows (e.g. Lamanda *et al.*, 2012) rather than "escaping" from the farming system to work on its embedding or co-existing systems. Managing or designing such complex agricultural systems (AgSys) require science-based operational frameworks combining all these system's components and at the proper scale (field, farm, landscape…).

We argue that this can be achieved with only two concepts that support the development of methodologies across the various scales of AgSys. Discussions during the 5th Farming Systems Design symposium will provide the opportunity to analyse if these concepts are operational in any type of agriculture and research posture and which other concepts are required to complete the framework.

2 Concepts and scale integration

As shown by LeGal *et al.*, (2011) AgSys can be analysed as nested hierarchical systems with three sub-systems from quite different domain: (i) a biophysical domain composed of ecological processes at stake in plants, soils, animals (the "process-based operating" sub-system); (ii) a technical domain where techniques are combined in a coherent set to achieve farmers objectives under a limited set of machineries, land, input and labour (the "technique-based managed" sub-system); (iii) a decision system made of objectives and decision rules (the "human-based decision" sub-system). Each of these domains can be the system under study in a research activity but the design of innovative systems requires to adress the whole, as environmental sustainability emerge from the first domain while economic and social sustainability emerge from the two others. In the seek for a trade-off between parsimony and completeness in system's analysis (Lamanda *et al.*, 2012), we propose that every AgSys can be defined by the combination of two concepts, the other aspects and especially the human component of farms being captured in the interactions with other systems.

2.1.The Agrosystem and its basic processes

An *Agrosystem* (As) can be defined as a biophysical « controlled » system meaning that, in contrary to natural systems, its structure and a large part of its input and output are managed by a « pilot » (generally a farmer) in order to derive plant (or animal) production(s) as well as ecosystems services (Lamanda *et al.*, 2012). From this definition and agro-ecosystem can be understood as a combination of As (which are controlled by one or several farmers) and ecosystems which are generally not under the control of a pilot. An As is analyzed and managed as a combination of desired plants (productive plants and service plants) and undesired plants (weeds), of desired (e.g. worms) and undesired (e.g. pests) animals and of a set of soil horizons. It can be considered at any scale from a m², a field, a landscape or the cultivated area in a region. Our experience of conceptual modelling of As, mainly at field level, with the protocol of Lamanda *et al.* (2012) showed that, in order to avoid over-complexification, the structure of the system should be built with a unique type of component, that we called the "*Basic Agrosystem Process*" (BAP), which is an extension to soil-plant-animal systems of the basic plant process defined by Wery (2005). A BAP is defined by three attributes:

- It can be quantified or specified at a daily time-step and at the level where resource capture or sharing has a meaning (e.g. m² for the example of the daily net primary production of each species in an agroforestry system). This n level is called the level of "Analysis" of the system.
- It is a major driver of the performance, service or emerging property under study and allows to define the problem that the conceptual model is aimed to address. This n+1 level is called the level of "Relevance" and it is expressed at a more aggregative level (in space and time) than level n (in the above example it would be biomass produced per ha and per year for each of the two species in association).

- The BAP can be supported by knowledge on functions of plant organs, soil aggregates or animal at a lower level (n-1) which is called the “Functional” level.

2.2. The Activity

The technical system by which a farmer “control” at least part of the BAPs of an As can be described with the concept of “*Activity*” (Act), which is widely used in bio-economic models of AgSys (Flichman *et al.*, 2011). An Act is a coherent set of techniques using farm resources (land, labour, money), inputs (fertilizers, pesticides, energy….), and natural resources (land, water, biodiversity…):

- to provision a service to the AgSys. The output of an Act can be money from direct selling (eg. wheat grain), resource to another activity (eg. forage from cropping system provided to the animal sub-system), money from non productive services (e.g. on farm tourism, Environmental Services such as C sequestration),

-to provision a service (or dis-service) to another system: food for the household, quality water to refill a water table, habitat to biodiversity, landscape for recreation…

An Act (e.g. wheat crop) may provide several services (e.g. grain, straw, C sequestration) or di-services (e.g. N leaching) and a given service (e.g. C sequestration) can be provisioned by several act (e.g crops, grasslands, trees) (Flichman *et al.*, 2011).

As for the As, the Act concept can be used to analyse a problem at field level (e.g. a wheat field), at farm level (e.g. all wheat fields managed on the same way by a farmer), at landscape level (e.g. the area on which a cooperative collect wheat) or at global scale (the wheat production area of a food system).

3 Revisiting Agricultural Systems definition

We hypothesize (Fig. 1) that these concepts of As and Act and their interrelationships should allow for the “conceptualization of a problem” in agriculture into an *Agricultural System* (AgSys), defined as a complex controlled system combining biophysical processes and technico-economic activities at one of the above scales or across these scales. In addition to providing a definition to the widely used but poorly defined concept of AgSys, this approach allows to manage the multi-scale and multi-domain dimensions of challenges for agricultural systems analysis, assessment or design at the interfaces with other socio-ecosystems (food security, climate change…). Each of these concepts are supported by an intense and diversified activity of modelling (mainly dynamic process-based modelling for As and bio-economic modelling for Act) and their interrelationships at multiple-scales support integrated modelling of AgSys (van Ittersum *et al.*, 2008).

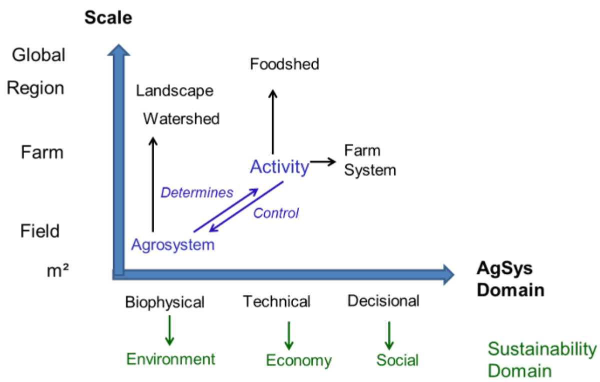

Fig. 1. Agricultural systems defined as a multi-scale and multi-domain combination of Agrosystems and Activities.

This framework also allows for studies focussed on specific levels and domains such as the *Farm System* (i.e. a combination of activities with farm territory and household as boundaries), the *Farming System* (as a population of individual farm systems in a territory (Giller, 2013), or the *Cropping System* (as a combination of activities controlling the dynamic of an Agrosystem on a set of fields).

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Designing ecological intensive farming systems in China: Challenges and strategies

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1 Introduction

Production of food grains has increased from less than 300 to 600 million tons in China over the past 50 years. However, this great achievement has been accomplished at high resource, environmental, and economic costs. Water shortages, environment deterioration, and increasing production cost become more and more prominent in China, and these represent the major challenges to sustainable agriculture development (SAD)(Ju *et al.*, 2009 ; Guo *et al.*, 2010; Carberry *et al.*, 2013). Therefore, it is crucial for SAD to design novel farming systems that are input-resource efficient and environmental safe. The objective of this study was to assess agricultural input efficiency in China and identify the challenges and strategies for designing ecologically sensitive intensive farming systems in China.

2 Materials and Methods

Agricultural input efficiency data related to production of gains in China was adapted from statistical bulletins of agricultural production published in the Chinese Agricultural Statistics Yearbook from 1979 to 2013. We selected the wheat-maize (*Triticumaestivum* L. - *Zea mays* L.) double cropping system (CS) in the North China Plain (NCP) as a case study due to the NCP being a region of typical intensive farming with scarce resources. The case study data were collected from farmers who participated in a survey (120 questionnaires) and on-farm experiments in Wuqiao, Hebei Province in 2013. The technological efficiency (Y/Y_N: Y is the yield of the farms and Y_N is the simulated yield by DNDC model with the same nitrogen input conditions) was also analyzed based on the questionnaires.

3 Results - Discussion

Food grain production in China increased from 3.32×10^8 to 6.02×10^8 t from 1979 to 2013, which was nearly a doubling (Fig. 1). The yield per hectare also nearly doubled from1979 to 2013, from 2785 to 5377 kg/ha. In addition, agricultural inputs also increased rapidly. For example, the fertilizer consumption increased 4.4 times, pesticides increased 1.3 times (compared to 1991 due to a lack of data before 1991), and effective irrigation area increased by 41%. In the last 30 years, the requirements of fertilizers, pesticides, effective irrigation area, total power of agriculture machinery, rural electricity consumption, and agriculture supporting expenditure expenses have been increased dramatically by 18- 34%. In addition, the efficiency of agriculture input-resources has tended to decrease and the economic cost per unit of area has almost increased by 2 times during this period.

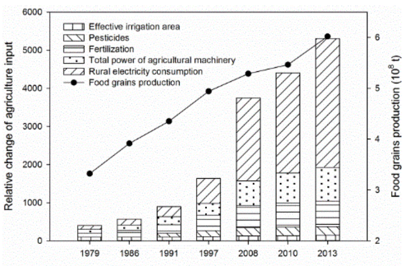

Fig. 1. Relative change in agriculture inputs and food grain production (10^8 t). The input items in 1979 were regarded as 100, apart from the pesticide consumption, for which 1991 was regarded as 100 because of a lack of data before 1991.

The conventional intensive farming system has resulted in not only an increase in the cost of input-resources, but also resulted in severe pressures on the eco-environment in China. Further agricultural development in most of northern China is challenged by serious water shortages, with the area affected being greater than 30 billion m^3. Groundwater has been universally over-exploited in the NCP and Sanjiang Plain of Northeast China. In addition, agricultural non-point source pollution has been aggravated due to the high input of chemical fertilizers. Currently, nearly 1.3×10^7

ha of cultivated land have been affected by pollution from pesticides, and 3.3×10^6 ha of cultivated land have been exposed to a moderate degree of pollution or worse. Therefore, there is an urgent requirement to develop an ecologically safe intensive farming system for use in China. This case study in the NCP indicated that the usage efficiency of fertilizers and irrigation water for most farmers was still at a low level. Among the 120 questionnaires, more than half showed high nitrogen inputs with low outputs and approximate one third with low inputs with low outputs, which means that less than 20% of the farmers achieve a reasonable result (Fig. 2). In addition, the irrigation efficiency varied greatly (Fig. 3). These indicate that yield increases from only adding more inputs have not been realized. The technological efficiency of the wheat-maize cropping system was only around 0.7 in Wuqiao, and the technological efficiency higher than 1 only accounted for 2.1% of the survey. The land per family is only about 0.4 ha, and the net income from the wheat-maize cropping system is ~$1960/ha in the NCP, and this is not adequate for the farmers to meet their needs. Thus, it is critical to design novel farming systems with high input-resource efficiency, which are environmentally safe and give high incomes to for farmers. It is essential to improve crop yields by integrated soil and crop management practices, rather than only by increasing inputs of chemical fertilizers, pesticides, and plastic films, especially not by increasing the input rate of a single nutrient. In addition, to promote greater efficiency, farm sizes should be increased.

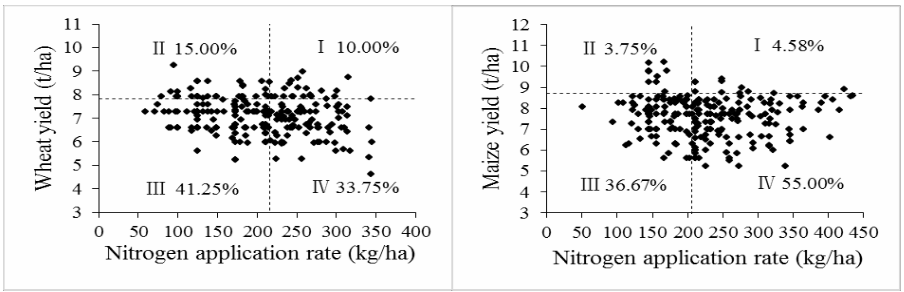

Fig. 2. Yield distributions with different nitrogen application rate based on farmer questionnaires. I, II, III, and IV denotes ideal inputs with high yields, high inputs with high yields, low inputs with low yields and high input with low yields, respectively.

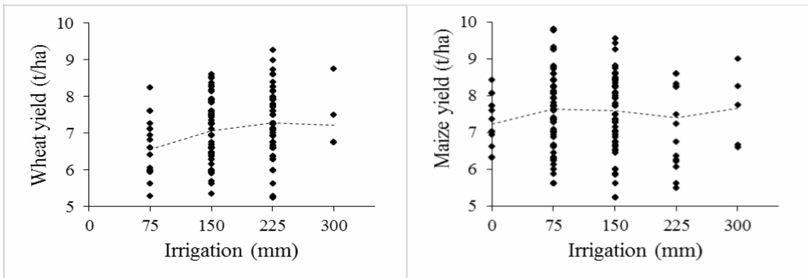

Fig. 3. Yield variations under different irrigation levels based on farmer questionnaires.

4 Conclusions

Challenges (e.g., high inputs, shortage of resources and laborers, and agro-environmental pollution) lie ahead for China's agriculture. Therefore, a conversion of the traditional farming system to a novel ecologically sensitive intensive one could be a solution to these issues. This research suggests that it is necessary to establish a resource-environment subsidizing system based on environmental capacity, ecological safety, and level of farm inputs; this will help to regulate farmer behavior and enhance their environmental awareness. Above all, coordinated efforts by policy makers, researchers, extension agents, farmers, and other relevant stakeholders are important keys to the successful design of a new farming system.

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From cropping systems design towards sustainable agrifood systems design: new challenges for agronomists

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1 Introduction

Instead of working to increase the sustainability of agriculture and food separately, what benefit would be gained by reconnecting the innovation dynamics in both domains, improving the entire agrifood system?
The agrifood system (« the way in which people organize themselves, in space and in time, to obtain and consume their food » Malassis, 1994) includes production, trade, processing, distribution and consumption activities that are in very close interaction with each others. Because both the stakeholders and the researchers are specialists in one or other of these segments, innovation in agriculture is today carried out separately from innovation in processing or nutrition (Spiertz, 2012). Our objective is to specify the consequences, for the design of innovations, of an integrated approach, taking the whole of the agrifood system into account.

2 A design of coupled innovations, involving production, processing and consumption

A first approach consists of transferring the solution of a problem to another level of the agrifood system. Usually, to optimize the processing procedure, agrifood industry imposes standards of marketable quality on farmers (Allaire, 2010), or draw up contracts with precise specifications (Hensen & Humphrey, 2012), thus configuring the raw material. Innovation in agriculture relates to the technical practices or cropping systems which make it possible to attain the quality desired by the processors. Innovation can then take the form of rules for adapting the techniques to the environment, or for excluding certain cropping systems (for low protein malting barley, see for ex. Le Bail & Meynard, 2003). Innovation can also take the form of specifications with imposed techniques (for ex., following a precise schedule for the production of vegetables for the canning industry). It is less frequent for a production problem to be solved by innovating in the processing procedure. For ex., today the need for high-protein wheat grains to make bread, leads to field applications of large amounts of nitrogen fertilizer, which increases losses of non-used nitrogen. Producing bread with low-protein wheat grains or even without any wheat protein at all (Benatallah *et al.*, 2012) could be possible to the condition of changing the technological process or the formulation. The technological innovation could help to decrease the environmental impacts of wheat production, but changes are required from several actors, including bakers, millers, cooperatives, farmers and consumers.
Indeed, a more ambitious coupling consists of designing simultaneous innovations coordinating the domains of production, processing and consumption, while taking into account synergies or antagonisms between innovations. A good example of this is the development of short distribution channels for vegetables in the industrialized countries; it is based on innovations that are both organizational and agronomic, as the production methods are very different from those used in long distribution channels (Lefèvre *et al.*, 2015). Another example is the objective of reducing the consumption of animal protein, to the benefit of plant proteins, which would be necessary for global food safety (Baroni *et al.*, 2006). Increasing the legume family, which produces protein-rich grains, would be interesting: as they fix atmospheric nitrogen, they do not require nitrate fertilizer, thus saving fossil energy resources and emitting few greenhouse gases (CO_2 and N_2O). However, in Europe, there is still very little legume production for human consumption. Developing it will require the coordination of different innovations to make the crop, agro-industrial use and legume consumption attractive to the stakeholders, and particularly to consumers precooked preparations making them easy to use in cooking; technological processes enabling the grains to be extracted from new ingredients; innovative crop successions and intercrops including grain legumes; breeding of productive varieties suitable for food uses and for production and processing techniques… (Voisin *et al.*, 2014). Connecting simultaneous innovation procedures in these various domains, to ensure they are compatible and maximize their synergies, requires the design procedures to be revised, and the functioning of the R&D departments of the companies concerned to be reorganized. Theoretical frameworks of innovative design (Le Masson *et al.*, 2006) offer pathways for such an ambition: innovative design, that refers to a process of exploration aimed at satisfying very new expectations, seems to be particularly relevant for coupled innovations, whose identity is not fully specified in the early stages of design, and become progressively more precise as the designed objects take shape.

3 Collective design in innovation niches

The previous examples and the literature (e.g. Bos, 2008) show that innovation for the sustainability of agrifood systems may rely on broad-based stakeholders collectives. The innovation process unfolds in a sociotechnical regime, defined by a collective of stakeholders and their networks, practices and knowledge, the technologies they use, their collective representations, the standards and rules they adopt. The regime configures the innovation process: innovations that do not call into question the networks of stakeholders, the social representations and the standards, and which are in synergy with innovations previously diffused, have more chance of seeing the light of day and being diffused (path dependency). Consequently, the dominant socio technical regime is locked-in by this path dependency, and it should not be expected that radical innovations will emerge. As underlined by the sociotechnical transitions theory, radical changes are prepared outside the dominant sociotechnical regime, in "innovation niches", composed of minority actors who convey challenges for the future (Kemp *et al.*, 1998). In these niches emerge new networks of stakeholders, new practices, new technologies or modes of organizing exchanges. If the socio-political context develops in their favor, or if, in the name of the general interest, they have the support of public authorities, they will be able to be diffused in the dominant regime (Geels, 2002).

Thus the transition of agrifood systems requires not only an effort of organizational and technical innovation in the niches, but also institutional and regulatory innovations (the latter supported by public authorities) to favor the hybridization of the niches with the dominant regime. Let's take the example of crop diversification. The increase in international trade has supported the specialization of agricultures, as each nation, each region, develops the productions where it has a competitive advantage: soybean in the argentinean Pampa, wheat and oilseed rape in the Paris basin, the oil palm in South-East Asia, the banana in Central America…. The result is wide expanses of monocultures and short rotations, which are prejudicial to biodiversity and are often only possible with the massive use of pesticides. In France, although crop diversification is seen as desirable by many stakeholders and the public authorities, there is a technological lock-in around the dominant species, which blocks or at least greatly handicaps the development of minor species, even though new outlets could exist for their products. Meynard *et al.* (2014) showed, in coherence with the transition theory, that the situation could be unlocked if there were a simultaneous and coordinated mobilization of the levers of: i) genetic innovation, i.e. the selection of diversification species; ii) agronomic innovation, i.e. successions that include these crops and iii) technological innovation, such as processing procedures opening up new outlets for minor species. But this would also involve levers which relate directly to public authorities, intended to facilitate the consolidation of new sectors, via arrangements to coordinate actors or standards that help the market to institutionalize those diversification products (Meynard *et al*., 2014). Designing in the niches, and with the actors in the niches, does not mean that agronomic and technological innovations will necessarily be only for a limited audience, but their appropriation by a wider audience will depend on social, institutional or regulatory innovations, which will need to be placed in the schedule of interdisciplinary research involving the agronomic sciences.

4 Conclusions

For agronomists, designing in agrifood systems involves a renewal in the organization of design: coordinating the design of a wide variety of innovations (agronomic, technological, organizational, institutional), integrating new knowledge linked with new social pressures (ie. nutrition, health and pleasure) and public policies, and redefining the round table of stakeholders engaged in design to lock-out the dominant regime.

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Quantifying beef production gaps of two farming systems in the Charolais basin, France

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1 Introduction

Sustainable intensification of livestock production systems is a way to realise the increasing global demand for meat. Current empirical studies reveal meat production levels obtained by best practices, but do not clarify the theoretically achievable (*i.e.* potential) and feed limited production. Potential production is defined by animal genotype and climate only (Fig. 1). Feed limited production is determined by genotype, climate, availability of drinking water, and the quality and quantity of feed. Actual production is the production that farmers achieve in practice. This production level is, next to genotype, climate, water, and feed, determined by diseases and stress in livestock (Van de Ven *et al.*, 2003).

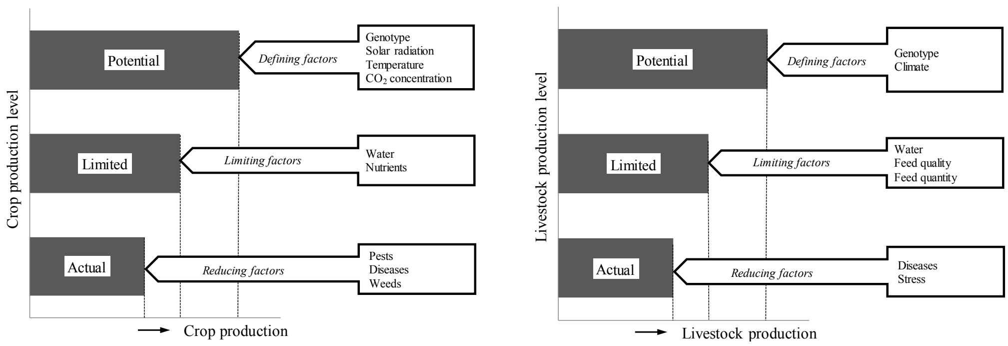

Fig. 1. Potential, limited, and actual production of crops (left) and livestock (right).

In crop production, the production ecological concepts of potential, limited, and actual production (Fig. 1) (Van Ittersum & Rabbinge, 1997) are generally used to give insight in the scope to increase production from their actual levels (Van Ittersum *et al.*, 2013). These concepts are also applicable to livestock production (Van de Ven *et al.*, 2003 ; Van der Linden *et al.*), but so far the effects of genotype, climate, feed quality, and feed quantity have not been quantified systematically using production ecological concepts in livestock production. This research, therefore, aims to quantify potential, feed quality limited, and actual beef production in two French beef production systems at herd level. Feed quantity limitation is not included.

2 Materials and Methods

A mechanistic, dynamic model was developed to simulate beef cattle growth based on genotype, climate, housing, feed quantity, and feed quality. This model is analogous to crop growth models that are based on the production ecological concepts. The beef cattle model combines feed digestion, thermoregulation, and feed utilisation sub-models in a novel way to simulate processes at animal level. Results from animal level are scaled up to herd level. Energy, heat, and protein flows are described in the model, which is programmed in R 3.0.2. Input data for the model are parameters for a specific genotype or breed, daily climate data, and information on housing, feed quality and feed quantity intake. The model was applied to two beef production systems with different feeding strategies of Charolais cattle in the Charolais Basin, France. System A corresponds to farm type 11111 and system B to farm type 31041 as described by Réseaux d'Elevage Charolais (2012). System A produced heavier animals and has a longer grazing period than system B. The fraction concentrates in the diet is larger in system B than in system A.
Potential production was expressed as a feed efficiency (FE, g beef kg^{-1} DM feed). Potential production in both systems was simulated with an *ad libitum* fed diet containing 65.8 % barley and 34.2% hay. This diet prevented feed quality and quantity limitation. Under potential production, FE was maximized at herd level, and all female calves were kept for replacement. Culling was set at 50% per year after birth of the first calf. Feed quality limited production was simulated with a diet containing concentrates and hay when cattle were housed during winter, and grass during other periods of the year. Concentrate intake (barley) was 4.8% of the DM intake in system A and 18.3% of the DM intake in system B,

which corresponded to the diet under actual production. Feed quality limited production was simulated with the same culling rates and slaughter weights as under potential production. Actual production was calculated from data provided by Réseaux d'Elevage Charolais (2012). Yield gaps were calculated as the difference between potential and actual production, and the difference between feed quality limited production and actual production. Relative yield gaps were calculated as the yield gap divided by potential or feed quality limited production.

3 Results and discussion

FE at herd level was highest under potential production and feed quality limited production, when male calves were slaughtered at 1000 kg. Potential production in systems A and B (Fig. 2) was slightly different (64.0 vs 64.4 g beef kg^{-1} DM feed). FE in system A was lower due to a longer grazing period and hence a higher energy requirement for grazing. Feed quality limited production, with the same culling rates and slaughter weights as under potential production, was lower in system A than in system B (51.7 vs 54.1 g beef kg^{-1} DM feed), which is explained by a lower fraction of concentrates in the diet. Actual production was lower in system A than in system B (24.9 vs 31.2 g beef kg^{-1} DM feed).

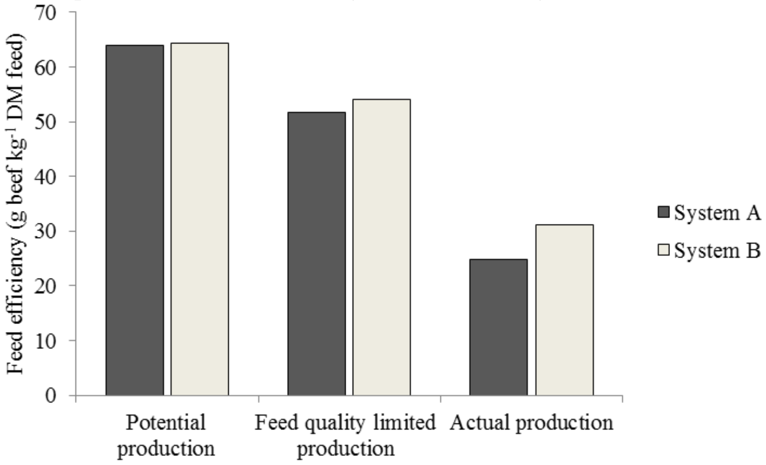

Fig. 2. Simulated feed efficiency in beef production systems A and B under potential, feed quality limited, and actual production.

The relative yield gap between actual and potential production was 61% in system A and 52% in system B, and the relative yield gap between actual and feed quality limited production was 52% in system A and 42% in system B. The latter yield gaps can be explained by feed quality limitation, as well as stress and diseases. In crop production, yields tend to plateau at 75-85% of potential or water limited production (*i.e.* minimum yield gaps equal 15-25%), and further yield gap mitigation is not economically or practically feasible (Van Ittersum *et al.*, 2013). In our study, simulated yield gaps are much larger than such minimum yield gaps. Grazing and suckler cow premiums might not urge farmers to mitigate current yield gaps, but also social factors (*e.g.* labour availability) may play a role. More model validation is required to further improve accuracy of the simulation results. Multiplying beef production (kg beef t^{-1} DM feed) and feed crop production (t DM ha^{-1} year^{-1}) results in the beef production per unit of land (kg beef ha^{-1} year^{-1}). Quantifying potential and limited production of crops *and* livestock according to production ecology allows us to assess land use per kg of animal product.

4 Conclusions

The production ecological concepts were successfully applied to livestock production. We benchmarked actual beef production relative to potential and feed quality limited production of two French beef production systems at herd level. Results indicate that potential production is more than two times the actual production in both systems. Hence, there is considerable scope to increase beef production in the Charolais basin, from a bio-physical perspective.

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PATH DEPENDENCE AND TRANSITION: A THEORETICAL PERSPECTIVE ON FARM STRUCTURES

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Farming systems are closely connected with the regional farm structures. Even within and between regions with similar agricultural conditions (climatic, soil, infrastructural, economic, social), farm structures and farming systems can be very heterogeneous. One general explanation for this heterogeneity is the path dependence of structural change (Balmann, 1995). Current agricultural structures are shaped by historical events and previous pathways. Agricultural structures tend to be locked in certain regimes and evolve at a rather slow speed. This inertia is caused by long investment cycles, slow changes in human and financial capital, persistent institutions, specific mental models of the actors and state conserving agricultural policies. As a result, agricultural structures appear often resilient to external changes.

Path dependence is however not absolutely perpetual. Under certain conditions, farm structures and related farming systems may be subject to abrupt changes. Such changes can be considered as structural transitions or regime shifts. On the one hand, these changes can be triggered by pull factors such as path breaking and path creating activities of certain actors or by new opportunities resulting from new technologies or markets. On the other hand, these changes may also be caused by push factors such as changing environmental conditions (natural, economic, institutional) which erode the preconditions of the current farming structures and systems. An erosion of preconditions may also result from an unsustainability of the existing system. Often, pull and push factors complement each other for a transition.
Before however, fundamental structural changes occur from such causes, some additional facilitators or catalysts of changes are necessary. One reason is that a “valley of tears” might have to be overcome or is assumed by the actors as to huge. Another reason is that structural changes generate winners and losers.

Path dependent systems typically have multiple optima. The transition from one optimum to another one implies then the necessity to cross a local minimum, i.e. a “valley of tears”. Accordingly, transitions require investments. These only pay off, if the additional value of the new optimum is higher than the investment costs. Even if the additional value is sufficiently high, there is still the question whether the payoffs are to the benefit of those who are investing. Another question is whether it is possible to coordinate a transition among the actors. Reasons for such coordination problems can result from communication deficits, moral hazard, and bounded rationality. With regard to structural changes, all these types of obstacles are to be expected (Balmann et al., 2006). One problem are sunk costs of existing assets which would be devaluated. Another reason is that a modernization on one stage of a supply chain may also require investments on other stages, and last but not least, smart solutions for successful transitions need to be identified.

Although, structural changes which occur slowly or as transitions have to be seen as important drivers of economic development, structural changes are often perceived negatively. This can partly be explained by the Schumpeterian argument of “creative destruction” saying that “*the process of industrial mutation (…) incessantly revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating a new one*” (Schumpeter, 1942). Over the past two centuries, structural changes affected particularly the agricultural sector which nowadays contributes in western economies only marginal shares to GDP and employment while two hundred years ago, agriculture was the main sector in Europe and even more the US (USDA, 2001). This development was driven by enormous productivity increases within agriculture and by fast economic growth outside agriculture. A side effect was a substitution of labor through capital. As a result, on the one hand incomes of many farmers and their families increased while many other farms exited, i.e. there were winners and losers.

The process of structural change is neither smooth, nor are farms homogeneous. The distribution of farm sizes is skewed and follows to some degree the Pareto rule, saying that a minor share of large farms farm a major share of total land and produce a major share of total production. These differing preconditions imply that farmers have quite different opportunities to develop as well as differing perceptions about the likely impacts of changes. Because of the skewness, usually a large fraction of farms is on the downside with rather poor development perspectives. As experimental results show that loss aversion affects individual behavior more that potential gains (Kahneman and

Tversky, 1984), the uncertainty on the implications of substantial innovations and eventually resulting subsequent path breaking structural adjustments causes often more skepticism about losses that enthusiasm about the gains.

Both factors, the skewness of individual development perspectives and the loss aversion provide additional explanations why many farms are concerned about structural changes. These concerns have further implications. If the original cause of structural change is that the current system is under pressure to change (either because superior states exist or because its preconditions are eroded), the concerns of the potential losers may cause pressure to stabilize the existing system. If these attempts are successful, the external pressure to adapt may accumulate and cause a kind of subsidy trap (cf. footnote 2) in which the burdens to adapt towards superior solutions increase, as neither the sustainability problems are resolved nor the competitiveness of the current systems improves. This phenomenon resembles the Luhmannian problem of selfreproducing systems. Accordingly, "*systems develop own degrees of freedom, which they can exhaust as long as it is possible, that is, as long as the environment can tolerate it … The overall effect [of operational closure] however is … not adaptation, but amplification of deviations*" (Luhmann, N., 1997, p.133). Luhmann argued that social systems fulfill their function at the cost of developing autopoietic properties which lower their sensitivity to the complexity of their environment (Valentinov, 2014).

The above conceptual reflections will be analyzed for the future of the dairy sector after the abolition of the quota system. On the one hand, it will be illustrated that path braking activities of a few dairy farmers may trigger a fundamental change at the system level. On the other hand, it will be discussed which intrasectoral frictions may arise.

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Innovation by smallholder farmers for more diverse and intensive farming systems

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1 Introduction

The east Indian states of Jharkhand, Bihar and West Bengal are characterised by endemic poverty, high incidence and severity of malnutrition, and entrenched discrimination against women. Rice dominates local cropping systems and transplanted rice monoculture is the traditional farming practice. Rice also dominates traditional diets and contributes to widespread malnutrition. In similar communities in neighbouring Bangladesh up to 77% of household calorie intake is derived from rice, contributing to 'hidden hunger'. The dominance of transplanted rice also contributes to the disempowerment of women with the menial tasks of transplanting and hand weeding traditionally reserved for women. Against this background, an agricultural research for development project is working with local indigenous communities to diversify and intensify cropping systems, increase household income, improve food security and empower women farmers. The project is having positive impacts on crop productivity, household income, food security, and human capacity for independent innovation. This paper focusses on the process of engaging women farmers in the research process that leads to development of their capacity for solving problems and realising opportunities, including their role in developing more diverse and intensive farming systems.

2 Materials and Methods

The research is located in three tribal villages, Bhubhui and Talaboru in Jharkhand and Churinsara in West Bengal, all three on the East India Plateau. Average annual rainfall is around 1,200 mm, highly concentrated in the monsoon (June-October), and highly variable both within and between seasons. The landscape is undulating and soils variable ranging from mainly coarse textured soils in the uplands and medium-uplands, with finer textured soils in the lowlands. Transplanted rice is the dominant cropping system and while this system is well adapted in the wetter lowlands, it is a very risky proposition in the medium-uplands which dominate in terms of area. Rice is risky in the medium-uplands due to the unreliable timing and duration of ponding that is essential for transplanting (Cornish, *et al.*, 2015). The research is focussed on developing alternatives to transplanted rice in the medium-uplands. Options include vegetables, maize, and aerobic Direct Seeded Rice (aDSR) during the monsoon (*kharif*), and vegetables, pulses, oilseeds, and wheat post monsoon (*rabi*). The research is conducted on farm and experimental treatments are managed by farmers. Individual research farmers are selected from within local Self Help Groups previously established by PRADAN for development purposes. Participation in research through these SHGs facilitates individual and collective learning.

3 Results – Discussion

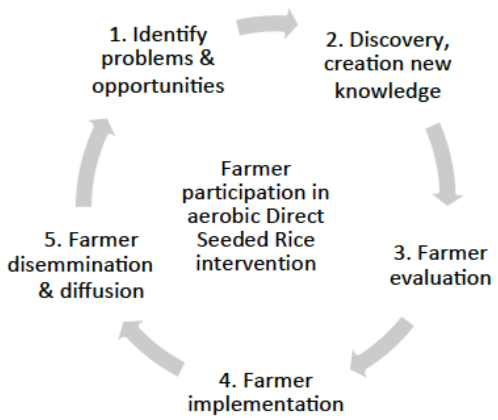

Fig. 1. Smallholder farmers play critical roles in the innovation of new farming systems.

Innovation is described here as the process by which new knowledge, discovery, invention, etc. is developed into commercial (or in this case including subsistence) practice. Figure 1 is employed as a framework for describing the active role of farmers in research and innovation using the example of aerobic Direct Seeded Rice as a case study.

1. Identification of problems and opportunities worthy of research

Potential research topics are identified in partnership with local farming communities. The research team hold discussions with Self Help Groups (SHGs) established by Professional Assistance for Development Action (PRADAN) to discuss current needs and future opportuities. Out of these discussions the initial problem of failed transplanted rice emerged and led to research comparing transplanted rice with aDSR under farmer-managed conditions. After several years of on-farm research new research questions have emerged, e.g. the importance of early sowing of the *rabi* crop necessitating early sowing and short duration cultivars of the preceding rice crop, and the improvement in soil physical conditions following cessation of puddling associated with ponding and transplanting.

2. Research, discovery, creation of new knowledge

The research involves side-by-side comparisons of the two rice systems (transplanted rice vs aDSR), including the possible sowing of a *rabi* crop following rice harvest, in farmer fields under farmer management. Farmers were involved in developing a locally acceptable version of aDSR including the absence of puddling, hand sowing of seed and fertiliser in lines, opportunistic ponding, and mechanical weeding between rows. Data is collected on basic soil and crop performance, as well as management inputs and practices. Farmers are involved in data collection and results are discussed collectively in the SHGs. Farmers make direct observations and pose new questions.

3. Farmer evaluation of the intervention

The small fields, close community and high population density result in many farmers observing the research fields. Farmers are free to observe progress at any time and free to draw their own conclusions. In recent years, when the monsoon has arrived late, transplanted rice has often failed and the aDSR treatment has performed comparatively well. Another attraction of aDSR is the reduced labour requirement, freeing women for more profitable use of their time. Farmers are also reporting improved soil physical conditions after aDSR leading to better *rabi* crop establishment. The area under aDSR is expanding each year indicating farmer acceptance.

4. Farmer implementation of the intervention

An integral component of this locally developed aDSR system is the use of manually operated implements for line sowing and between-row weed control. Demand for these simple implements currently outstrips supply. Farmers have initiated variations on the aDSR system, e.g. intercropping rice with a pulse crop (Black Gram, *Vigna mungo*), and relay sowing chickpea (*Cicer arietinum*) prior to rice harvest. These farmer initiated comparisons are evidence of a culture of experimentation emerging from the SHGs. Concerns with aDSR raised by farmers include choice of cultivar, fertiliser rates, weed management, and crop damage from pests associated with early maturity.

5. Farmer disemmination and diffusion. scaling out

The local SHG facilitates the process of data collection and results are quickly communicated within and beyond the SHG. Villagers inspect the research fields on a fortnightly basis often coinciding with data collection, stimulating much debate and discussion. Research farmers have also hosted field visits of over 200 farmers from neighbouring villages. Farmer-to-farmer communication has much greater credibility and influence than outside experts on farmer practice.

4 Conclusions

The key to diversifying and intensifying local cropping systems is the transition from transplanted rice to aDSR. This is partly because aDSR can be sown and harvested earlier than transplanted rice, making a *rabi* crop, with or without irrigation, possible. Also, the labour requirement of aDSR is much less than for transplanted rice, thus freeing up labour, particularly that of women, for more profitable and nutritious enterprises such as vegetables. The transition from traditional transplanted rice to aDSR represents a major change for farmers and researchers, both in thinking about, and the practice of, the rice-based cropping system. Aerobic Direct Seeded Rice represents not just a change in rice establishment method, but a transformation of the cropping system. The consequences of changing to aDSR include bio-physical, socio-economic and psycho-social effects. This complex chain of events requires a deep understanding of constraints and opportunities from participating farmers and is justification for the process of deep engagement of farmers in the research activity. Farmers play an active and essential role in all stages of the innovation cycle and there is evidence that farmers are developing independent capacity for innovation. Without this active farmer participation the aDSR intervention would be scaled out much slower, or possibly not at all in these regions.

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Analysing farming system design activities in the light of Design Studies concepts

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1 Introduction

Major environmental challenges and increasing societal demand for food and non food products lead to the necessity of a deep redesign of farming practices (Meynard *et al.*, 2012). This redesign generates a great deal of research in agronomy, about innovative solutions. Design Studies (Cross, 2007), which focus on the nature of design processes and their organization (e.g. Detienne 2006, Le Masson *et al*., 2013), provide useful concepts to address the methodological challenges that farming system design is now facing. Design is an active and deliberate process aiming at generating simultaneously concepts and knowledge, which might result in new products or new technologies, used by actors. As innovation is not only the aggregation of existing knowledge, design is a bridge process between research (as an activity of knowledge production) and innovation. In this paper, from our experience of several case studies, we analyse design in agriculture in the light of two concepts proposed by the Design Studies, *innovative design* and *users' activities.*

2 Redesign in agronomy calls for innovative design

As agriculture is currently facing many and sometimes contradictory challenges, agriculture calls for a considerable effort of *innovative design*, defined in Design Studies as a process of exploration aimed at satisfying completely new expectations. Opposed to rule-based design, which aims to gradually improve existing products or technologies without changing the objectives, innovative design is required when the identity of the objects to be designed is not *a priori* known (Le Masson *et al.*, 2006).
In order to meet the huge challenges of agriculture, agronomists developed various methods for innovative design of cropping and farming systems. First, model-based design helps to explore large combinations of techniques, to determine those that are the most suited to a set of specifications. Model-based design allows to predict long-term effects of the designed solutions, and to estimate impacts that are difficult /impossible to be measured (Bergez *et al.,* 2010). As models restrict the exploration to the scientific existing knowledge, other methods, were proposed, that make space for different sources of knowledge (expert and scientific, local and generic). They are grouped under the name "prototyping" that was initially used by Vereijken (1997) in agriculture. For instance, the prototyping design workshops of Reau *et al*. (2012) gather a large diversity of stakeholders, researchers and agricultural actors, bearing knowledge and points of view on objectives for agriculture. They are based on an animation enhancing the exploration of breakthrough innovations, designed to reach new objectives and to overcome the problems or impacts encountered in the present farming systems. A third method is the system experiment (Colnenne-David & Doré, 2014). It consists in implementing, assessing and improving prototypes of cropping or farming systems, integrating experts" knowledge in the system management and reframing it progressively (Meynard, 2015).The fourth method is the step-by-step design, aiming at progressively improving existing systems in order to adapt them to new objectives. It begins by a diagnosis on the present system, then changes are proposed and implemented, a new assessment is realised, in a continuous loop of progress (Meynard *et al.*, 2012). Finally, at the territorial scale, companion modelling, combining modelling and role-playing games (Etienne 2014), are powerful approaches to accompany the collective learning process and the design of innovative solutions involving a large diversity of actors. All these methods allow to build innovative farming systems or collective organizations of farming systems, the limits, purposes, and characteristics of which being unknown at the start of the design process.

3 Design is strongly linked with the users' activities

In agriculture, many actors and stakeholders, by their activities, contribute to the design of cropping or farming systems: design is highly distributed. Sometimes, some practices are designed and imposed on farmers by contracts or specifications from food processing firms. Other times, the target of collective firms being to optimize the logistics, these organizations impose to grow particular varieties in some locations, thus contributing to the design of the cropping systems. In other cases, farmers use monitoring tools, designed by pesticide or fertilizers sellers. Most often, cropping systems design is enhanced by the participation of the farmer in exchange groups involving other farmers and advisors (Compagnone, 2014). The methods presented above were developed to involve the knowledge, aims and means of action from all the actors concerned by the successful implementation of new farming systems. Indeed, in agriculture,

this implies that all the actors who by their activities influence the potential value and feasibility of a given farming system, contribute themselves to the design.
This distributed design process should adapt in a flexible way to the huge diversity of pedo-climatic conditions and socio-economic environments in which the innovative system will be implemented. Farms differ in terms of soil types, climatic conditions, available resources (human labour, machinery, economic resources), ecological vulnerabilities, surrounding agro-industries. Farmers also differ from each others in their vision for the future. Thus, it is not possible and not desirable to design innovations that might fit everywhere. Rather than designing a small number of „ideal" innovations, agronomists have to prepare and make available a diversity of solutions, in which farmers could choose, such as libraries of innovations (Meynard *et al.*, 2012;Guichard*et al.,* 2015). Agronomists face to this variety by designing either local systems, strictly adapted to local conditions, or generic solutions fitted to a large range of environments, thus leading to strategic choice to be done. They should be more involved in developing tools and methods helping farmers to innovate (and to assess their own innovations) and to adapt to their situation the innovations that have been judged interesting by others. Design Studies show that the implementation of a designed object is a creative process during the course of which both this object and the users" activities are reframed (Rabardel & Béguin, 2005). Design methods proposed by agronomists should allow taking on board use situations in a way that enables users to experiment the changes that might occur through the use of the designed artefact.

4 Conclusions

Design in agronomy should enrich its exploration and implementation methods, inspired from Design Studies. In this aim, it could be relevant to imagine original combinations of already existing methods presented in this paper, as each one has limits regarding the strong challenges for agriculture. For example, combining modeling, allowing assessing interactions, with local knowledge should be a great challenge for agronomists, leading to a renewal of models, and to the production of new types of knowledge for action, such as indicators for monitoring the long-term action or for allowing learning for farmers (Toffolini *et al.*, 2015).
Moreover these challenges also call for a renewal of the designer skills and design organizations. For example, a successful design workshop does not require a scientist putting on the table all the scientific knowledge, part of it being impossible to use in the local situations, but a combination of skills: scientists, experts with local knowledge, experts in innovations enhancing the exploration process, and a facilitator organizing the discussions and governing the design process (Reau *et al.*, 2012). To enhance this process, this huge call for design should require a change in the activities of people involved in design, and a change in the organization of their institutions. The experience of the industry shows that design should partially pilot knowledge production, while it is often considered, in scientific bodies, that design is a simple assembly of knowledge. Finally, as the design process is based on an exploration of new concepts and knowledge, it is not possible to plan the design process, and to identify the scientific domains required and the skills to invite. The paradox is that innovative design is an increasing priority in research bodies, but this activity is not consistent with the actual organization of research, based on short-term well defined projects.

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Bridging the gaps between ecological principles and actions for designing biodiversity-based agriculture

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1 Introduction

In developed countries, a production-oriented agriculture was intensively promoted after World War II. It is based on the use of "off-the-shelf" technologies (synthetic inputs, fossil energy, genetics…) that limit, as much as possible, the effect of reducing production factors and level the heterogeneity of the environment. This model led to a standardisation of production methods and to a specialisation of territories according to their suitability for specific land uses. In the 1980s, the negative effects of this production system on biodiversity, ecosystems, global changes, and human health started to emerge. Moreover the increasing scarcity of fossil resources, healthy soils and water started to be a society concern. Objectification of the negative impacts of agriculture and redefinition of the objectives of agriculture in agricultural policies have led to two forms of ecological modernisation of agriculture (Horlings and Marsden, 2011). One, in continuity with the production-oriented agriculture aims at increasing the resource-use efficiency. It does not fundamentally renew the features of scientific knowledge production mode. The second, departing from the production-oriented model, aims at developing biodiversity to produce ecosystem services (ES) that support production and regulate flows. Provision of these ES requires managing biodiversity at field, farm and landscape levels (Kremen *et al.*, 2012). We focus on issues related to the implementation of biologically diversified farming systems and landscapes.

2 Foundations and issues of a biodiversity-based agriculture

Increasing biodiversity in space and time is expected to provide ES to agriculture (eg. soil fertility conservation, biological control of pests) and to society at local (eg. water regulation) or global scales (eg. climate regulation). ES to agriculture are of particular importance because they offer opportunities to farmers to strongly reduce use of synthetic inputs. Several authors (e.g. Altieri, 1999) agree about three prime-order agroecological principles for designing agricultural practices that favor these ES: (i) increasing plant diversity and soil cover through adapted crop sequences (cover-crops, varieties or species mixtures)to decrease nutrient and radiation losses and increasing above and underground biomass production and rhizosphere deposition to, in turn, increase biological, physical and chemical soil fertility, and biological regulations; (ii) minimizing mechanical and chemical disturbances of soil functioning and, whenever possible, seeding or planting directly into untilled soil to increase soil organic matter to support development of soil micro-, meso- and macrofauna for promoting soil fertility, biological regulation, and hence improve soil structure; (iii) organizing the landscape matrix (spatial crop distribution, grass trip, hedgerow, other semi-natural habitats…) to increase biological regulations favoring natural pest control and pollination.

However, implementing agricultural systems based on these principles remains difficult because locally-relevant knowledge on relationships between management practice, biodiversity, and ES is still incomplete, especially when ES depend on associated biodiversity (eg. micro-, meso- and macro fauna: Bommarco *et al.*, 2013). Therefore, promoting biodiversified farming systems and landscapes requires site-specific transformational changes. Management practices for enhancing ES need to be adaptive and flexible. Farmers practicing biodiversified agriculture usually proceed by trial-and-error process, sharing their experience with their peers to facilitate and accelerate learning and in turn limit risk. This is akin to what is called "adaptive management" in science, *i.e.* iteration of design and implementation of actions, monitoring of their effects, learning about agroecosystem functioning (William 2011). This leads researchers to produce methods and tools that are: (i) flexible enough to take local specificities into account and to integrate both emergent scientific and local knowledge, (ii) integrative, to reproduce with adequate accuracy the emerging properties of complex assemblages of species and practices, (iii) learning-oriented to promote the development of local knowledge, and (iv)a means to cope with uncertainty within an adaptive management scheme.

3 Building learning-oriented support tools to link principles and actions

To reach these above objectives, and from our diverse experiences, we argue that the development of learning-oriented tools should be collegiate (*i.e.* involving scientists, extensionists, farmers and other stakeholders), to stimulate knowledge exchanges. Because the main objective is to design a consistent foundation of the complex agroecosystem to implement and manage, user-friendliness and accuracy of predicted effects of management practices are also important characteristics. To support the key steps of the adaptive management they have to be useful both to design farming systems and to assess the ecosystem benefits that they bring.
Researchers, farmers and agricultural advisors are not well-equipped to deal with design of complex adaptive systems and assessment of their dynamics. Few mechanistic models dealing with agroecosystems address relations between management, biodiversity and ES. Most existing models focus on representations of the plant-soil-atmosphere system with mechanistic modeling of abiotic resources interactions and effects on plant production (energy, water, N, C). Given the expected features of learning tools, we identify three main types of emergent support tools likely to be helpful to lead the transition toward biodiversity-based agriculture: (i) knowledge bases, (ii) model-based, (iii) farm-landscape indicators usable by farmers and allowing them to think about past effects and predicting effects of future actions:

i. Knowledge bases contain structured scientific facts and empirical information compiled from cumulative experiences that enable biodiversity management to be inferred in specific situations. They have been developed recently, for example, to help selecting cover-crop species by providing information about suitable production situations (main cropping system, climate, soil) and expected ecosystem services. Some are built from plant-trait-based functional profiles (Ozier-Lafontaine *et al.* 2011), while others rely on expert knowledge about plant features (e.g. Naudin *et al.* 2011). A challenge would be to allow consolidate these knowledge bases with practitioner's feedbacks.
ii. Model-based games allow designing potentially adapted farming systems and even landscape organizations through stimulation of knowledge exchange and learning about the effects of planned and associated biodiversity on ecosystem services. They can be used to perform iterative design and *ex-ante* assessment of spatiotemporal distributions of crops, livestock and semi-natural habitats potentially promoting input services. These participatory-design approaches are based on manipulating "boundary objects" such as board games, cards, geographic or cognitive maps and computer models to create a shared language among the actors involved (e.g. farmers, advisors, students, scientists, other stakeholders). Materials and computer items are used either simultaneously or successively to collectively design and assess alternative farming systems (Martin *et al.* 2011) or landscapes.
iii. Finally field-farm-landscape indicators are necessary to reveal aspects of agroecosystems that provide ecosystem services to be estimated. Such aspects first include the soil state, for which several indicators already exist and are used. However, indicators of the balance between noxious, beneficial and neutral soil organisms, hence of the real or potential natural pest control of soil, have to be made available, in a simplified form, to farmers. Surprisingly little is known about the status of farmland biodiversity and how it changes under different farming practices. A new toolbox, called the "BioBio indicator set" (Herzog et al 2013), has recently been developed for a variety of farm types and scales in Europe. It is the fruit of a close collaboration between scientists, environmentalists and farmers, which imparts saliency to the toolbox.

4 Prospects for a research agenda

The development of learning tools to support biodiversity-based agriculture is still in its infancy. To develop toolsin the line with an adaptive management frame, we propose to combine several scientific disciplines: (i) advances in ecological science for characterizing, first, planned and associated-biodiversity responses to locally controllable or exogenous drivers, and, second, effects of biodiversity on ecosystem services, (ii) advances in management and design sciences for designingmethods facilitatingthe collaboration betweenstakeholders involved in biodiversity-basedagriculture and farmers, and the evaluation of these collaborations, and (iii) agricultural and social sciences for building learning-support tools taking into account their use.

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Exploration of windows of opportunity for improved nutrition, productivity and resource management at the landscape level

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1 Introduction

The Nutrition-Sensitive Landscapes (NSL) approach focuses on building diversity into the landscape and food systems to provide multiple sources of nutrients as well as other ecosystem services that are critical for environmental and population resilience. The NSL method offers proactive management towards more sustainable diets for vulnerable populations. We aim to explore tradeoffs and synergies between nutrition security, agricultural production, market interactions and natural resource management. It entails multi-disciplinary analyses of how women's and men's choices in land and farm management and in food acquisition and consumption patterns affect the food system, nutrition adequacy and ecosystem services. Systems analysis is one of the pillars in the NSL approach. It applies experiential learning cycles in case study sites in Zambia, Kenya and Vietnam.

2 Materials and Methods

Central to the methodology is a gendered participatory approach in all phases of the learning cycle. Results obtained with and for women and men in the study communities include descriptions of use of terrestrial and aquatic resources and of place and time-determined food consumption and farming practices. Case studies are undertaken in Vihiga County (Kenya), Son La province (Vietnam) and the Barotse Floodplain (Zambia) to assess the interactions and interconnectivity in agricultural production, natural resource management (NRM) and nutrition diversity. In each country, two small landscapes were selected for a participatory inventory of diet diversity and sufficiency in relation to farm productivity, exchanges with markets, ecological functions, and the availability of food resources in the landscape. The case study landscapes are contrasting in natural resource availability, farming practices and/or dominant market orientation (subsistence or commercial). The current diet and nutrition, resource endowment, productivity and NRM are characterized and evaluated through surveys and stakeholder sessions.

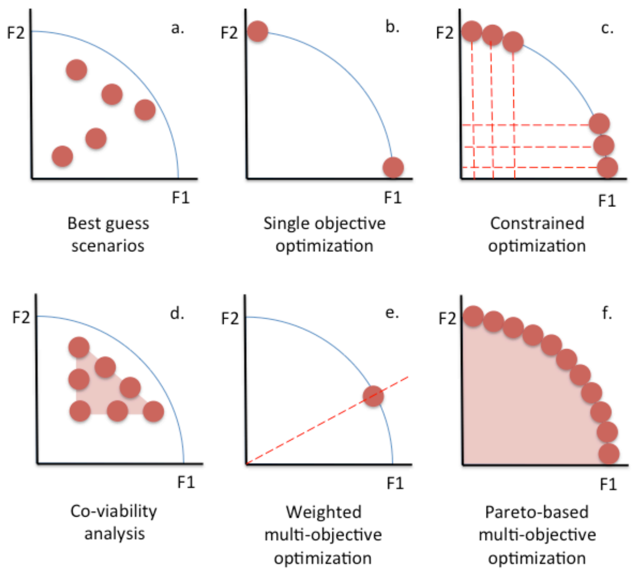

Fig. 1. Exploration of solution spaces delineated by the solid line (i.e. tradeoff), using different techniques.

3 Results – Discussion

In addition to the participatory assessment of the multifunctional food systems, in these sites we describe and explain current systems, and we systematically explore windows of opportunity for sustainable redesign and innovation in landscape and farm systems for improved nutrition. Instead of identifying an arbitrary set of possible scenarios (Fig. 1a) or applying single or constrained or weighted optimization (Figs. 1b-e), we explore the whole spaces of solutions (Fig. 1f) (Groot *et al.*, 2009). Solution spaces show a larger and broader set of alternative agro-ecosystem configurations that differ in performance of selected indicators, and thereby allow exploring and visualizing the windows of opportunities, and trade-offs and synergies.
The potential of new options for land-use and diet composition will be explored using the spatially explicit multi-objective optimization models (Fig. 2), linking farm level bio-economic models (Groot *et al.* 2012) with landscape models (Groot *et al.*, 2007). Indicators relevant to evaluate the dietary diversity (Kennedy *et al.* 2010), food patterns and nutrient adequacy at the individual and household level are added to the bio-economic models. Moreover, the diversity of foods available on-farm and in the surrounding landscape is quantified through the nutritional functional diversity indicator (Remans *et al.*, 2011). These nutrition-related indicators can be analyzed in relation to socio-economic indicators like profitability, household budgets and labor use, and environmental indicators such as habitat connectivity, land-use diversity, nutrient losses and soil organic matter accumulation.

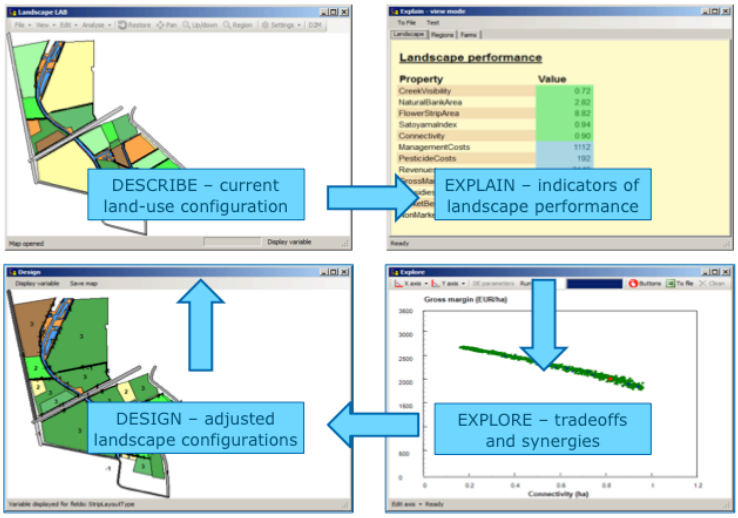

Fig. 2. Exploration with models following the Describe, Explain, Explore and Design phases of the DEED cycle.

4 Conclusions

The combination on-farm trials, surveys, modeling analyses and participatory evaluations drive the learning cycle from which innovations can emerge. This integrated approach and visualization of windows of opportunities through solution spaces will effectively inform discussions with stakeholders in the planning process of possible interventions to increase diet diversity, agricultural productivity and NRM in project action sites.

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Impact of farming systems on agricultural landscapes and biodiversity: from plot to farm and landscape.

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1 Introduction

Green-way policies in agricultural landscapes focus on ecological continuities between semi-natural elements (hedgerows, permanent grasslands, woods). These policies assume that annual crops and temporary grasslands have a negative or neutral impact on biodiversity. However, some works have shown that the presence of annual crops with dense cover and spatial continuities between different crops could also have a positive impact on biodiversity, either on woody species (see e.g. Ouin *et al.* 2000) or on crop species (see e.g. Burel *et al.* 2013). These landscape patterns are directly linked to farmers' decisions about the choice of crops they cultivate and their allocation on the farm fields. These decisions are related to fields characteristics and crop management requirements. In livestock farms, these decisions are also linked to animal management, particularly the way they are fed and the way fodder is produced (on- farm or bought) (Garcia *et al.*, 2005). The aim of this study was to evaluate the impact of contrasted livestock farming systems management on landscape patterns related to cultivated covers and potential biodiversity, here carabid beetles in bocage landscapes in Brittany, France. We achieved this goal through a multi-level modelling framework in order to combine field, farm and landscape level analysis.

2 Materials and Methods

We developed a methodology combining farmers' decision making analysis, ecological observations and modelling. Modelling has been done at the field, farm and landscape levels. We applied our methodology to a case study in Brittany, France. We compared two livestock systems, swine and dairy, in one bocage landscape (circle of 1 km diameter) which fields were farmed by 8 farms. A farm decision-based model was first built from farmers' interviews to simulate cropping patterns at the field and farm levels. Land-use patterns were then simulated at the landscape level by aggregating predicted cropping patterns of the 8 farms. Ecological statistical models were built from empirical data on carabid beetles, to predict carabid abundances at the field level in (i) annual crops and (ii) in semi-natural (woody) elements in simulated landscapes. Each farm were either simulated as a dairy or a swine farm, leading to a total of 256 landscape scenarios, each repeated 250 times, one scenario corresponding to 10 years of rotation. We used APIland library dedicated to landscape modelling (Boussard *et al.*., 2010).

3 Results and Discussion

From an ecological point of view we predicted that carabid species of annual crops were more abundant in swine production landscapes due to increased spatial continuities (edge length) between maize and winter cereals, whereas abundances of species of woody elements were enhanced in mixed landscapes (dairy and swine) because of higher land- use diversity (Fig. 1).

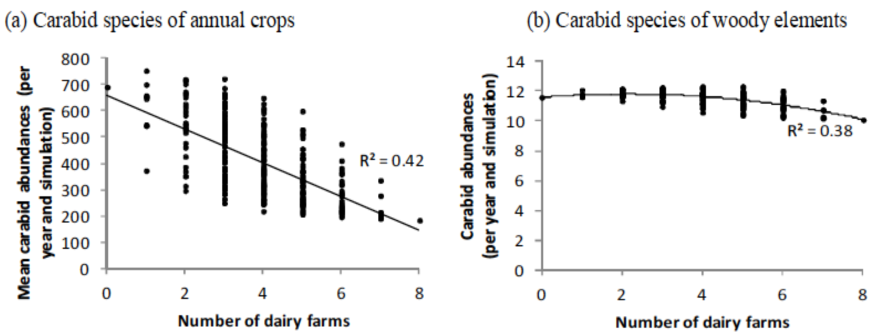

Fig. 1. Predicted abundances of (a) carabid species of annual crops and (b) species of woody according to the number of farms in dairy vs. swine production systems.

On table 1 we can observe that there is a relation between farms' farming system and crop areas within the simulated landscape. This is particularly true for wheat and grassland, while maize area is relatively less variable. As a result we can see a significant relation between farms' farming systems and spatial continuities between maize and winter cereals. A second result is that the intra-scenario variability is rather high (S.D. between 4.4 and 8.7 ha except for grassland in the swine scenario; from 288 to 466 meters of spatial continuities), which points out some flexibility to manage landscape to promote crop acreage and spatial continuities that would enhance carabid abundances.

Table 1. Mean and S.D. of land-uses areas and spatial continuities (edge length) between winter cereals and maize for 3 contrasted scenarios out of the 256 simulated (2500 landscapes per scenario: 10 years and 250 repetitions).

	Wheat (ha)		Maize (ha)		Grassland (ha)		Spatial continuities (m)	
Scenarios	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Swine only	27.6	8.7	16.8	7.2	0.4	0	2246	466
Mixed	14.9	5.9	15.1	6.7	27.9	5.1	1095	433
Dairy only	5.8	4.4	21.6	6.8	37.4	6.2	339	288

Relative contribution of each farm to carabid beetles abundances was then calculated (Table 2). It corresponds to the increase in the mean number of carabid beetles predicted when converting a farm from dairy to swine farming system. Farm size is the main factor explaining this contribution (see farms 1,2 and 4). But, it is not a general rule, since farm 2 and 9 contributions are respectively higher than the ones of farm 4 and 8. Potential grassland area in the landscape, related to the position of milking facilities (within, close or far from the landscape), and the edge length between fields are two other factors to consider. Indeed, they favor the increase of spatial continuities between maize and winter cereals when shifting from dairy to swine farming systems.

Table 2. Farm relative contribution (case of annual crops carabid beetles)

	Areas and edges length calculated for each farm				Relative contribution
	Arable land (ha)	Edges (m)	Min grassland area (ha)	Max grassland area (ha)	
F2	16.6	2 544	1.9	16.6	230.1
F4	20.5	2 829	0.0	20.5	122.9
F1	14.3	1 484	0.0	14.2	72.7
F9	4.7	1115	0.0	4.7	42.2
F6	2.5	345	0.0	2.5	16.4
F3	1.2	222	0.0	1.2	16.2
F7	3.2	1177	0.0	3.2	14.1
F8	7.3	713	0.0	0.0	0.1

4 Conclusion

Our multi-level and agro-ecological modeling framework allowed to evaluate the impact of different farming systems (dairy and swine) on landscapes patterns and abundances of carabid beetles. We showed that over-representation of swine farming system leads to increased edge length between maize and winter cereals and so favoring crop carabid beetles. On the contrary, a diversity of farming systems seems to be required in order to favor woody carabid beetles. Moreover we showed that for a given set of farming systems in a landscape there was a variability of crop patterns and edge length between cultivated covers. This indicates that there are some rooms to maneuver crop allocation to fields in agricultural landscapes. But these rooms for maneuver have to be thought at a collective level since they result from several farmers decisions, some farms having a higher contribution to the landscape pattern and resulting biodiversity.

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Policies and institutions fostering sustainable agricultural systems

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1 Introduction

The aim of this paper is to investigate how policies and institutions do or do not foster sustainable agricultural systems. First, the paper reviews how policy—in interaction with institutions, including supply chain practices—affects farm structures and their sustainability. Second, an overview is given of how policy has influenced farm structures over time and across various geographies. Third, the paper derives which policy mix would be required to generate sustainable agricultural systems and evaluates to which extent current policies worldwide are or are not evolving towards such a policy mix.

2 Theoretical perspectives on the interaction between policies, institutions and sustainable agricultural systems

Economic theory posits that farm structures result from farmers' choices concerning specialisation, technology and scale, which in turn are affected by the relative prices of farm inputs and outputs. Under perfect institutional and political settings, farms reach their optimal scale and factors of production are paid their opportunity costs (Kislev & Peterson, 1983), while at the same time environmental externalities are internalised into input and output prices, thus resulting in sustainable agricultural systems. In addition, farmers' decisions are influenced by a variety of constraints related to availability of production technologies, the biophysical environment, input and output markets, credit and insurance markets and knowledge (Stoorvogel *et al*., 2004), the farmers' resources and abilities. Finally, institutions—including policies— can affect this economic rationale in multiple ways.

Scott (1994: 68) defines institutions as "…symbolic and behavioural systems containing representational, constitutive, and normative rules together with regulatory mechanisms that define a common meaning system and give rise to distinctive actors and action routines." Policies and regulations may provide financial incentives or disincentives and may set limitations, thus influencing farmers' relative prices and thus choices. Policies may influence trade, property right regimes, farmer decisions about to what and how much grow, the relative cost of land through regulations, taxes and subsidies, or standards. Furthermore, non-agricultural policies may affect agricultural systems, such as labour law, fiscal regimes and environmental standards (Bowman & Zilberman, 2013). Such policy is partly desirable, as without it environmental externalities would not be internalised by markets, but may partly also distort farmers' choices. In turn, public policy cannot be seen without consideration of supply chain practices, that reflect output demand and input supply conditions, and of credit and risk considerations, that greatly influence farmers' choice set for instance through standards.

But institutions also refer to meaning systems—as proposed by Scott (1994)—an important part of which are mental models and social structure. While there is a rich literature on the adoption of environmentally friendly practices in agriculture pointing to influence of farmers' personal characteristics, attitude, social norms, etc., this literature does not show a universal pattern, such that efforts to promote sustainable agricultural systems need to be tailor made for local conditions (Knowler & Bradshaw, 2007; Wauters & Mathijs, 2014). Furthermore, transforming agricultural systems towards sustainability entails changing mental models, which proofs to be particularly difficult. As a result, farm development trajectories are often locked-in, that is, strongly dependent on historical events as demonstrated by for instance Happe *et al.* (2008).

3 A global overview of policies and institutions influencing sustainable agricultural systems

How have policies and institutions influenced the sustainability of agricultural systems over time and across geographies? For this, three clusters of countries are considered, depending on their level of development. Typically, countries tend to increase the protection of their agriculture as they develop economically (Thompson, 1998).

First, low-income countries typically do not support agricultural development through policy, as they lack the financial means to do so. Often, agricultural exports are even taxed to raise revenues. Food security is the major concern, while concern for the environment is absent. As a result, natural capital tends to be overexploited, leading to land degradation, particularly in population dense areas, where the incentive to intensify production is very high. The demand for organic produce is rising leading to increasing market incentives for sustainability as mediated by some multinational retailers and food processors.

Second, in emerging economies—such as Brazil, Russia, India and China—economic growth is the dominant paradigm using export-led strategies. Concern for the environment is still limited and mainly market driven if at all present. Agricultural systems tend to modernize as labour costs increase due to increasing non-agricultural incomes resulting in a substitution of labour by capital and increasing farm size increases. Partly, the situation is similar to that in Europe and the USA after the Second World War. Partly, global trends such as increasingly integrated supply chains accelerate modernisation

Third, high-income countries are typically characterised by policies setting various limitations to agriculture on the one hand, but also by providing a relatively large amount of financial support. In addition, demand for products produced in a sustainable way increases, leading to both public and private incentives for agricultural systems to become greener. An important barrier is path dependences resulting from existing institutional settings, sunk costs, know-how and mental models. Particularly in areas with high population density, the intensity of agricultural systems may be too high leading to high land prices making it very costly to extensify.

4 Designing policies for sustainability

What policy mix leads to sustainable agricultural systems? As indicated before, no universal answer is possible, as local conditions may vary too much across sectors and regions. We formulate three sets of principles we deem important for policies to truly lead to sustainable agricultural systems:

1.Set the right targets and framework. Any good policy starts from formulating and communicating a clear, normative objective. Setting the right targets and translating them into standards is therefore the first key step towards creating sustainable agricultural systems. Targets will not only guide policy, but also private investment in clean technologies, thus leading to a competitive advantage when markets start asking for sustainable products (Porter & van der Linde, 1995).

2.Develop knowledge, institutions and infrastructure. Changing practice requires developing new knowledge, while changing structures requires investing in new infrastructure. Failure to do so, will result in lock-in, that is, efforts towards making systems more sustainable will be focused on making current systems more resource efficient, rather than designing new systems (Freibauer *et al.*, 2011). As institutions lay the foundation for knowledge and structures, institutional change should accompany policy for sustainability. Institutional change involves changing the mind-set of anyone involved in the agricultural knowledge and innovation system.

3.Provide the right financial incentives and regulations. Markets are generally not capable of correcting the environmental externalities generated by firms, due to high transaction costs, the non-point nature of pollution, etc. Regulation is thus necessary. However, setting financial incentives such as environmental taxes at the right level requires correct information, but also coherence in policies—for instance farmers should not face contradictory public policies related to their practices and choices (Mathijs *et al.*, 2015).

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T1. Assessing performances and services of cropping systems (field level experiments, surveys and databases)

Chair: David Parson, University of Tasmania
Co-chair: Eric Malézieux, CIRAD

Improving resource use efficiency and soil conservation in smallholder vegetable systems though improved soil tillage and residue management

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1 Introduction

Smallholder vegetable farmers tend to specialize and intensify their production systems to secure income. In south Uruguay, frequent tillage and little or no inputs of organic matter have resulted in soil degradation that has decreased soil productivity and threatens systems sustainability (Alliaume *et al.,* 2013). The development of production systems that are able to stop soil deterioration and even improve soil quality is key to the sustainability of vegetable production systems in this region. In a context where water availability limits irrigation, and spatial and temporal variability of rainfall is increasing, it is imperative to introduce practices that reduce runoff and erosion, and increase the capture of rainfall water in the soil. Reduced tillage in combination with mulching maybe a viable alternative to reduce runoff, soil degradation and erosion, and improve water conservation (Alliaume *et al*., 2014). Our aim was to develop a tool that illustrates the effect of adopting different soil management practices in terms of water balance and erosion at a farm scale.

2 Materials and Methods

A three year on-station experiment was carried out to analyse the effect of reduced tillage, cover crops and organic matter addition on water runoff, soil erosion, soil moisture supply capacity on tomato, maize and onion crops. Treatments were: reduced tillage +oat as a cover crop left as mulch + chicken manure (RT), and three conventional tillage treatments: one that incorporates chicken manure (CChm), one with a cover crop incorporated to the soil and a third one as control, with no organic material addition. The rotation involved tomato -oat/fallow - tomato - oat/fallow - tomato- oat/fallow- sweet corn - oat/fallow - onion. The results showed that RT contributed to in situ moisture conservation and reduction of runoff and soil loss on degraded mollisols used for horticulture. Based on the results of this experiment we developed a summary model with a generic approach that needs local parameterization to estimate water infiltration and water balance under vegetable cropping as a function of rainfall, residue and crop cover, and soil water content. We also measured all the variables needed by Revised Universal Soil Loss Equation (RUSLE) model and incorporate a routine to estimate soil erosion.

3 Discussion

The soil moisture during the four commercial crops was both measured and estimated to be larger under RT than under CChm at all soil depths. The model developed requires few inputs and was sensitive to differences in soil cover, reproducing moments in which the soil was wetter and drier, although in several moments, there was an overestimation of the soil moisture (Fig. 1). The water infiltration however was accurately estimated (data not shown).

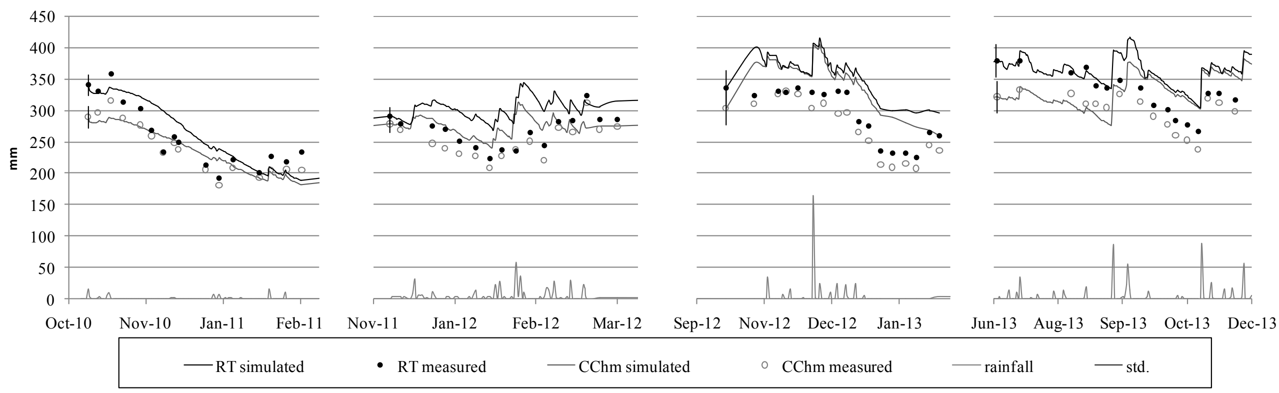

Fig. 1. Simulated and measured soil moisture from 0 to 100cm depth, during two tomato, maize and onion crops.

The larger soil water capture under RT was explained by a larger infiltration into the soil, except during the first tomato crop because it was a very dry season and the interception by the mulch resulted in less water infiltrated; and by reduced soil evaporation (Table 1.). The change in water dynamics have at least two direct positive consequences: reduced runoff led to reduced erosion risk, and larger water availability for transpiration may result in larger yields. Larger soil water capture under RT, might result in larger deep drainage, especially during a winter-spring crop such as onion (Table 1).

Table 1. Water balance components estimated for two soils management during four commercial crops.

	Tomato 2010/2011		Tomato 2011/2012		Sweet Corn		Onion	
Soil management	**RT**	**CChm**	**RT**	**CChm**	**RT**	**CChm**	**RT**	**CChm**
Rainfall (mm)	113,7		467,9		346,6		575,9	
Runoff (mm) (% of rainfall)	4,9 (4)	13,3 (12)	42,7 (9)	107,2 (23)	75,0 (22)	113,5 (33)	115,9 (20)	191,5 (33)
Interception (mm)	40,9	16,5	52,3	16,5	21,6	6,3	44,4	24,3
Deep drainage (mm)	0,0	0,0	33,6	25,5	100,7	62,5	136,5	19,1
Infiltration (mm)	71,1	84,3	368,1	345,1	252,4	227,8	425,5	363,4
Actual evap. (mm)	50,4	72,5	105,2	155,3	35,3	55,3	45,4	68,7
Actual transp. (mm)	152,1	108,4	244,8	192,2	134,9	130,1	202,7	203,3
ETP (mm)	572,5	569,7	559,6	559,1	318,7	318,5	401,7	404,6
P. transp. (mm)	355,3	354,5	277,7	277,6	140,6	140,5	211,2	212,0
Pot. - Actual. transp. (m^3)	2032	2461	329	854	57	104	85	87

The water use efficiency reported for processing tomato crop in Uruguay (Scarlato, 2009; Alvarez, 2010) ranges between 100 and 180 kg ha^{-1} of fresh fruit per mm of irrigated water. From that data and looking at the differences in actual transpiration between soil treatments (Table 1), we can estimate an yield increment under RT between 4000 and 9000 kg ha^{-1} compared with CChm assuming that the transpiration efficiency is the same as the irrigated water, which is a conservative assumption. In the same way, in order to fulfil the transpiration demand (P. transp) during both tomato crops we would have to irrigate between 400 and 500 m^3 more under CChm than under RT (Table 1), water that in many farms is not available, or the farmer could have saved it or increased the irrigated area.
A major consequence of introducing RT is the reduction in erosion risk. As we can see in Table 2., an estimate for a LuvicPhaeozem (k=0.23), common in the south of Uruguay, resulted in soil losses below or equal to the tolerance level 7t ha^{-1} $year^{-1}$for slopes till 3% and 80 m long managed under RT, while CChm was over the tolerance level in all combinations of length and slope.

Table 2. Average annual soil loss during a three years vegetable crops rotation under two soil managements. Estimations using RUSLE for various combinations of length and degree of slope are presented.

length (m)	slope (%)	RUSLE LS factor	Soil loss (t ha^{-1} $year^{-1}$)	
			RT	**CChm**
30	4,5	0,579	8	25
80	3,0	0,528	**7**	23
30	3,0	0,389	**6**	17
80	2,5	0,430	**6**	19
30	2,5	0,327	**5**	14
80	1,5	0,249	**4**	11
30	1,5	0,204	**3**	9

4 Conclusions

The model developed was sensitive to differences in soil moisture due to soil management. Even if it has to be improved, it already illustrates the effect of adopting different soil managements in terms of water balance and erosion at rotation scale. Results show significant decrease of soil erosion and water requirements for irrigation under RT, thus enabling an increase in irrigated area of vegetable crops and crop yields.

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IMPACT OF A LEGUME LIVING MULCH ON WINTER WHEAT YIELD AND ITS NITROGEN NUTRITION

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1 Introduction

A living mulch has a life cycle which can be far longer than the one of an annual cover crop. It can have a stronger impact on soil characteristics, on the environment and on commercial crops included in the rotation. A cover crop already established in the preceding crop can also have a stronger development than an annual cover crop, especially in dry summer conditions or in short intercropping periods. A living mulch can facilitate the main crop growth through for example soil structure improvement (Carof *et al*., 2007) or soil nitrogen availability (Bergkvist, 2003). It can also show strong competition on the main crop for light, nutrients and water. Depending on the main crop growth dynamics, the living mulch growth dynamics and the cropping system management, the balance between facilitation and competition can be completely different (Den Hollander *et al.,*2007).

2 Materials and Methods

This article presents a field trials synthesis on winter wheat established on legumes living mulch (Table 1). Wheat was harvested in 2013 and 2014 in northern France. The living mulches were mainly established in the previous crop (oilseed rape, fodder maize…). Wheat has been sown directly in the living mulch with a disc drill. The cover crops were either terminated in the wheat crop cycle or stayed alive during the entire wheat crop cycle. In the first case, living mulch were killed usually in winter with herbicides. Sometimes, wheat crop was too much competitive on cover crops, especially for light on white clover (*Trifoliumrepens L.*). When cover crops were not terminated in wheat crop, they were suppressed by wheat herbicides in order not to be too much competitive on wheat.
In all cases, nitrogen supply was the same between all treatments. The impact of cover crops on nitrogen absorption by wheat has been investigated in all these experiments.

Table 1. Description of the field experiments.

Trial location zip code, village (country)	Crop (previous crop)	Crop harvest year	Living mulch species	Sowing period / Destruction period of living mulch
91720 Boigneville (France)	Winter wheat (oilseed rape)	2013	White clover (*Trifoliumrepens*) White clover (*Trifoliumrepens*)	August 2011 / October 2012 August 2011 / March 2013
91720 Boigneville (France)	Winter wheat (fallow)	2014	Lucerne (*Medicago sativa*) White clover (*Trifoliumrepens*) Common sainfoin (*Onobrychisviciifolia*) Black medic (*Medicagolupulina*) Firdsfoot trefoil (*Lotus corniculatus*)	July 2013 / March 2014 July 2013 / March 2014 July 2013 / March 2014 July 2013 / March 2014 July 2013 / No destruction
91720 Boigneville (France)	Winter wheat (grain corn)	2014	White clover (*Trifoliumrepens*)	July 2013 / No destruction
36100 Brives (France)	Winter wheat(oilseed rape)	2013	Lucerne (*Medicago sativa*)	July 2013 / No destruction
44370 La Chapelle Saint Sauveur (France)	Winter wheat (fodder corn)	2014	Mixture of 3 clovers : berseem, subterranean, crimson (*TrifoliumAlexandrinum, subterraneum and incarnatum)*	May 2014 / Winter 2013/2014

3 Results – Discussion

The impact of legume living mulch on wheat yield was variable, from -17% to +15% as compared to wheat managed as a sole crop (figure 1). In the case of living mulches that have been terminated in the wheat crop cycle, the impact on wheat yield has been on average positive. In one case, black medic showed a negative impact on wheat development at the end of winter. This cover crop did not stop growing in winter 2013/2014 that has been mild. It has not been enough suppressed by herbicides or cold weather. For other legume species terminated in the wheat crop, we had neutral to positive impact of living mulch on wheat yield. Nitrogen supply to the crop seems to explain this trend. In the experiment carried out in la Chapelle St Sauveur, the mixture of three clovers allowed an increase of 10% of wheat yield, without modifying the optimum amount of nitrogen necessary to obtain the best yield. It is

supposed that cover crops improved soil structure and helped to reduce waterlogging. In these wet conditions, in a drained loamy soil during a rainy winter, cover crops helped wheat establishment.
We had three trials in which the legumes living mulch stayed alive during the entire wheat crop cycle. Results varied depending on the situation. In the case of Boigneville2 in 2014 (figure 1), wheat was established late in autumn 2013 after a grain corn. Wheat establishment was poor (126 plants.m^{-1}). In this case, wheat has not been able to suppress white clover development because it was not enough competitive for light. Cover crop decreased wheat biomass and nitrogen status from the stem elongation and yield by 17%.
In the case of the Brives experiment, different nitrogen amount were spread on wheat drilled directly on a lucerne living mulch as compared to a control situation (soil tillage, no living mulch). The optimum yield was the same in any case but we could get it with a smaller amount of nitrogen in the living mulch. Nitrogen supply from the soil+lucerne system to wheat was improved from 30 to 60 kg N.ha^{-1} as compared to the control.
In the last field trial with a birds foot trefoil living mulch, we got an increase of wheat yield. The cover crop biomass was of approximately 2.7t.$ha^{-1}$of dry matter at wheat harvest. Birds foot trefoil dormant variety showed a small development in winter and in spring. Wheat crop was very competitive on this cover crop, except in July when wheat has become senescent. Due to rainy conditions, the cover crop produced much biomass in late July, before harvest.

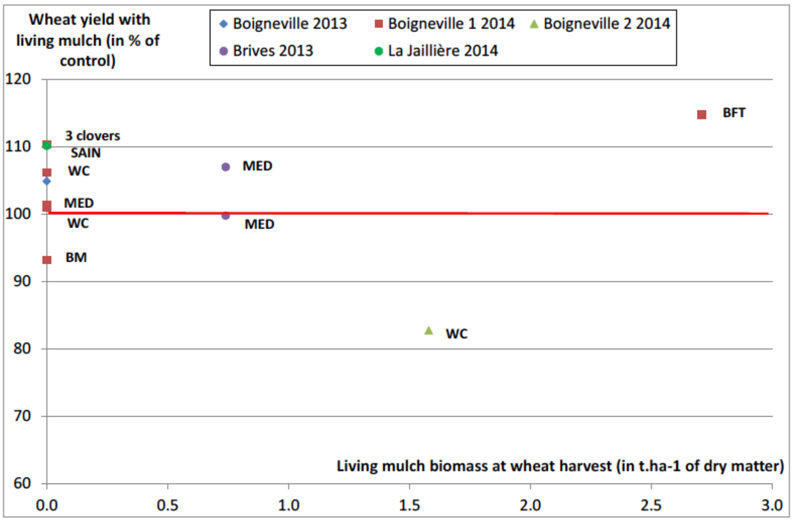

Fig. 1. Impact of legume living mulches on wheat yield in five field trials. The cover crops were either terminated in the wheat crop cycle (biomass = 0 at wheat harvest) or stayed alive during the entire wheat crop cycle (biomass> 0). Cover crops were : white clover (WC), lucerne (MED), birds foot trefoil (BFT), common sainfoin (SAIN), black medic (BM), mixture of berseem, subterranean and crimson clovers (3 clovers).

4 Conclusions

Sowing wheat crop in a living mulch is an innovative practice that seems to improve cropping systems in some cases. Sowing cover crops in the previous crop can allow a strong biomass production in spite of short intercropping periods. When cover crops are terminated before sowing wheat or during winter, positive impacts on wheat such as nitrogen release or soil structure improvement could be expected in some cases without too many constraints on wheat management. As the legume living mulch stays alive during the entire wheat crop cycle, wheat management has to be adapted: crop establishment, weed control, cover crop suppression… Three factors are very important to manage facilitation / competition process: the crop competitive ability, the living mulch competitive ability and the cover crop suppression (chemically or mechanically). Some field trials are currently carried out by ARVALIS-Institut du vegetal in order to optimize this new practice and to assess their impact on crops yield, nitrogen release and the environment.

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Integrated double-mulching practices optimizes soil temperature and improves soil water utilization in arid environments

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1 Introduction

Water deficit is a single most important factor threatening economic and environmental sustainability, especially in arid area, saving water from agriculture is one of the most useful way to solve the problem (Chai *et al.*2014). Plastic film mulch has been widely used to conserve soil water and reduce evaporation in many arid area (Liu *et al.* 2001), and to accelerate crop growth, increase crop yields (Zhou *et al.* 2009). However, the widespread use of non- biodegradable plastic film over years has potential to damage the sustainability of agro-ecosystems (Briassoulis 2006). Also, high soil temperature in the root zone at the blossom and grain filling stage of crops grown with plastic mulch can lead to crop root senescence and decrease crop yield. Different to plastic mulch, crop straw mulch combined with no tillage can effectively keep soil moisture, reduce water and wind erosion, decrease soil temperature, and increase crop yields (Li *et al.*2011). But, the low soil temperature caused by crop residues can delay seedling emergence, and lead to crop yields decrease (Chen *et al.* 2011). Thus, integrate plastic film mulch and straw mulch into one cropping system, maybe has great substantial in saving water and improving sustainability of crop production. Here, we propose a “double mulching” system, in which, plastic film mulch is integrated together with crop straw mulch in the wheat-maize intercropping system. The purpose of the test is to determine (1) the water use characteristics of the integrated double mulching system, and (2) the response of soil temperature during key plant growth stages under the integrated systems.

2 Materials and Methods

The experimental design in randomized completely with three replicates. Three approaches were implemented for water conservation and soil temperature optimization; they were (i) no-till with straw covering (i.e., NTS), where no till was combined with wheat straw of 25 cm high that was chopped and evenly spread on the soil surface at wheat harvesting the previous fall; (ii) reduced tillage with straw incorporation (i.e., TIS), where 25 cm high of wheat straw was incorporated into the soil through tillage at wheat harvesting the previous fall; and (iii) conventional tillage (i.e., CT control), where conventional deep plowing was applied to the plot with straw removed off the field. These three straw mulching approaches were applied to the wheat-maize intercropping systems. In late October to early November, wheat strips were managed as described above, and maize strips were deep plowed and raked. In the next spring, a wheat crop was planted on the maize-preceded strips and maize planted on the wheat-preceded strips. All the maize strips were mulched with plastic film. Each plot area was 48m^2 (10×4.8 m) with a 0.5 m wide by 0.3 m high ridge between two neighboring plots to eliminate potential effect of lateral soil water movement.

3 Results and Discussion

3.1 Soil temperature

At eight and eighteen o'clock, soil temperature of NTS treatment was significantly greater than that of TIS treatment or CT treatment. However, at fourteen o'clock, soil temperature of NTS was significantly lower than that of CT. Compared to CT, the NTS treatment decreased soil temperature of the wheat strips by an average of 1.26-1.31ºC in the top 10 cm depth. Also, the NTS treatment decreased soil temperature of the maize strips by 1.31-1.51ºC in 2011 (Fig. 1). In double mulching systems, the soil temperature of maize strip at 0-10cm profile is 125-1.94 ºC higher than that in wheat strip, but in terms of CT the temperature gap is 1.58-2.11ºC.Thus, plastic film and no-till with straw covering on the soil surface played an important role in optimizing soil temperature both in maize and wheat strips.

3.2 Soil water content

At sowing stage, the integrated double mulching system conserved more soil water than the CT. In the soil profile of 0-30cm, the water content of NTS and TIS is 5.7-7.7% higher than that of the CT, but in deeper soil layers, the water content gap between double mulching systems and CT is decreasing. After wheat harvest, the remained bare strips in CT lead to a significantly decrease of soil water content. Compared to NTS and TIS, the soil water content of CT in 0-30cm profile was decreased by 15.9-17.8% and 8.0-10.0% respectively, NTS is the most effective way conserving water in the later growth period. Averaged through whole water content of 0-30 cm profile in wheat strips by 12.9% -13.5%, by

9.8%-11.9% in maize strips. In general, NTS has a positive effect on water status across 0-110 cm soil profile, it increased soil water content by 3.9 % before sowing, 8.6% during co-growth period, 5.2% after wheat harvest, and 5.7% after maize harvest, compared to CT.

3.3 Evaporation (E) and evapotranspiration (ET) of the intercropping system

Double mulching can significantly decrease ET and E of the intercropping system, the total ET of NTS was 4.5%-4.6% less than CT, and the evaporation of NTS and TIS was averagely decreased by 32mm (11.0%) and 18.5 mm (6.4%) compared to CT. At the same time, double mulching decreased the E/ET of NTS and TIS by 8.9% and 7.7% in 2010, 4.7% and 2.9% in 2011, respectively, than that of CT (Fig.2).

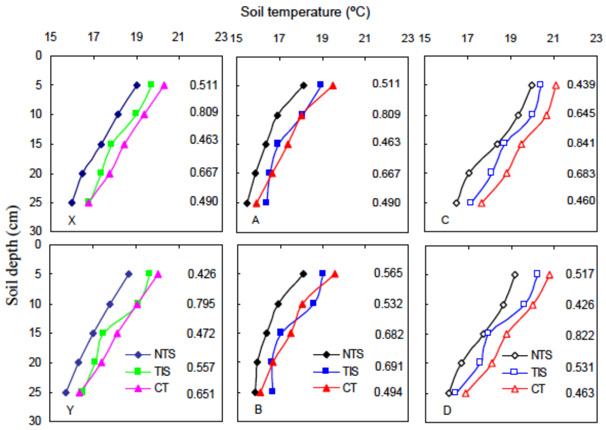

Fig. 1 Soil temperature(T) in 0-25 cm depth. X and Y represent T of intercropping, A and B represent T of wheat strips, C and D represent T of maize strips in 2010 and 2011.

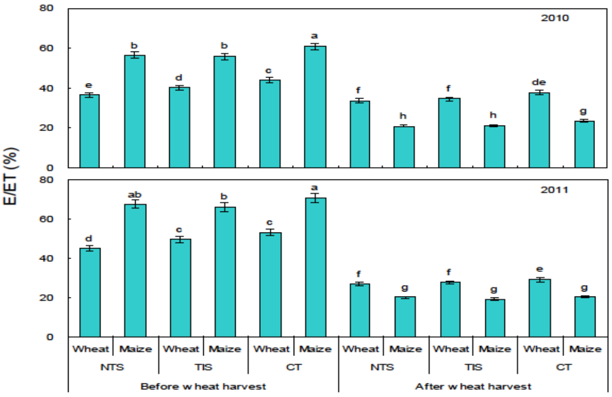

Fig.2 The ratio of soil evaporation to evapotranspiration (E/ET) in different treatment

4 Conclusions

Wheat-maize strip intercropping in combination with plastic film and straw covering on the soil surface can conserve more soil water, not only in crop growth stage, but also in the fallow stage. The „double mulching" system also decreased total ET, E as well as E/ET significantly. In the same time, „double mulching" system decreased soil temperature in the top 10 cm depth by 1.26 to 1.51ºC, and the soil temperature of maize strips was 1.25 to 1.94ºC higher than that of wheat strips in the double mulching system, the temperature gap between maize and wheat strip in double mulching system is small than that in conventional treatment; this allows the two intercrops to grow in a well "collaborative" status under the „double mulching" system during their co-growth period. The improvement of soil moisture and the optimization of soil temperature for the two intercrops allow us to conclude that wheat-maize intensification with the „double mulching" system can be used as an effective farming model in alleviating water shortage issues experiencing in water-shortage areas.

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A preliminary study on adaptability of maize-maize double cropping in Hebei area of the North China Plain

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1 Introduction

Irrigated winter wheat (*Triticum aestivum L.*) growing prior to summer maize (*Zea mays L.*) in the Hebei Plain, north part of the North China Plain, has been blamed for water consuming as well as low economical efficient. In recent years some farmers have developed double maize system harvesting vegetable maize cobs as an alternative to the traditional wheat–maize doubel cropping sytem. Although some researches (Li *et al.*, 2011a) have been done on grain maize double cropping, adaptability and appropriate cultivar combination, the key issues deciding biological and economic efficiency of this new cropping system, have not yet been clarified.

2 Materials and Methods

A field experiment was conducted in Quzhou county of Hebei province (114.93°N，36.79°E）in the year of 2012-2013. The trial-run experiment in 2012 was for selecting suitable cultivars and appropriate sowing dates. Based on the results in 2012, three cultivar combinations were designed for the bedded-filmed spring maize-summer maize in 2013, ie. Demeiya_1 (early maturing)- Zhengdan_958 (currently popular) (EM1-C1), Chengdan_22 (early maturing)-Xianyu 335 (currently popular) (EM2-C2) and Xianyu 335-Chengdan 22 (C2-EM2). The traditional winter wheat-summer maize system (W-M) was compared as control. Crop data at critical phenostages, soil moisture to 200 cm depth before sowing and at mature, and daily weather data were collected. APSIM (Keating, et at, 2003) simulations were calibre with the data. Air and soil temperature under and outside plastic film were measured everyday on three fixed sites at 8: 00 am, 14:00 pm and 20:00 pm after sowing till the field ground is fully covered by crop canopy.

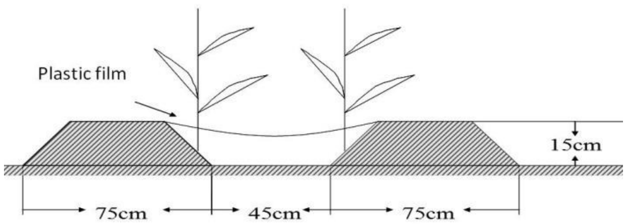

Fig.1 Illustration of bedded-filmed maize planting

3 Results – Discussion

Yield, economic return and water use efficiency (WUE) of different treatments are presented in table 1. There was no significant difference in annual yield between EM-C_1, EM_2-C_2while the C_2-EM_2 maize-maize system had a 15.8% lower annual productivity, comparing to the W-M system. The result that the early maturing cultivar had a higher yield when it was sown in spring than in summer worth of special attention. There is no significant difference in net economical return between EM-C_1, EM_2-C_2 and the W-M systems , while that of the C_2-EM_2 combination was 26% lower than W-M system. Double maize systems had a higher machinery cost.

There is no significant difference in evaportranspiration (ET) among the three cultivars combinations of double maize system but it is much greater in the W-M system. WUE in the two EM-C combinations is 77% and in the C-EM combination is 54% higher than it in the W-M system.

The regression of air temperature inside and outside the film is established as Ti=1.2512To+0.8304 (R2=0.7878. Ti= inside temperature; To=outside temperature）. With is equation it is calculated that filming added 126.6°Cextra degree days (DD) to the micro habitat under the film. Filming is necessary in the Hebei plain for maize double cropping and bedded/ridged filming is better that filing on flat field (Li, et al, 2011b)

The outputs of APSIM simulation suggest that EM-C cultivar combination of maize –maize system is adapted to the south part (south to 38°N) while the combination with two early maturing cultivars to the north part of Hebei Plain.

Table 1. Yield, economic return and WUE of different treatments （Yuan·ha^{-1}, 2013）

	EM_1-C_1		EM_2-C_2		C_2- EM_2		W-M	
	EM_1	C_1	EM_2	C_2	C_2	EM_2	wheat	maize
Yield（kg·ha^{-1}）	7495	9115	7822	8982	7369	6939	6822	10167
Value of production	16264	19780	16973	19490	15991	15057	16045	22061
Machinery cost	2925	1425	2925	1425	2925	1425	2475	2175
Material cost	9459	5787	9408	5989	9229	6166	9033	7887
Net return	6805	13994	7567	13502	6763	8891	7012	14175
Annual yield（kg·ha^{-1}）	16610 a		16803 a		14308 b		16988 a	
Annual net return	20799		21069		15654		21187	
ET (mm)	430 b		435 b		428 b		778 a	
WUE (kg·mm^{-1}·ha^{-1})	38.5a		38.5 a		33.5 b		21.8 c	

Note: Different lower case letters after figures indicate a statistically significant difference of 95% probability.

4 Conclusions

5

A preliminary conclusion can be made that double maize system is competitive to the traditional wheat - maize system in annual productivity and economic return, and much more water efficient, given that suitable cultivars are selected and properly combined. It could be an alternative cropping system in the north part of the North China Plain, or be used as a remedy after winter kill of winter wheat. However, systematic and in-depth studies on ecological, economic and social impacts of the system are needed and relevant techniques need to be fine-tuned and packaged before the new system can be widely extended.

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Trade-off between productivity and nitrous oxide emissions in subtropical broad-acre systems – a modelling approach

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1 Introduction

Subtropical regions host 23 % of global agricultural land, and hence have a considerable contribution to global food production and to nitrous oxide (N_2O) emissions. N_2O emissions from subtropical farming systems contribute more than 15 % of the global N_2O emissions from fertilised land. Efficient N_2O mitigation strategies for this climate zone that also preserve crop yields are therefore necessary. In this study we explored possible mitigation opportunities for representative subtropical grain cropping systems and management practices by simulating long-term scenarios with the agricultural systems model APSIM (Holzworth *et al.* 2014). Beforehand APSIM was calibrated and validated with data from two field sites in subtropical Queensland, Australia.

2 Materials and Methods

In the first step, APSIM was calibrated with measured water contents, yields and high frequency N_2O emission data from field experiments in subtropical Australia. The experiments included contrasting soil types (an Oxisol and a Vertisol), various fertiliser and irrigation treatments and different crops (Scheer *et al.*, 2012; 2013 ; De Antoni Migliorati *et al.*, 2014 ; 2015). In the calibration step, we focused on a thorough calibration of soil physical properties for each site, i.e. field capacity, permanent wilting point and the water filled pore space above which denitrification starts ($dnit_{lim}$), instead of calibrating a large number of parameters controlling the carbon and nitrogen (N) cycles. A small subset of the data from each site was used for calibration, while the majority were used for validation. In the second step, long-term (40 yrs) crop rotations with varying fertilisation and irrigation strategies representative for the humid subtropics were simulated with the validated model to assess possible N_2O mitigation options.

3 Results – Discussion

Water dynamics (not shown), yields (Fig. 1a) and seasonal N_2O emissions (Fig. 1b) were accurately predicted for the crops subjected to different irrigation and fertilisation strategies. These results confirm the capability of APSIM to reliably predict these output variables without adjusting process parameters for each site, season or treatment. The parameter $dnit_{lim}$ was the only parameter calibrated separately for each site because it had a large effect on predicted denitrification and may be related to other, measurable soil properties such as soil texture. Being able to accurately simulate the results with minimal calibration suggests that the model can be more readily applied in other locations.

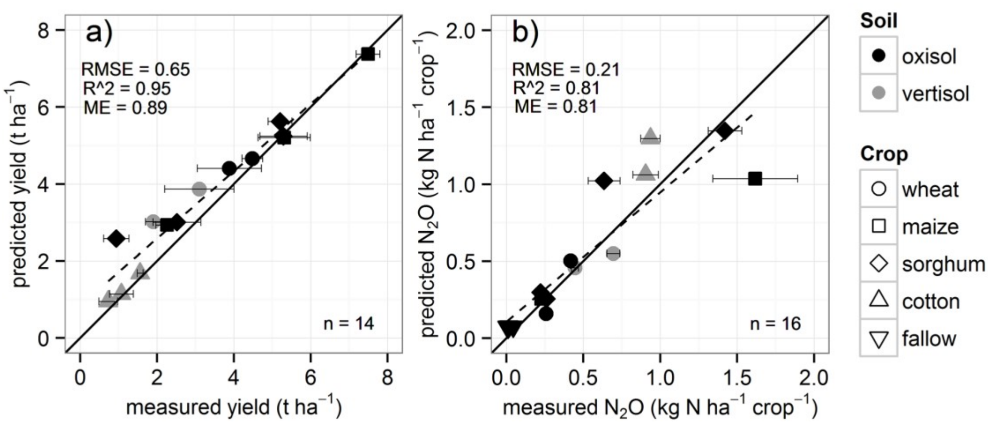

Fig. 1. Predicted against measured (a) crop yield and (b) seasonal N_2O emissions for the validation data sets of the two experimental sites. Standard deviation of the observations, 1:1 (solid) and regression lines (dashed) are shown. RMSE is root means square error, R^2 is coefficient of determination and ME is model efficiency.

The long-term scenarios revealed two relationships between yield and N_2O emissions (Fig. 2). At high N rates (large symbols), increasing N input increased N_2O emissions but not yield, resulting in a negative outcome for both variables. At low N rates (small symbols), increasing N inputs led to an increase in both yield and N_2O emissions and resulted in a trade-off between maximising yield and minimising N_2O emissions. Crop yields were significantly higher when irrigation (open symbols) was applied, compared to the rainfed counterparts (closed symbols), indicating that water supply limited plant growth and yield. At the same time, however, N_2O emissions at high N rates were lower in irrigated than in rainfed wheat. This appeared counterintuitive because high soil moisture is an important driver for N_2O emissions, but it occurred because water stress in highly-fertilised rainfed wheat resulted in higher surplus N compared to the irrigated treatments. Thus more substrate for denitrification was available when the soil got wet.

When a legume (here chickpea) was included in a crop rotation, the yield plateau for wheat was reached at lower N rates compared to a monoculture (Fig. 2). This provided savings of up to 40 kg N ha^{-1} per wheat crop and reduced N_2O emissions by 0.5 to 0.9 kg N ha^{-1}. However, the yield plateau for rainfed wheat was ~20 % smaller when in rotation with chickpea than in monoculture, suggesting that chickpea depleted more water from the soil than wheat. Thus, less water was available for the next wheat crop, which is important in this environment where water is often limiting for crop growth. Long-term scenarios showed high interannual variability of N_2O emissions and yields. Results from short-term experiments may therefore not be representative of the long-term behaviour of these subtropical agro-ecosystems, and so simulation studies may be important to gain insights into long-term emissions and mitigation options.

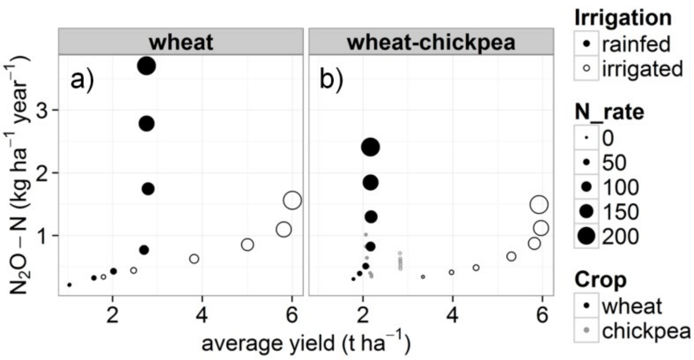

Fig. 2. Trade-off between yield and N_2O emissions for two crop rotations simulated for the vertisol; seven fertilisation intensities: 0, 20, 40, 80, 120, 160 and 200 kg N ha^{-1} (size of bubbles) per non-legume crop, rainfed and irrigated (irrigation when 50% of the plant available water capacity in the upper 60 cm of the soil was depleted).

4 Conclusions

After targeted calibration of a small number of site-specific parameters, the APSIM model was able to adequately predict water dynamics, yields and cumulative N_2O emissions for two soils in the subtropics, four crops and a number of irrigation and fertilisation intensities.

N_2O emissions were not caused or influenced by only one management factor (e.g. irrigation or fertilisation) but by a complex interaction of several factors. Consequently, a holistic approach should be taken to identify N_2O mitigation strategies that do not compromise yield. N fertiliser should be applied after considering soil N stocks and available water (soil water storage, irrigation and expected rainfall). When legumes were included in the crop rotation, N application and thus N_2O emissions could be reduced. Given the annual variability in climate and in soil N, yield forecasting tools in combination with soil testing for mineral N and reliable weather forecasts would provide great benefit in managing N application and thus optimising the dynamic trade-off between yield and N_2O emissions.

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Impact of two simple fertilization strategies on farmers' product carbon footprints and gross margins of wheat and maize production in the North China Plain

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1 Introduction

Overuse of Nitrogen (N) fertilizer in crop production exerts massive negative environmental effects in the North China Plain (NCP). In the intensive winter wheat (WW) – summer maize (SM) double cropping system, which is the dominant cropping system of this important crop production region, excessive N rates are common practice (e.g. Cui *et al.*, 2008). Additionally to the pollution of groundwater excessive N is also a major contributor to agricultural greenhouse gas (GHG) emissions and thus strongly contributes to global climate change. Despite the ongoing efforts, which mainly focus on field experiment based development of improved fertilization strategies, and include the promotion of technologically sophisticated N management schemes (e.g. Cui *et al.*, 2008), farmers' N rates maintain at excessive rates. Therefore the current study tests two simple and easily to apply N fertilizer recommendation strategies, which could be implemented on large scale through the existing agricultural advisory system of China, at comparatively low cost. To capture farmers' current crop management conditions and the inherent diversity among farmers, the present study builds on a primary data set of detailed crop management information of 65 WW-SM producing farm households. In a first step the farmers' individual product carbon footprint and gross margins of WW and SM are determined. In the next step the effects of the two simple N fertilization strategies are tested under conditions of constant, increasing and decreasing yield levels.

2 Materials and Methods

Farm household survey was conducted in 2011 in Quzhou – a representative county of the NCP. Detailed crop management data, including timing, amounts and prices of all crop production measures, inputs and outputs were interrogated and complemented by secondary data sources. Product carbon footprint (PCF), describing the amount of emitted CO_2-equivalents per unit produced grain, was determined following ISO 14040 standards (ISO, 2006). Gross margin (GM) was selected as economic indicator, describing the difference between sales revenue and variable production cost expressed in monetary value per land use area (EURO ha^{-1}). A detailed description of the methodological procedure for PCF and GM calculations as well as the status quo performance of the surveyed farm households can be found in Ha *et al.* (2015).
The first of the two simple fertilizer recommendation strategies, the N-uptake strategy is based on a comprehensive study conducted by Ju & Christie (2011), who assessed numerous long-term field experiments for WW and SM production in the NCP. Here the recommended amounts of N are determined based on the farmers' individual expected yield levels. The second N fertilization strategy (N-fixed) is based on Meng *et al.* (2012), who determined the optimum N rates for WW and SM in Quzhou at 176 and 185 kg N ha^{-1}, respectively.
To account for the uncertainty regarding the effect of adjusted N fertilization levels on the potential grain yields obtained by the individual farmer two yield change scenarios were introduced, additionally to the assumption of constant yields under changed fertilization (baseline yield). In the yield loss scenario (Y_{loss}) yields were reduced by 10 %, while in the yield increase scenario ($Y_{increase}$) yields were increased by 10 %.

3 Results and Discussion

Table 1. Status quo average, minimum and maximum PCF and GM of WW and SM production of the 65 sampled farm households.

	Units	Average	Min	Max
		WW		
PCF	kg CO_2e kg^{-1}	0.90	0.25	2.61
GM	EURO ha^{-1}	713.5	48.3	1433.9
		SM		
PCF	kg CO_2e kg^{-1}	0.46	0.17	1.62
GM	EURO ha^{-1}	980.5	483.9	1372.4

The mean PCFs in WW and SM production were 0.90 and 0.46 kg CO_2e kg^{-1}, respectively, while the average GMs of WW and SM production were 713.5 and 980.5EURO ha^{-1}, respectively. This clearly shows that SM performs relatively better regarding its environmental effect and economic performance compared to WW. Furthermore, a huge heterogeneity in PCF and GM was observed among the 65 sampled WW-SM farm households, as shown in Table 2. In both WW and SM the PCF of the worst performing farm household was ten times higher than the PCF of the best performing farm household. Those results highlight the importance of assessing PCF and GM improvement potentials of the alternative simple fertilization strategies in the context of the existing diversity in crop management.

Table 2. Average PCF reduction and GM increase of WW and SM production under the three yield and two N fertilization scenarios compared to baseline conditions; percentage changes to average PCF and GM under baseline conditions are given in brackets.

	PCF reduction (kg CO_2e kg^{-1})		GM increase (EURO ha^{-1})	
	N-uptake	N-fixed	N-uptake	N-fixed
WW:				
yield loss	+0.236 (+26 %)	+0.209 (+23 %)	-80.6 (-11 %)	-82.5 (-12 %)
yield constant	+0.259 (+29 %)	+0.277 (+31 %)	+45.9 (+6 %)	+52.2 (+7 %)
yield increase	+0.278 (+31 %)	+0.332 (+37 %)	+172.2 (+24 %)	+186.9 (+26 %)
SM:				
yield loss	-0.037 (-7 %)	-0.022 (-4 %)	-142.1 (-15 %)	-137.7 (-14 %)
yield constant	-0.026 (-5 %)	+0.029 (+5%)	-6.5 (-1 %)	+7.3 (+1 %)
yield increase	-0.010 (-2 %)	+0.078 (+14 %)	+129.2 (+13 %)	+152.2 (+16 %)

The impact of the two tested N fertilization strategies on farmers' PCF and GM under potential yield change was evaluated with regard to the average improvement in PCF and GM over all farmers (Table 2). Except for the PCF reduction potential in WW under yield loss conditions, the N-fixed strategy always resulted in a better performance compared to the N-uptake strategy. When comparing the relative improvement potentials of the two N scenarios in PCF with the improvement potentials in GM under constant yield a strong difference can be observed for both crops. While the mean PCF reduction potentials in WW range from 29 % to 31 %, the potential GM increases only reach from 6 % to 7 %. For SM the effects are generally smaller with 5 % to -5 % in PCF and 1 % to -1 % in GM.

Over all scenario combinations the PCF reduction potential is much higher in WW compared to SM, both in absolute and relative terms. The differences are mainly caused by the comparatively stronger over fertilization in WW compared to SM, both with regard to quantity of farmers and amount of fertilizer per farmer. Assessing the impact of the yield scenarios over both N scenarios reveals that yield change has a much stronger impact on GM than on PCF, even under the N fixed rate scenario.

4 Conclusion and Recommendations

The study revealed that fertilization according to the recommended fixed N rate (N-fixed) would result in a massive reduction of GHG emission from crop production in the NCP. It was furthermore revealed that saving fertilizer as a result of improved N fertilization strategy reduced farmers' PCF significantly, while it had no significant effect on farmers' GM under the assumption of constant yield. On the other side, a potential 10 % yield loss would have only a marginal effect on PCF, but a detrimental effect on farmers' income. With farmers currently applying excessive N rates as a "cheap insurance" against potential N limitations, the agricultural advisory system of China requires fundamental changes to successfully overcome the excessive fertilizer use and respective environmental pollution. The study concludes that the indirect subsidization of N fertilizers needs to be stopped and a cross compliance system should be implemented, which punishes non-compliance with maximum allowed N rates by cutting direct farm payments.

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Environmental performance of nitrogen fertiliser limits on root crops potatoes and sugar beets

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1 Introduction

Previous efforts to improve the quality of ground- and surface water have resulted in improvements, but in several regions in Flanders, the 50 mg nitrate (NO_3^-) l^{-1} norm from the European Nitrates Directive has still not been achieved. Limiting nitrogen (N) fertiliser application rates is one of the best N management measures to minimise N losses. This limitation, however, can not only be seen in view of improving the water quality (regulating ecosystem service) but also taking into consideration its impact on crop yield and quality (provisioning ecosystem service).
In the range from low to optimum fertilisation rates, most crops show a rather constant residual soil mineral N (RSMN) at harvest. This constant RSMN is considered to be the mimimum mineral N buffer necessary to guarantee optimal growth. When N fertiliser rates are increased to rates above this optimum, the RSMN shows a breakpoint and increases steeply for most crops, thus increasing the risk of NO_3^- leaching during winter (Hofman *et al.*, 1981). Nitrogen fertilisation experiments can help to determine this breakpoint. In this study, we collected a large set of data from N fertiliser experiments on root crops potatoes and sugar beets and critically re-analysed these data to calculate the effects of N fertiliser rate and soil N availability on RSMN, yield and N uptake and to evaluate the current fertiliser limits.

2 Materials and Methods

We used the pooled data of different field trials (1991-2010) on potatoes and sugar beets in Flanders and northern Wallonia (D'Haene *et al.*, 2014) to determine the effect of different N fertiliser rates (= applied effective N) and crop N availability on RSMN, yield and N uptake. The N in organic manure is only partially crop available. Mineral fertiliser, slurry or farmyard manure contain 100, 60 and 30% effective N, respectively (Anonymous, 2011; Webb *et al.*, 2011). The crop available N equals mineral N in the soil at the start of the growing season + N deposition + N mineralisation + applied effective N during the growing season.
We re-analysed the data sets consisting of RSMN values (NO_3^--N only) of the 0-60 and 0-90 cm layer (rooting depth) for potatoes (sampled 14/09 - 13/10) and sugar beets (sampled 17/09 - 29/10), respectively. The mixed soil was analysed for NO_3^--N by extraction with 1M KCl solution (ISO, 2003). We have tested a (segmented) linear, exponential, quadratic and power model for RSMN versus applied effective and crop available N. The breakpoint with the smallest confidence interval of segmented linear regression was calculated according to Oosterbaan *et al*. (1990).
If measured N concentrations (Kjeldahl method) were available, these were used to calculate N uptake, alternatively calculations were based on measurements made in other locations and on literature data. To avoid an over- or under-estimation of the N uptake, any unmeasured N concentration was adjusted via a process of gradual N increase in function of crop available N. A minimum % N on dry matter (DM) was fixed at a crop available N of 225 kg N ha^{-1}, being the average of fields fertilised with less than 50 kg applied effective N ha^{-1}. Based on the measurements performed by PCA, an increasing % N between 1.15 and 1.75% N on DM was used for tubers of potato plots with 225 to 375 kg crop available N ha^{-1}. Nitrogen export of sugar beets was calculated by multiplying fresh yield by 0.23 (DM fraction) and a % N (increasing % N between 0.6 and 0.8% N on DM for plots with 225 to 325 kg crop available N ha^{-1}) (Hofman *et al.*, 1984 ; IRS, 2013). For the unharvested roots, stalks, cobs and leaves of unfertilised and fertilised plots, the N uptake data are based on measurements of PCA and KBIVB and various literature data (Hofman *et al.*, 1984 ; Bries *et al.*, 1995 ; Draycott, 2006 ; IRS, 2013). A logistic model was used to relate exported yield and total N uptake to i) crop available N and ii) applied effective N. Its characteristic S-shape gives it a broad applicability to a variety of processes that exhibit such sigmoidal behavior, including yield and crop N uptake (Overman *et al.*, 2003).

3 Discussion

For potatoes and sugar beets a maximum tuber yield of 61.8 and 90.9 Mg fresh matter ha^{-1}, respectively, was calculated with a logistic model in function of applied effective N. Calculated maximum total N uptake (= N uptake by tubers and unharvested plant parts) in function of applied effective N was 268 and 365 kg N ha^{-1} for potatoes and sugar beets, respectively (Fig. 1). The calculated exported tuber yield and maximum total N uptake differed insignificantly between the two approaches (in function of crop available and applied effective N) ($P > 0.05$).

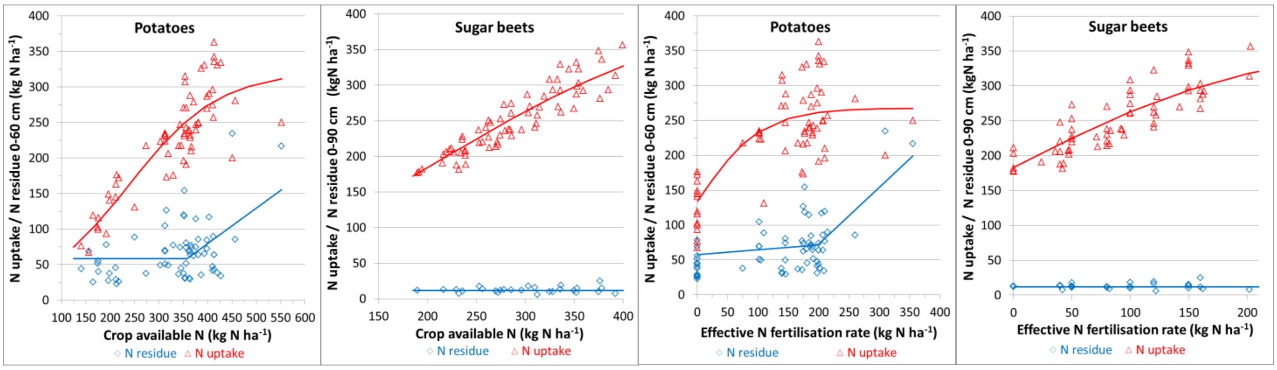

Fig. 1. Nitrogen (N) dose-response curves (Δ) and residual soil mineral nitrogen (rooting depth) (◊) in function of crop available N (left) and applied effective N fertilisation rate (right) for potatoes and sugar beets.

For potatoes, a breakpoint in RSMN was noticed for both approaches (Fig. 1). RSMN at the breakpoint in function of the effective N fertilisation rate was 72±29 kg N ha^{-1} and was situated at 199±77 kg applied effective N ha^{-1}. There is no ground for increasing the Flemish maximum allowed effective N application rates of 190 and 210 kg N ha^{-1} for sandy and non-sandy soils (Anonymous, 2011), respectively, given that RSMN increases sharply after the breakpoint. A decrease of the N fertiliser limit is not advised from an economic standpoint, as the N fertilisation rate not only affects total but also marketable yield (van Evert *et al.*, 2011). For both approaches, RSMN for sugar beets was low and constant (13±4 kg N ha^{-1}) over the entire range under study (0-160 kg applied effective N ha^{-1}). The maximum applied effective N application rate of field experiments with sugar beets is relatively low, as an excessive N amount increases impurities and decreases extractable sugar content. The maximum allowed effective N fertilisation rates for sugar beets (135 and 150 kg N ha^{-1} on sandy and non-sandy soils, respectively) (Anonymous, 2011) result in low RSMN, showing that the current fertiliser limits are well-founded, and there is even room to slightly increase the N limits.

4 Conclusions

Combining dose response curves with RSMN enables to derive maximum allowed N fertilisation rates which allows improving the provisioning ecosystem service (i.e. optimal qualitative yield) but also the regulating ecosystem service by limiting the potential risk of NO_3^- leaching during winter. RSMN not only depends on the crop but also on crop available and applied effective N, except for sugar beets where RSMN is low within the range of applied effective N not negatively affecting tuber quality. The presence of a breakpoint between RSMN and applied effective N for potatoes gives the opportunity to deduce optimum N fertilisation rates limiting the potential risk of NO_3^- leaching during winter whilst maintaining yield levels. However, even after an optimal fertilisation the maximum allowed NO_3^- concentration can be exceeded after the harvest of some crops. RSMN before the breakpoint of potatoes is rather high and only part of the N mineralised from the potato and sugar beet leaves, which remain on the field after harvest, is denitrified or can be found in the soil in the following spring. Therefore, NO_3^- leaching during winter period after optimal fertilisation has to be estimated in order to evaluate the necessity of measures such as sowing catch crops or removal of crop residues.

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FARMING SYSTEMS TO SUPPORT FLEXIBLE CLIMATE RESPONSE STRATEGIES FOR CAMBODIAN SMALLHOLDER FARMERS

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1 Introduction

The production of rice (*Oryza sativa* L.) is an important contributor to the Cambodian economy and to national food security. With government policy aiming to increase annual paddy rice production and to significantly increase annual exports, there is an imperative to increase national rice yields. Currently, the Cambodian national average yield of 2.41 t/ha is lower than those of the neighbouring countries of Thailand (2.86 t/ha^{-1}), Laos (2.67 t/ha^{-1}) and Vietnam (5.6 t/ha^{-}) (2010-12) (IRRI, 2013). As rainfed, lowland rice constitutes around 90% of the annual harvest area of 2.4 million hectares (MAFF, 2011), it is an obvious starting point in meeting national goals and in supporting the food security of a nation where 25% of the population suffered undernourishment in 2004-05 (Magnan and Thomas, 2011).
Overarching the agronomic and social challenges facing policy makers and farmers is the effects of seasonal climate variability on productivity, and the vulnerability of agriculture to the future impacts of climate change which are predicted to increase the frequency, severity and unpredictability of extreme weather-related events such as hurricanes, droughts, floods, and rising sea levels (IPCC, 2007). Nowhere is this likely to have more impact than in the south-eastern provinces of Svay Rieng (11.089N, 105.819E) and Prey Veng (11.485N, 105.328E) where a combination of variable climate and low quality soils affects rice productivity (average provincial yield of 2.29 t/ha^{-1}) (IFAD, 2013). In response, economic migration to population centres has been an important societal trend, with resultant labour shortages further exacerbating the challenges of increasing agricultural productivity (Roth *et. al*, 2013). It was hypothesised that in these provinces productivity could be increased, climate risk reduced and farmer livelihoods improved through the introduction of a number of systems interventions which were tested using on-station and on-farm biophysical research, financial analysis and cropping system analysis using the APSIM farming system model (Keating *et al.* 2003).

2 Methods

On-farm research was conducted on 167 farms (mean treatment size of 1230 m^2) between 2011 and 2013. Comparisons were made between typical farmer practice, of using locally sourced medium and long duration rice varieties, transplanted in mid-wet season (June/July) and grown with low levels of nutrition, and a range of system interventions that included the use of modern, open-pollinated, short and medium duration varieties, increased cropping intensities and levels of nutrition and weed control, the use of supplementary irrigation and direct seeding (Table 1).

Table 1. Intervention options tested during on-farm research undertaken in south-eastern Cambodia (2011-2013).

System	Rice variety (duration)	Crop establishment	Seasonal crop number; establishment	Agronomic practice
Farmer practice	Local, farmer retained seed (140-170 days)	Transplanted	Crop 1: mid-wet (June/July)	Limited organic/inorganic fertiliser; hand weeding
Inter1- early	Modern, short duration (90-110 days)	Direct-drum seeding or hand broadcast	Crop 1: early-wet (May-early June)	N50:P23:K30 basal/top dress; hand/chemical weed/ insect control
Inter1-mid	Modern, short duration (90-110 days)	Direct-drum seeding or hand broadcast	Crop 1: mid-wet (July-Sept)	N50:P23:K30 basal/top dress; hand/chemical weed/ insect control
Inter2	Modern, short duration (90-110 days)	Direct-drum seeding or hand broadcast	Crop 1: early wet (May to early June). Crop 2: mid-wet (Sept)	N50:P23:K30/crop-basal/top dress; hand/chemical weed/insect control; irrigation to establish and/or to complete crop if required
Inter3	Modern, medium duration (120-140 days)	Direct-drum seeding or hand broadcast	Crop 1: mid-wet season (June/July)	N50:P23:K30-basal and top dress; hand/chemical weed/insect control

On-station research was used to calibrate the APSIM-Oryza model for current Cambodian rice varieties and conditions (Poulton *et al.* 2014) before being validated using on-farm experimental data. Confident in its ability to predict yield for local conditions, the model was then used to investigate the riskiness of rice production under current environmental conditions and future climate scenarios (Poulton *et al.* 2015, in these proceedings).

3 Results and Discussion

The use of modern, short and medium duration rice varieties, established using direct seeding, and grown using recommended fertiliser rates and agronomic management resulted in higher seasonal productivity and financial return than traditional practice (Table 2). The growing of 2 consecutive, short duration crops (Inter2) provided the highest median seasonal rice production in both 2012 and 2013, although in 2012, a season marked by late monsoonal onset and later flooding, the highest median gross margin (GM) (and the GM range for the middle 50% of farmers) was achieved by the medium duration crop (Inter3). In 2013, a more benign climatic season, the growing of 2 sequential crops (Inter2) achieved both the highest seasonal yield and GM (with labour).

Table 2. Median rice yield (kg/ha^{-1}) and gross margin (GM) for the production interventions tested (2011-2013).

System	2012*				2013a			
	Median yield (14% moisture) (kg/ha^{-1})	**Median GM (-labour)** (US$/ha^{-1})	**Median GM (+labour)** (US$/ha^{-1})	**GM-Mid 50% (+labour)** (US$/ha^{-1})	**Median yield (14% moisture)** (kg/ha^{-1})	**Median GM (-labour)** (US$/ha^{-1})	**Median GM (+labour)** (US$/ha^{-1})	**GM-Mid 50% (+labour)** (US$/ha^{-1})
Farmer practice	1852	283	(91)	(179)-(9)	3185	315	119	(33)-318
Inter1- single short crop, early plant	2740	193	(19)	(98)-125	3784	450	245	71-360
Inter1- single short crop, mid-season plant					3663	522	392	337-424
Inter2 –2 short crops, early/mid plant	4923	376	9	(112)-255	6491	824	485	330-598
Inter3-single medium crop, mid season plant	1886	343	171	129-371	3404	469	292	249-351

*2012 season-late monsoon start and seasonal flooding; a2013 season-early monsoon start and no extreme seasonal conditions

While the timing of establishment of a single short duration crop (Inter1-early and -mid) had little impact on the median yield or the yields achieved by the middle 50% of farmers (not shown), there was a marked difference in median GM and an increased level of risk associated with early planting (Inter1-early) as shown by the GM range achieved by the middle 50% of farmers. This was a result of the increased variability associated with early monsoon season rainfall and the higher input costs associated with the growing of an early crop, in particular, weed and pest control and the need for supplementary irrigation. Farmer practice yields were similar to Inter3 (the nearest comparable intervention), but GMs were 2.5-3 times lower than those achieved for Inter3 with the differences reflecting the higher labour costs associated with rice transplant (25 person days/ha, compared to <1 day/ha with direct seeding) and high levels of variability in farmer input costs. The higher median farmer practice yield achieved in 2013 reflects the increasing confidence of individual farmers to adopt the more easily applied interventions including direct seeding and modern varieties.

4 Conclusions

There is little doubt that the adoption of the intervention options will increase crop yield and improve current farmer livelihoods. However, the replacement of a relatively simple, but inflexible, recipe based approach, with a range of more complex technologies which vary according to timing of monsoon onset and seasonal conditions are likely to be more attractive to those aiming to optimise production or are labour constrained. While the above examples could indicate that an individual would utilise a single cropping option, it is more likely that multiple options would be used to mitigate climatic and financial risk with choices varying according to seasonal conditions. Options include the use of short and medium, modern and traditional varieties, established at varying times to spread production risk, balance labour supply and demand and to meet market requirements, in conjunction with improved agronomic management.

Underlying these improvements will be the increasing use of mechanisation to reduce labour inputs and to improve timeliness of operations, particularly crop establishment and harvest.

As a result of this research, response farming now forms part of government and non-government extension programs across a number of the lowland rice provinces with detailed training materials currently being developed to support these activities.

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Reducing pesticide use while reaching economic and environmental sustainability in Arable Farming

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1 Introduction

The substantial reduction in pesticide use is one of the key-issue for improving agriculture sustainability. Integrated farming, based on Integrated Pest Management (IPM) principles that emphasize physical and biological regulation strategies to control pests while reducing the reliance on pesticides, is presented as an alternative path in between conventionnal and organic farming likely to better reconcile agricultural productivity with other components of sustainability (Holland *et al.*, 1994). Here, we used a network of 48 contrasted cropping systems (conventionnal, integrated or organic) to analyse the relationship between the level of pesticide use and eight aspects of agricultural sustainability (Lechenet *et al.*, 2015).

2 Materials and Methods

The cropping systems included in the study were from two regions in France (Burgundy and Poitou-Charentes), and were either tested in cropping system experiments or surveyed in commercial farms sampled so as to maximise the variability in the level of pesticide use. Eight systems complied with the specifications of organic farming, 30 systems followed some IPM principles (diversified crop rotations and/or non-chemical pest management options such as resistant cultivars, mechanical weeding and false seed bed techniques) and 10 systems were classified as conventional systems. At each site, a conventional system was identified as a local reference corresponding to the current standard crop rotation and crop management. Each system was described with a detailed sequence of operations for soil tillage and crop management.

For each system the level of pesticide use was estimated using the Treatment Frequency Index (TFI) quantifying the number of registered doses applied, and eight indicators of sustainability were computed from the management data, namely the productivity (harvested MJ ha^{-1} $year^{-1}$), the energy efficiency, the economic profitability expressed as the semi-net margin (Euros ha^{-1} $year^{-1}$), the fuel consumption (L ha^{-1} $year^{-1}$), the level of N fertilization (kg of N ha^{-1} $year^{-1}$), the indicator of environmental impact related with pesticides I-Pest in standardized environmental conditions (van der Werf & Zimmer, 1998), the sensitivity of the semi-net margin to price volatility, and the workload (h ha^{-1} $year^{-1}$). The Dia'terre® reference database was used for the computations of energy inputs and outputs. The sensitivity to price volatility was defined as the relative standard deviation of the semi-net margin calculated over ten contrasting real prices scenarios selected between 2000 and 2010. Each indicator was expressed as natural logarithm of the ratio between the cropping system and the local reference indicators, and this allowed separating the effects of the cropping system itself from the effects of the specific production context at each site. Pesticide use was expressed as relative TFI, i.e. as a ratio with the TFI of the local reference system.

3 Results - Discussion

Productivity of organic systems was about -50% on average below productivity of non-organic systems, which is a higher gap than highlighted in a recent review (Ponisio *et al.*, 2015). But we found no correlation between TFI and productivity for conventional and integrated systems (Fig. 1A). The energy efficiency was frequently higher in integrated systems as compared to organic and conventional ones (Fig. 1B), partly because the frequency of crops for which the whole above-ground biomass is harvested was higher in IPM-based systems. Excluding organic systems, the correlation between TFI and energy efficiency kept a negative tendency when cropping systems producing grain crops only were considered, because IPM-based systems reduced energy inputs thanks to lower levels of N fertilisation and higher frequency of legume crops. In spite of their low energy input, organic farming yielded significantly lower energy efficiency as compared to IPM-based systems.

The semi-net margin, when averaged over the ten price scenarios, was very similar for organic, conventional and IPM-based systems, and no correlation was detected between TFI and the average semi-net margin (Fig. 1C). The range of profitability was higher for IPM-based systems, as both the systems providing the highest and the lowest profitability were following IPM principles. The sensitivity to price volatility was significantly lower in organic cropping systems than in other ones, probably because (i) they were based on more diversified crop rotations, which spread risks and buffered semi-net margin at the farming system scale, and (ii) they are less dependent on exogenous inputs, and notably volatile inputs such as N fertilizers.

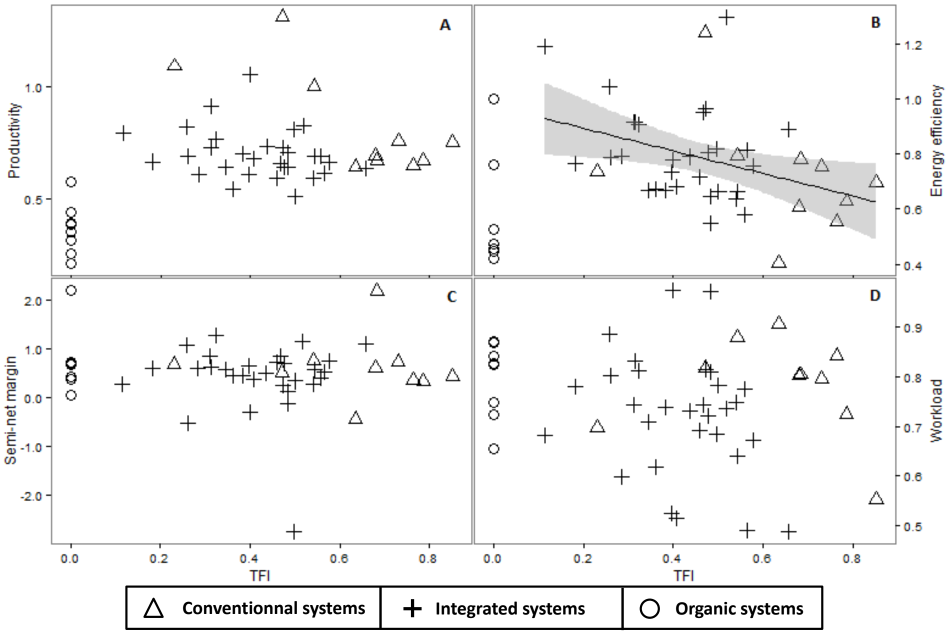

Fig. 1. Relationship between the level of pesticide use (relative TFI) and four sustainability indicators for 48 contrasted cropping systems: (A) productivity, (B) Energy efficiency (linear regression is represented with standard error, Pearson correlation test: rp = −0.38, P = 0.02), (C) Semi-net margin, and (D) workload. Each sustainability indicators is expressed as the natural logarithm of the ratio between the cropping system and the local reference indicators.

We found a large variability in the workload required to manage cropping systems (ranging from 2.5 to 6.2 h ha^{-1} $year^{-1}$), but surprisingly there was no correlation with TFI. High labour requirements were mainly correlated with the application of organic manure.
As expected we found a close relationship between TFI and the indicator related with the impact of pesticide residues in the environment I-Pest. Organic systems consumed significantly higher levels of fuel as compared to the rest of the sample, but we found no correlation between this non-renewable input and TFI for non-organic systems.

4 Conclusions

According to the results, IPM-based system appeared as the best compromise in sustainability trade-offs: they contribute to reduce substantially the use of pesticide and related environmental impacts while providing high productivities (higher than organic farming), good profitability, high energy efficiency, and this without necessarily increasing the workload and the consumption of non-renewable inputs. Both the crop diversification and the insertion of legume crops in grain crop rotations appear as major components of sustainable cropping systems (Lechenet *et al.*, 2015).

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USING FADN TO DERIVE CROPPING SCHEME DISTRIBUTION IN ITALY

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1 Introduction

Arable land is a major component both in landscape and in food production system. The ability to understand and describe how spatial and dynamical characters affect human life and eventually to design the agricultural systems beyond the processes ruling them is fundamental to preserve land and ensure economic, ecological and social sustainability.

In this paper, we will refer to cropping scheme as a general term merging two aspects of cropping systems, the spatial and the temporal one, represented respectively in terms of crop pattern and crop rotation. Analysis of crop rotations is of basic importance in sustainable farming strategies dealing with climate change, food security and organic farming. In fact crop rotations are fundamental to maintain fertility and, even if their analysis often focus on local crops, they help facing market and weather uncertainties as well as interpreting landscape diversity and its dynamics (Dury *et al.*, 2012, Thenail *et al.* 2009).

In European Community (EC) an agricultural holding data-base standard has been developed, the Farm Accountancy Data Network (FADN), which is seldom rich of information on farm management techniques. The present study makes use of Italian FADN to identify more recurrent crop patterns and evaluate the possibility to describe them as a crop rotation.

2 Materials and Methods

The FADN survey platform (http://ec.europa.eu/agriculture/rica/) is designed to monitor and evaluate agricultural dynamics to assess Common Agricultural Policies (CAP) and is based on the collection of information in a complex data-base (RICA). Italian data are from on a sample of farms extracted from Italian Census (ISTAT) farm population (about 750,000). Representativeness and geographic homogeneity requirements make the sample to be adjusted yearly not ensuring holding to be observed continuously. For the present investigation years 2008-2012 have been used, involving 18,608 different farms. As the study is addressed to detect rotations, a number of exceptions have been formerly identified (e.g. farms with no arable land) which makes to retain about 50% of farms of the initial sample.

RICA data-base includes, beyond economical accounting information, a description of environment, land use, crops and live stocks, agricultural practices, productions and resources (e.g. fertiliser, labour).

The crop list is comprehensive of 270 items: as they cannot be used directly for pattern / rotation recognition, they have been grouped into six categories on the base of the agro-technical inputs: set aside and not cropped surfaces (TR), forages, where tillages are performed each several years together with sowing, no treatments, no-irrigation, multiple harvests (FO), cereals, characterised by main and refining tillage, few treatments, no-irrigation, sowing, harvest (CR), intensive crops, including industrial crops and maize, similar to CR but with a higher environmental control together with irrigation (IN), rice, which has been considered separately because of its peculiar character in the Italian scenario (RI), other crops (OC).

Also this former analysis adopts two basic assumptions: 1) a crop rotation reflects the pattern observed on the whole arable surface - one crop rotation for farm; 2) annual crops are only involved in rotations (which also means neglecting the practice of successions winter-summer crops). Such assumptions allow to identify those patterns whose surface stay in integer ratios, reflecting both a surface and a time divide, which are coded after crop-groups and their ratios, e.g. “1CR-3FO” means that 25% of surface is grown with cereals and 75% with forages, or in a time-representations corresponds to a four-year rotation with 1 year cereals and 3 years forage crop; 4 is pattern rank.

3 Discussion

From the 411 patterns emerged from analysis,16 of them are able to explain 90% of farms. On such patterns a stability analysis has been performed showing that yearly pattern records own to the same population (χ^2> 99.95). Observing the same pattern on a farm for multiple years is both a validation of the pattern and an indicator of possibility to interpret the pattern as a rotation. However the real possibility of interpreting every patterns as rotation is prevented from some intrinsic feature of RICA protocol, which address population representativity, not requiring a farm be included in the survey every years; also RICA does not include any information of single fields.

Distribution of patterns in Italy on a regional basis (Fig.1) show a sound picture: in the north (Veneto and Friuli-

Venezia-Giulia and Lombardia) a marked presence of industrial crops (including maize which is continuously cropped) the similar distribution on middle Italy hilly regions (Umbria, Marche and Toscana) as well as the extensive cerealsdominating the south landscape (Puglia and Calabria). Rice monocolture characterising only the Piemonte region is not reported.

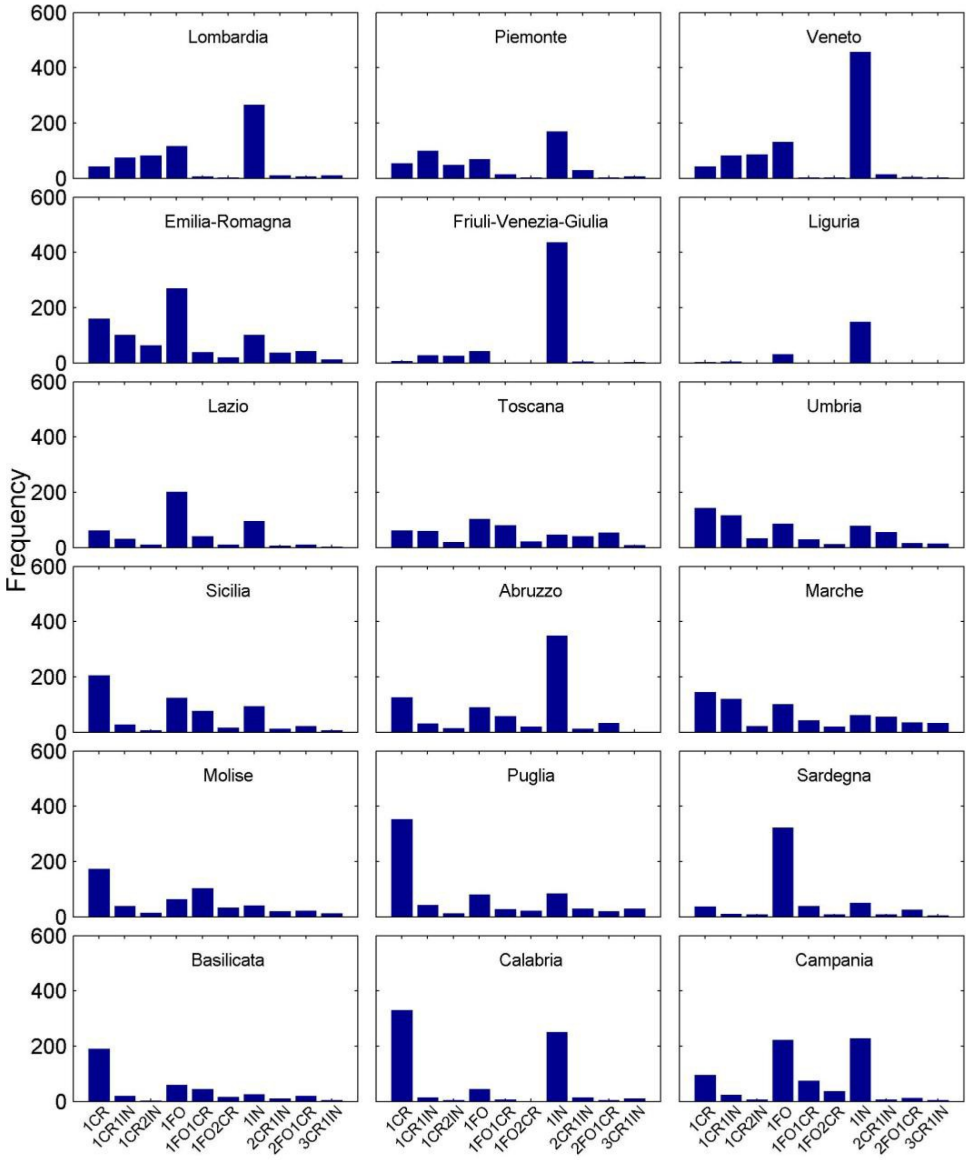

Fig. 1. Distributions of crop patterns in Italian regions; in X axis is reported the pattern code given by space/time frequency and crop codes: CR: cereals, IN: intensive crop, FO: forage.

4 Conclusions

The present analysis represents a former approach in using FADN data to recognise cropping schemes. The methodology, based on crop clustering based on technical inputs, seems able to put in evidence the more common schemes practised in Italy but still limited is the possibility to relate crop patterns to crop rotations required from policy makers, landscape analysts, farm decision process and also useful to be compared to outputs of rotation generators used in landscape and farm modelling.

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CHARACTERIZATION AND QUANTIFICATION OF ROBUSTNESS FOR DESIGNING MORE SUSTAINABLE AND ROBUST WHEAT PRODUCTIONS

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1 Introduction

The context of increasing uncertainty for the farmers (global warming, price volatility…) defines major challenges for agronomic research. In European crop production, climatic variability has strong impacts, as illustrated by wheat yield stagnation since the middle of 1990's despite variety improvement (Brisson *et al.*, 2010). An important challenge is then to design more sustainable agricultural systems in a more variable environment (Naylor, 2008). Different concepts have been mobilized to discuss adaptability in a changing world (resilience, vulnerability, robustness …) but the meaning attributed to each of them is ambiguous and operationalization into empirical studies remains a challenge. In this paper, we propose a new method for quantifying robustness in agricultural systems and apply it on French bread wheat production to quantify yield robustness against abiotic constraints.

2 Materials and Methods

2.1 Robustness framework

Robustness has been first used in industrial production to optimize desired system characteristics despite internal or external perturbations (Taguchi and Clausing, 1990). In agricultural systems, robustness can be seen as the ability to maintain agricultural performances (or ecosystem services) above a certain threshold despite abiotic, biotic, economic or other constraints (ten Napel *et al.*, 2006). In the following case study, yield robustness against abiotic constraints will be assessed through the response of wheat yield to abiotic stress variability.

2.2 Case study on wheat yield

Wheat yield and crop management data were collected from DEPHY-Ecophyto network run by InVivo and including 210 farms distributed in contrasting soil and weather conditions and studied over a three years time span (since 2011). It corresponds to 1600 wheat crops. Daily climatic data between 1983 and 2013 were provided by Météo-France at local scale (8 x 8 km). The 210 farms have been first classified into 33 climatic zones regarding their average exposition to 8 ecophysiological stresses (including water excess, water deficit, frost occurrence and high temperature during grain filling). Classification was done using hierarchical clustering method on these 8 variables. For each climatic zone, soil diversity among wheat crops was characterized using Arvalis Institut-du-Végétal regional soil database. Six different soil types were described on average for each climatic zone.

2.2.1 Simulated impacts of abiotic stress on wheat yield

Over the 1983-2013 period, wheat yield variability was simulated for each soil type through STICS crop model (Brisson *et al.*, 2002). STICS crop model integrates plant, soil and climate interactions and has been recently validated over a wide range of agro-environmental conditions (Coucheney *et al.*, 2015).
To reflect only the impact of climate variability on yield, we used a fixed and standardized crop management file (i.e. constant in time and space)[1]. The simulation period was long enough (1983-2013) to cover contrasting climatic conditions. For each year, an Abiotic Stress Index (ASI) was calculated by relating the simulated yield on year *t* (y_t) to the maximum yield reached during the 1983-2013 period (y_{max}): $ASI_t = (y_{max} - y_t) / (y_{max})$.
As defined, ASI summarizes the impact of the different abiotic stress on yield production as a percentage of yield reduction in reference to the maximum yield potential (without limiting factors from climate).

2.2.2 Yield variability and robustness against abiotic constraints

Temporal yield variability was measured through the coefficient of variation for the 62 farms scored over the three years of data. Based on elasticity measure, robustness of wheat yield was then assessed through the responsiveness of

[1] Only sowing date was differentiated between North (sowing at 5th October) and South (sowing at 20th October).

yield to a change in simulated abiotic stress index. Robustness was calculated for each farm as the ratio between Abiotic Stress Index variability and observed yield variability (R = ΔASI/ΔYield).

3 Discussion

3.1 Abiotic Stress Index

Mean simulated and actual yields over 2011-2013 period were compared between the 62 farms and average simulated yields were consistent with observed data ($R^2 = 0.65$).

Simulation results of wheat yield over the 33 climatic zones are highly variable in space (from less than 6 t/ha in South-West to 10 t/ha in Bassin Parisien area) due to strong differences in climate and soil characteristics. Spatial variability of ASI is also important and the results indicate that wheat yields are particularly affected by abiotic constraints in the North-East of France where soils are more superficial and climate more severe (Fig. 1. left). We also observed an increasing temporal variability of ASI over the recent period (Fig. 1. right), meaning that impact of climate variability on agricultural production is getting stronger.

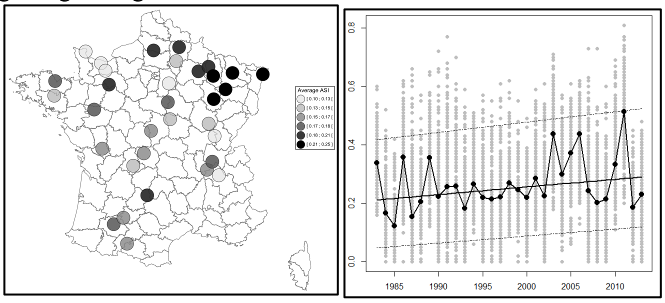

Fig. 1. Spatial (on the left) and temporal (on the right) variability of Abiotic Stress Index in wheat production.

3.2 Yield performance and yield robustness assessment

Temporal yield variability of the 62 farms with 3 years data is presented in Fig. 2. (left). Yield variability is higher in southwest and northeast France, i.e. regions with the lowest yields. Yield robustness was measured as the inverse of the ratio between yield variability and abiotic stress index variability (Fig. 2. right).

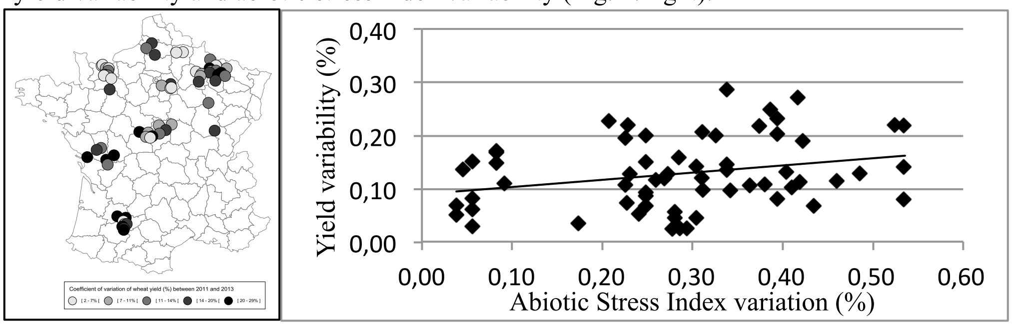

Fig. 2. Coefficient of variation of wheat yield (on the left) and response of yield variability to abiotic stress variability (on the right).

The preliminary results show a high variability of yield robustness to abiotic constraints in France. In a next step, agronomic determinants of yield robustness will be investigated to identify the most robust crop management strategies and economic and environmental consequences of yield robustness will be estimated. These findings will provide a better understanding of robustness in agriculture and potentially new decision tools to combine sustainability and robustness.

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Cut fallow to replace black fallow in an organic production system

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1 Introduction

Couch grass (*Elymus repens*) has large impact on yield and management strategies in temperate areas of the world, particularly in the Nordic countries. The control is to a large extent based on use of glyphosate in conventional agriculture and repeated soil cultivations in autumn, i.e. during a period when soil cultivations should be avoided due to the risk of increased nutrient leaching, in organic farming (Askegaard *et al.* 2011). The energy input for the common practice of stubble cultivation exceeds by large the input needed for chemical control in conventional farming (Tzilivakis *et al.* 2005). Therefore it is important to develop methods of couch grass control that are efficient and more environmentally friendly than repeated tillage or use of large quantities of glyphosate. By using subsidiary crops between cash crops and avoiding both glyphosate and tillage, environmental problems like nutrient and pesticide leaching could be avoided and positive cropping system effects could be achieved. However, competition from the subsidiary crop may not be enough to control couch grass.

In earlier investigations under-sown crops have competed well with couch grass during the autumn and the subsequent year and reduced the amount of couch grass substantially compared to treatments without competition, but generally, couch grass biomass have increased compared to the initial situation (Håkansson 1969, Dyke and Barnard 1976, Bergkvist *et al.* 2010). The possibility to improve the effect of competition by mowing has been investigated by e.g. Håkansson (1969) and Brandsaeter *et al.* (2012). According to Håkansson (1969) the method works, but the cutting interval must be very short. Brandsaeter *et al.* (2012) and Ringselle *et al.* (2015) found positive effect of mowing, but it was quite small.

Our aim was to investigate methods to improve the competitive effect of subsidiary crops by management. The hypothesis was that cutting (fragmentation) of the rhizomes by making slits in the soil by a spade (spading) would increase the number of couch grass shoots, thus improve the effect of repeated mowing. A recently developed prototype, “Kverneland Vertical rhizome/root cutter” (tractor propelled), can make similar slits in field scale.

2 Materials and Methods

The hypothesis was tested in three two-factorial field experiments arranged in complete randomized blocks with four replicates. The effect of cutting vertical slits in the soil was tested by comparing treatments with cross-cutting (grid) vertical slits with a control and the effect of mowing was tested by comparing mowed and not mowed plots (Table 1). Experiments were established at Krusenberg, Uppsala, Sweden, in 2012 and 2013, and at Ås, Norway, in 2013, by sowing a pure stand of white clover with 10 kg ha^{-1} in May. The mowed treatments were mowed to 3-5 cm above soil surface when the couch grass had about three new leaves in the experiments at Krusenberg and slightly later in the experiment at Ås. The experiments at Krusenberg were mowed eight and seven times during 2012 and 2013, respectively, and the experiment at Ås was mowed four times. Immediately after the first mowing, 10 cm deep slits was made by a spade in a 20 cm * 20 cm or 10 cm * 10 cm cross cutting pattern according to treatment (Table 1). The number of couch grass shoots was counted in the 80 cm by 80 cm centre in each 1.0 m^2 plot before first mowing and spading, before second mowing at Krusenberg and at final sampling in early October 2012 and late August 2013 at Krusenberg and in late October 2013 at Ås. The couch grass shoot and rhizome biomasses were sampled and dry weight determined at the final sampling. Data were log-transformed to equalize variance and analysed in accordance with the statistical design and with shoot numbers before first cutting as covariate using Model Mixed in SAS.

Table 1. Treatments used in six field experiments investigating the effect of cutting 10 cm deep slits in the soil (Cross Cutting (grid)) with a spade and mowing on couch grass

Treatment	Below ground weed control		Mowing
	Cross Cutting	Distance between slits	
Control	No	-	No
C20	Yes	20 cm	No
C10	Yes	10 cm	No
M	No	-	Yes
MC20	Yes	20 cm	Yes
MC10	Yes	10 cm	Yes

3 Results – Discussion

Cross cutting reduced the amount of rhizomes at Krusenberg (P=0.003), but the effect was different at Ås ($P_{Experiment*Cross\ Cutting}$=0.05) (Figure 1). At Ås, the amount of rhizomes was actually higher after cross cutting with the wide spacing than in the control or with narrow spacing between slits (P<0.05). Mowing reduced the amount of rhizomes at all sites (P<0.001), but the effect was similar with and without Cross cutting, which means that the effects of cross cutting and mowing were additive and that the mechanism was different from the hypothesized. Therefore, the hypothesis that Cross cutting increase the effect of mowing cannot be supported. The reason for the lack of interaction between the two factors could be that the number of shoots before mowing the second time, i.e about two weeks after first mowing and cross cutting, was lower than in the control at Krusenberg (data not presented), which was contrary to the hypothesis that Cross cutting would stimulate shooting and thereby increase the proportion of couch grass biomass cut of at mowing. Thus the control effect of cross cutting found at Krusenberg is probably an effect of damages to the rhizomes caused by the cross cutting procedure. The best effect of the cross cutting was found in the first year at Krusenberg, where cross cutting with 10 cm between the slits reduced the amount of rhizomes in late autumn compared to the control by as much as 60 %, on average (P<0.001). Repeated mowing was even more efficient and reduced the amount of rhizomes by more than 90 % (P<0.001). The combined effect was even greater. Cross cutting tended (P=0.13) to have an effect also at Krusenberg in 2013, but all effects at Krusenberg in 2013 were smaller than 2012. The reason for the smaller effect could be less soil moisture (data not presented) and therefore less growth in 2013 than 2012, but the difference could also be due to the shorter experimental period in 2013. The experimental period was shortened in 2013 compared to 2012, because a shorter fallow period would be beneficial for farmers that want to establish winter wheat after the fallow and because of the big effect of mowing in 2012 that almost wiped out the couch grass and made it difficult to evaluate the effect of cross cutting. We have not been able to interpret the stimulating effect of the cross cutting on couch grass at Ås.

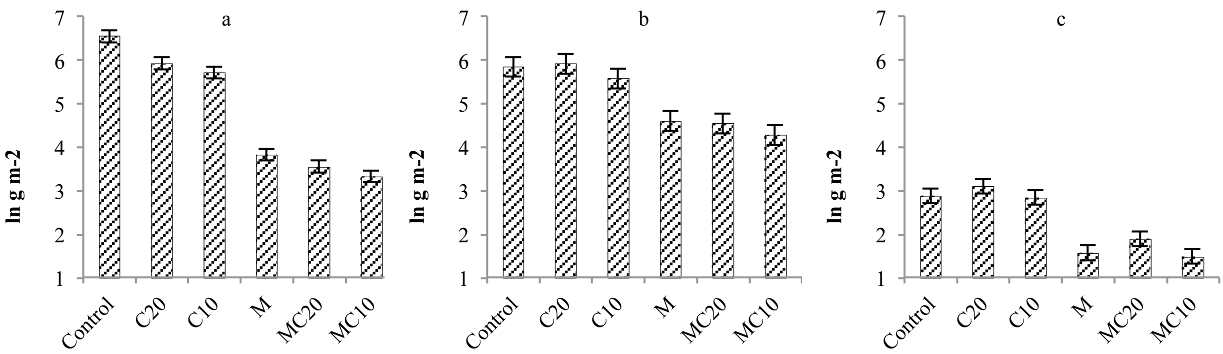

Fig.1. Predicted amount of rhizomes in autumn depending on cross cutting (grid) 10 cm deep vertical slits (C) in the soil with a spade (10 cm by 10 cm = 10; 20 cm by 20 cm = 20) in spring and repeated mowing (M) during summer at a) Krusenberg in 2012, b) Krusenberg in 2013 and c) Ås in 2013.

4 Conclusions

We conclude that Cross cutting to 10 cm could reduce the amount of rhizomes, but that the effect is variable. We also conclude that the cross cutting do not improve the effect of mowing, but that the effects are additive. Cross cutting reduce the amounts of couch grass shoots.

Acknowledgements. The work was funded by EU-FP7 as part of OSCAR (Optimizing subsidiary crop applications in rotations).

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Assessing environmental impacts of cropping systems: comparison of an indicator-based and a life-cycle analysis-based method

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1 Introduction

Design and experimental testing of innovative cropping systems requires assessing their performances. When measurements of impacts are not possible, direct impacts have mainly been assessed at the field level using indicator-based methods (Bockstaller *et al.*, 2008). Systemic assessment frameworks based on life-cycle analysis (LCA) have also been applied to cropping systems (Deytieux *et al.*, 2012). LCA methods address direct and indirect impacts (e.g. linked to production and transport of farm inputs) and therefore are scientifically interesting, but they require more input data and calculation time. This paper aims to compare both approaches and discuss to what extent it is necessary to implement an assessment method based on LCA.

2 Materials and Methods

Fifteen cropping systems were selected for study from the DEPHY database, containing average cropping systems from farms of the French national network "Ecophyto DEPHY"(French action plan to reduce pesticide use (Ecophyto, 2015)). These cropping systems have crop-rotation lengths ranging from 1 (maize monoculture) to 9 (maize/cereals/3-4 years grassland), application rates of mineral nitrogen fertilizers of 0-250 kg N.ha^{-1}, and pesticide treatment frequency indices of 0-5.3.

LCA methods implemented in the study were based on pollutant-emission models from the AGRIBALYSE framework, recently developed to support environmental labeling policies of agricultural products in France (Colomb *et al.*, 2015). For the indicator-based method, INDIGO was chosen to estimate direct impacts at the field level (Bockstaller *et al.*, 2008). We focused on the nitrogen-based emissions of nitrate (NO_3), ammonia (NH_3), and nitrous oxide (N_2O). They are estimated in the LCA method by models: the COMIFER approach for NO_3, EMEP/EEA 2009 Tier 2 (for organic fertilization) and EMEP/CORINAIR 2006 Tier 2 (for mineral fertilization) for NH_3 and IPCC 2006 Tier 2for N_2O. For the INDIGO method, these emissions were estimated by the I_N indicator (Bockstaller *et al.*, 2008). In both methods, a mineral nitrogen balance is calculated for the time from harvest to start of the drainage period at the beginning of winter to estimate nitrate leaching.

3 Results – Discussion

Among cropping systems, INDIGO tended to estimate more various nitrate leaching than LCA, and results of the two methods were weakly correlated (r = 0.18) (Fig. 1a). INDIGO tends to estimate slightly lower ammonia emissions than LCA, but results were strongly correlated (r= 0.88) (Fig. 1b). Estimates of nitrous oxide emissions were intermediate, with a weaker correlation than for ammonia but stronger than for nitrate (r = 0.55, data not shown).

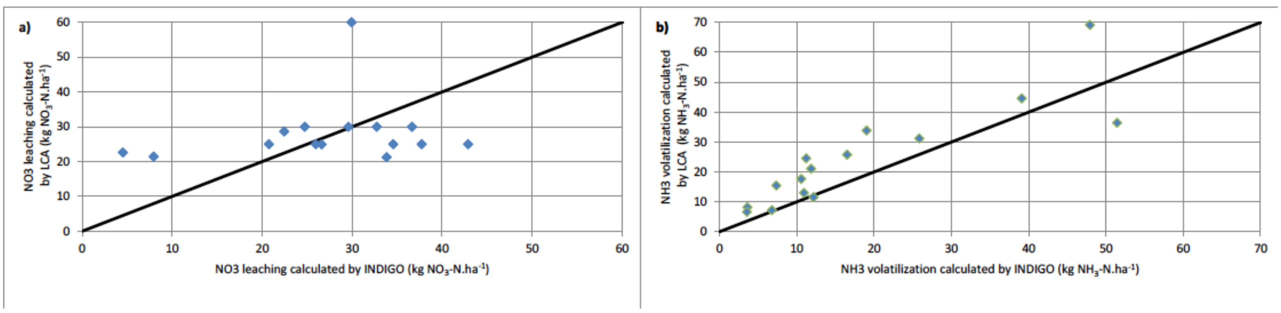

Fig. 1. Comparison of (a) nitrate leaching and (b) ammonia emissions of INDIGO and LCA methods.

According to the LCA method, eutrophication impacts were due almost completely to direct emissions(mainly phosphate and nitrate)from the crop field (Fig. 2a), while climate change impacts came mainly from production of mineral fertilizers, with the contribution of direct field emissions of nitrous oxide less than 30% (Fig. 2b). This highlights the utility of LCA in identifying the sources of impacts. Similar results can be found in the study of Deytieux *et al.* (2012).

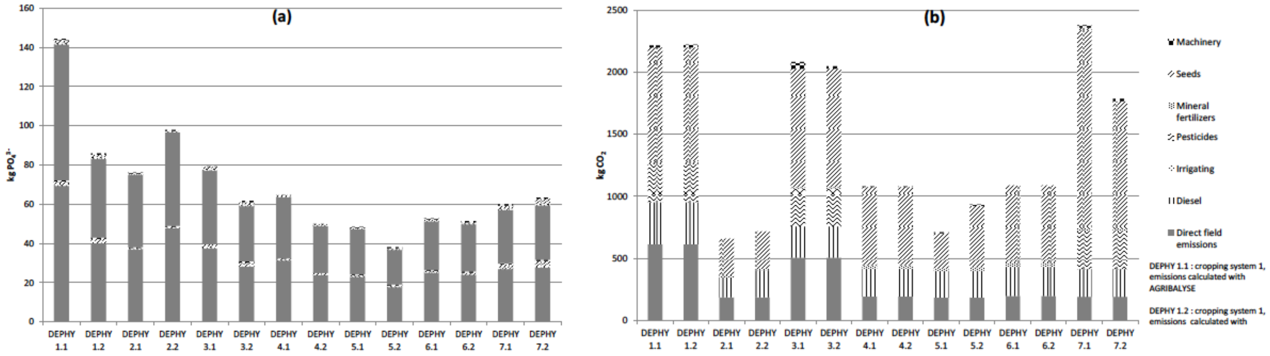

Fig. 2. Contribution of production stages or inputs to (a) eutrophication and (b) climate change impacts estimated by LCA.

4 Conclusions

This study shows that indicator-based and LCA-based methods can estimate similar magnitudes of emissions that contribute to potential impacts, such as eutrophication (or acidification), that are mainly determined by direct emissions from the crop field. Combining an indicator-based method with an LCA-based method could reduce the workload required to estimate direct field emissions in LCA. Such combination of methods will require data transfer between calculation tools to avoid entering the same data twice.

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Water productivity, Irrigation management and Systematization for Rice Farming Systems in Uruguay

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1 Introduction

A high proportion of water inputs for rice crop irrigation in the Central Region of Uruguay comes from rainfall water stored in dams. Maximizing water productivity is important as savings in water inputs would reduce the costs of pumping irrigation, increase annually sown rice area, allows to allocate water to irrigate other crops in a rotation and contribute to reduce the impact of farming systems on Water Footprint (Chapagain & Hoekstra, 2011) and to reduce environmental impact based upon Life Cycle Assessment, energy and water analyses (Thanawong *et al.*, 2014). The aim of this experiment is to determine irrigation management practices and systematization field layout techniques that increase water productivity (WP), contemplating the economic and environmental sustainability of rice farming systems in Uruguay.

2 Materials and Methods

A split plot experimental design trial was conducted in the Experimental Unit located in Tacuarembó (32.18S, 55.17W). Treatments included two types of systematization with different vertical interval between levees (big plots)l: I. Conventional (VI-8cm) and II. Alternative (VI-4cm) and three irrigation management practices (small plots): 1.Continuous (C), 2.Intermittent until panicle initiation (IP), and 3.Intermittent during all crop cycle (I). In C a water layer of 10cm is maintained after flooding throughout all the crop cycle. In IP and I the water layer alternates between 10 and 0cm and is re-established when the soil is still saturated. Irrigation started 30 days after emergence and finished 20 days before harvest date. Crop was direct drilled on 1th, 16th and 19th October with 160 kg seed/ha with cultivar INIA Olimar (Indica type). Basal fertilization was 160Kg / ha of 19-19-19 (N-P-K) and Urea was 100 kg / ha fractionated at tillering and panicle initiation. The results of the joint analysis of the previous three seasons (2012-2013-2014) were evaluated by analysis of variance and mean separation test of Fisher 5% using statistical package InfoStat (www.infostat.com.ar).

3 Results – Discussion

Intermittent irrigation systems led to significant water inputs savings in relation to continuous irrigation C, 2041 and 3554 m3 water ha^{-1} less for IP and I respectively (Fig. 1 a,b) (P<0.05). The systematization did not determine significant differences in water input (Fig. 1 c,d) (P<0.05).

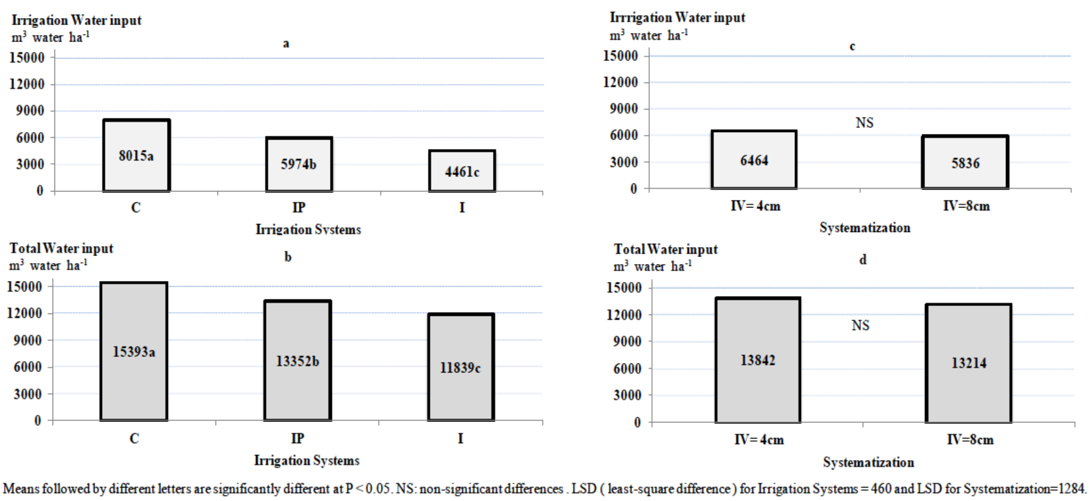

Fig. 1. Irrigation Water Input and Total Water Input (Irrigation plus Rainfall) for different irrigation systems and systematization (field layout techniques), Tacuarembó, Uruguay, (average seasons 2011-12, 2012-13 and 2013-14).

The highest WPi (irrigation) and WPt (irrigation plus rainfall) were recorded in treatment I, being 2.0 and 0.88 kg grain m^3 $water^{-1}$ respectively. These values are higher than the data reported worldwide where WPt of rice in Asia ranges from 0.2 to 1.2 kg grain m^3 $water^{-1}$, with 0.4 as the average value (Tuong *et al.*, 2005).
There were no differences in rice grain yield between irrigation treatments (P< 0.05) (Table 1). Similar results in the same region and comparable type of soils were registered by Lavecchia *et al.*, 2011. This results are explained because the soils on which the experiments were performed (planosols) have a low infiltration rate and rainfall was above the historical average throughout the crop cycle, 738 mm (from October to March). In analogous experiments conducted on soils with a higher infiltration rate in a different region (North), the intermittent irrigation determined a rice yield loss of 950 kg in relation to continuous flooding (Carracelas *et al.*, 2014).

Table 1. Rice Yield, Grain Quality and Water Productivity compared with three irrigation systems and two types of systematization, Tacuarembó, Uruguay (average seasons 2011-12, 2012-13 and 2013-14).

Site= Central Región, Tacuarembó.	Rice Yield (kg ha^{-1})	Industrial Quality		Water Productivity (WP) kg grain m^3 $water^{-1}$	
		White Grain %	Whole Grain %	WPi- Irrigation	WPt - Irrigation + Rainfall
Irrigation Systems					
1.Continuous (C)	7850	69.22	62.73 a	0.99 c	0.52 c
2. Intermittent until panicle initiation (IP)	7446	69.17	62.17 ab	1.31 b	0.57 b
3. Intermittent during all crop cycle (I)	7843	69.08	61.94 b	2.00 a	0.68 a
LSD (P<0.05)	*NS*	*NS*	*0.63*	*0.17*	*0.04*
Systematization					
I. Conventional - VI=8cm	7735	69.2	62.61	1.57	0.60
II. Alternative - VI= 4cm	7691	69.1	61.95	1.30	0.57
LSD (P<0.05)	*NS*	*NS*	*NS*	*NS*	*NS*
CV %	*12.12*	*0.71*	*1.95*	*22.44*	*12.16*

Means followed by different letters are significantly different with a probability less than 5% (P < 0.05). LSD : least-square difference. NS: non-significant differences. CV: coefficient of variation.

In relation to Industrial quality, continuous irrigation C determined a higher percentage of whole grain in comparison with intermittent irrigation I and no differences in quality with IP treatment (P<0.05) (Table 1).

4 Conclusions

The intermittent irrigation in low-infiltration rate soils, allowed for significant savings in water input of 35% on average without reducing rice grain yield relative to continuous irrigation, thus determining a significant increase in water productivity (P <0.05).
In relation to industrial quality, intermittent irrigation (I) determined a lower percentage of whole grain in relation to continuous irrigation C but with no differences in white grain percentage (P <0.05).
There were no significant differences in water input, grain yield, industrial quality and water productivity between the different systematizations-field layouts treatments (P <0.05).
Implementing crop irrigation systems involving savings in water input means a greater risk and would only be adopted by farmers on a larger scale if they determine more or equal rice yield per hectare without affecting the grain quality.

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Phosphorus offtake by silage maize and cut grassland in temperate regions

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1 Introduction

Long term phosphorus (P) overfertilisation have led to a large acreage of P saturated soils, high fractions of P in solution and increased diffuse P losses into ground- and surface water. In some European countries agriculture has become the main P source in water bodies (Bogestrand *et al*., 2005). Phosphorus losses are a major factor in eutrophication of surface waters and in a reduction of regulating and cultural ecosystem services as P is typically the limiting factor of algae blooming in freshwater systems (Sterner, 2008).
Phosphorus fertilisation advice should envisage an equilibrium maintenance phosphate (P_2O_5) fertilisation rate for fields with an optimal soil P content, with differentiation for other fields depending on their soil P content. In addition to a reduction of environmental pollution due to a more P efficient use, also the limited P_2O_5 rock reserve and the increasing price of mineral P_2O_5 fertiliser stimulate closing the P cycle. Up to date information of P_2O_5 removed by silage maize (*Zea mays*) and cut grassland (*Poaceae*) is needed as scientifically sound fertilisation advice takes both optimal crop yield and quality and environmental impact into account.

2 Materials and Methods

We re-analysed 26 and 14 Flemish nitrogen (N) fertilisation experiments (1996-2013) on silage maize and cut grassland without clover, respectively, to derive their P_2O_5 offtake. To preclude an effect of the applied N amount, only plots receiving the maximum allowed N fertilisation norm of Manure Action Plan (MAP) IV ±25%, meaning plots fertilised with 100-200 and 225-375 kg effective N ha^{-1} for silage maize and cut grassland, respectively (Anonymous, 2011), were included in the analysis. Phosphorus application rates were based on a fertilisation advice dependent on the expected yield. Total fresh and dry matter (FM and DM) yields were determined and P concentration of the harvested plant parts was measured colorimetrically after digestion and acid decomposition. The soil P content of the upper soil layer was determined with ammonium lactate (P-AL method).

3 Discussion

The P_2O_5 removed by silage maize in Flanders (1996-2013) had a median of 86 kg P_2O_5 ha^{-1} with a median 0.7 and 2.1 g P kg^{-1} on a FM and DM basis, respectively (Table 1). Regression analysis showed no correlation between P_2O_5 offtake by silage maize and soil P-AL content and/or P_2O_5 fertilisation rate. There was a significant correlation ($R^2 = 0.47$) between P_2O_5 offtake and yield. The median P_2O_5 offtake by silage maize increased significantly ($P < 0.001$ nonparametric Mann-Witney U-test). The increase of the median P_2O_5 offtake from 78 in 1996-1997 to 94 kg P_2O_5 ha^{-1} in 2003-2013 can be explained by the higher yield (median of 16.8 and 18.9 Mg DM ha^{-1} in 1996-1997 and 2003-2013, respectively) as the P concentration didn't change.

Table 1. Average, median and standard deviation (stdev.) of phosphorus and effective nitrogen fertilisation rate (kg P_2O_5 and N ha^{-1}), phosphorus content in the soil (mg P-AL 100g^{-1} soil), dry matter yield (Mg DM ha^{-1}), phosphorus concentration (g P kg^{-1} DM) and phosphorus offtake (kg P_2O_5 ha^{-1}) by silage maize in Flanders.

	119 plots (1996-2013)			73 plots (1996-1997)			46 plots (2003-2013)		
	Average	Median	Stdev.	Average	Median	Stdev.	Average	Median	Stdev.
P_2O_5 fertilisation (kg ha^{-1})	67	65	25	66	69	21	67	60	30
Effective N fertilisation (kg ha^{-1})	140	138	26	141	138	28	138	135	22
P-AL (mg 100g^{-1} soil)	34	30	15	35	33	11	32	29	21
Dry matter yield (Mg ha^{-1})	18.1	17.7	2.7	17.4	16.8	2.6	19.3	18.9	2.5
Phosphorus (g kg^{-1} DM)	2.1	2.1	0.4	2.1	2.1	0.4	2.1	2.1	0.3
P_2O_5 offtake (kg ha^{-1})	87	86	21	83	78	23	95	94	14

The P concentration in Flanders falls within the range of other temperate regions i.e. 1.8 g P kg^{-1} DM in the Netherlands and France (Ehlert *et al*., 2009 ; Gloria, 2012) and 2.2-2.3 g P kg^{-1} DM (2008-2013) in northern Germany (Egert, 2014). Fotyma & Shepherd (2001) measured in Northern and Eastern Europe on average 0.6±0.009 g P kg^{-1} FM (or 2.0 g P kg^{-1} DM). The median Flemish P_2O_5 offtake (86 kg P_2O_5 ha^{-1}) is higher than in other temperate regions. In France and Saskatchewan (Canada) fertilisation advice is based on an offtake of 60 (Gloria, 2012) and 64 to 78 kg P_2O_5 ha^{-1}

(Anonymous, 2012), respectively. In the UK, maintenance fertilisation advice is 55 kg P_2O_5 ha^{-1} (Defra, 2010). Aarts *et al*. (2008) calculated an average offtake of 69 kg P_2O_5 ha^{-1} from fields of representative Dutch dairy farms (1998-2006) based on an average 2.0 g P kg^{-1} DM measured by BLGG. The P_2O_5 offtake varied from on average 56 from wet sandy soils in 1998 to on average 78 kg P_2O_5 ha^{-1} from clay soils in 2006 (Aarts *et al*., 2008).

The median P_2O_5 removed by Flemish cut grassland was about 110 kg P_2O_5 ha^{-1} with a median P concentration of 4.1 g P kg^{-1} DM (Table 2). Regression analysis showed no correlation between P_2O_5 offtake and soil P-AL content and/or P_2O_5 fertilisation rate. There was a significant correlation ($R^2 = 0.50$) between P_2O_5 offtake and yield. The limited data from recent years suggest that the lower P_2O_5 fertilisation rate (90 compared to 116 kg P_2O_5 ha^{-1}) has resulted in an insignificant decrease of the average P concentration ($P = 0.06$ T-test). The median P concentration decreased from 4.2 g P kg^{-1} DM to 3.9 g P kg^{-1} DM. The average P concentrations of Dutch grass silage measured by BLGG decreased from 4.4 in 1998 to 4.0 g P kg^{-1} DM in 2007, which was also explained by the stricter legislation (Aarts *et al*., 2008). Although the median N fertilisation rate was 50 kg effective N ha^{-1} lower in 2003-2008 compared to 1997-1998, DM grass yield remained constant.

The Flemish P concentration of cut grassland falls within the range of measurements from intensively managed grassland under temperate climate i.e. 3.3 g P kg^{-1} DM in Wallonia (Mathot *et al*., 2009), 3.3-3.6 g P kg^{-1} DM (2008-2013) in northern Germany (Egert, 2014), 3.1-4.1 g P kg^{-1} DM in UK (Defra, 2010) and 3.5-4.4 g P kg^{-1} DM in the Netherlands (Aarts *et al*., 2008; Ehlert *et al*., 2009). Fotyma & Shepherd (2001) measured on average 0.6 g P kg^{-1} FM (or 3.0 g P kg^{-1} DM) in grassland with and without clover. The median Flemish P_2O_5 offtake is higher than other temperate regions, due to higher yields. In the UK, maintenance fertilisation advice is 90 kg P_2O_5 ha^{-1} (Defra, 2010). Aarts *et al*. (2008) calculated an average offtake of 89 kg P_2O_5 ha^{-1} from fields of Dutch representative dairy farms (1998-2006). The P_2O_5 offtake varied from on average 76 kg P_2O_5 ha^{-1} (wet sandy soils in 2006) to 110 kg P_2O_5 ha^{-1} (dry sandy soils in 1998) (Aarts *et al*., 2008).

Table 2. Average, median and standard deviation (stdev.) of phosphorus and effective nitrogen fertilisation rate (kg P_2O_5 and N ha^{-1}), phosphorus content in the soil (mg P-AL $100g^{-1}$ soil), dry matter yield (Mg DM ha^{-1}), phosphorus concentration (g P kg^{-1} DM) and phosphorus offtake (kg P_2O_5 ha^{-1}) by cut grassland in Flanders.

	56 plots (1997-2008)			**44 plots (1997-1998)**			**12 plots (2003-2008)**		
	Average	**Median**	**Stdev.**	**Average**	**Median**	**Stdev.**	**Average**	**Median**	**Stdev.**
P_2O_5 fertilisation (kg ha^{-1})	114	116	24	119	116	23	98	90	20
Effective N fertilisation (kg ha^{-1})	289	296	42	296	300	43	262	250	24
P-AL (mg $100g^{-1}$ soil)	28	27	11	29	37	12	23	22	8
Dry matter yield (Mg ha^{-1})	12.0	11.9	2.1	11.8	11.9	1.5	12.9	12.3	3.5
Phosphorus (g kg^{-1} DM)	4.0	4.1	0.6	4.1	4.2	0.6	3.7	3.9	0.4
P_2O_5 offtake (kg ha^{-1})	111	111	26	111	111	27	110	109	21

4 Conclusions

To fine-tune the P_2O_5 fertilisation rate, it is important that legislation and P_2O_5 fertilisation advice not only takes into account the soil P content but also the P_2O_5 offtake by agricultural crops as scientifically sound fertilisation advice accounts for optimal yield and quality, soil P content and water quality objectives. Re-analysis of Flemish N fertilisation experiments shows that the median P_2O_5 offtake by silage maize increased significantly from 78 kg P_2O_5 ha^{-1} in the last decennium of 20th century to 94 kg P_2O_5 ha^{-1} in recent years with a median of 2.1 g P kg^{-1} DM due to the increased yield. The median P_2O_5 removed by cut grassland was about 110 kg P_2O_5 ha^{-1} with a median of 4.1 g P kg^{-1} DM.

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The effect of bio-phosphate fertilizer to increasesoil phosphate, growth and yield of maize and P fertilizer efficiency on marginal soil

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1 Introduction

Phosphorus (P) is one of the macro- nutrients for plants that have an important role in plant growth. There are several problems that make the element P in the soil becomes unavailable to plants, especially on marginal soils such as Ultisols with high pH (>7). This soil has disadvantages in its use, among others, have physical, chemical and biological less support plant growth. pH values usually acid, and the amount of nutrients, especially Pare low due to fixation of Pis a constraint on the growth of plants. Soil with high pH has a problem low available soil P content due to fixation by soil calcium (Tan, 2008).
There have been many efforts made to improve productivity Ultisols with fertilization into the soil. However, many obstacles are encountered with this artificial fertilization. One of them is the residual effect of fertilizers that can pollute the environment, so that a continuous fertilization will affect not good for the soil and the environment.
To improve fertilizer efficiency and reduce costs, it is necessary to develop biotechnology ground. Some free- living microbes in the soil has the ability to dissolve P soil is bound to be available, so that the plant can absorb P to make ends meet (Lambers *et al.*, 2006). Phosphate solubilizing microbes (PSM) is a group of soil microbes that have the ability to extract P from its binding with Al, Fe, Ca, and Mg, so as to dissolve P whose origin is not available to the plant becomes available to plants. This happens because these microbes secrete organic acids that can form stable complexes with cations binding P in the soil microbes that play a role in the process of dissolving phosphorus, among others, oft he group of bacteria: *Pseudomonas, Bacillus, Mycobacterium, Micrococcus* called "phosphobacteria", while the group of fungi*: Penicillium, Aspergillus, Fusarium, Sclerotium*(Whitelaw, 2000).
Microbial groups phosphate solvent has many virtues in influencing plant growth, in addition to releasing the fixed P also can produce the enzyme phosphatase (Saparatka, 2003; Yadav and Tarafdar, 2003) and can produce phytohormones (Fitriatin and Simarmata. 2008; Fitriatin *et al.*, 2013). Phosphatase enzyme released by these microbes can mineralise organic P into P inorganic. (George *et al.*, 2002; Saparatka, 2003).

2 Materials and Methods

The experiment was conducted at the experimental farm of the Faculty of Agriculture, University of Padjadjaran in Ciparanje Jatinangor, Sumedang regency, West Java, which belong to the order Ultisol. Materials used in this study were (1) of hybrid corn seeds (*Zea mays* L.) (2) Phosphate solubilizing bacteria: *Pseudomonas mallei* and *Pseudomonas cepacea*; Phosphate solubilizing fungi: *Penicillium*sp and *Aspergillus*sp. (4) Nutrient Broth (NB) and Potato Dextrose Agar (PDA) (5) Urea, KCl, super phosphate (SP) and rock phosphate, (6) cow manure as fertilizer base, (7) Carrier (compost and peat in the ratio 1: 1).
The experimental design used is a randomized block design with nine treatments and three replications to test how applications of bio-phosphate (1,2 and 3 times application) as well as the type of P fertilizer (super phosphate and rock phosphate with 100 % and 50 % doses of recommendation). The land area used is 3 mx 2 m per plot and use spacing of 70 cm x 30 cm. So that in each plot contained approximately 30 plants. Fertilizer applied as basal fertilizer is organic fertilizer and inorganic fertilizer. Organic fertilizers such as cow manure mixed together inoculants were incubated 2 days before planting as much as 2 t ha^{-1}. Inorganic fertilizer used is urea (300 kg ha^{-1}), and KCl (100 kg ha^{-1}). Super phosphate fertilizer was given according to each treatment.

3 Discussion

The results showed that biophosphate application time and the type of fertilizer P was not significantly different effect on the available soil P (Table 1). Soil acidity greatly affects the availability of P. According to Tan (2008), states that the optimal pH range that supports the availability of P between 5.5 and7.0it is supported by the results of the analysis of soil that has a pH of5.84which is quite a bit acid. Based on Table 1, it can be seen that the fertilization of super phosphate with 50% and bio-phosphate with one application has the potential to increase the available soil P in comparison with the others, namely P is availablefor21.41mgkg-1 (an increase of 104.8%). This is presumably because of SP-36 has the properties of fast release and phosphorus contained in fertilizers SP has been in the form available to plants. Treatment type of rock phosphate fertilizer dose of 50% and the provision of PS Moneal so able to increase 55.12% p-available compared to the control. It is proved that the administration of one biological fertilizer is sufficient to increase the P-available in the soil.

Table1. Effect of bio-phosphate application and type of P fertilizer on soil P and yield of Maize

Treatments	Available P (mg kg^{-1})	P soil potential (mg 100 g^{-1})	Yield of maize (kg plot^{-1})
control (without fertilizer P and biophosphate)	10,45 a	9,07 a	296,87
super phosphate 100 kg ha^{-1}	16,12 ab	10,85 ab	318,53
rock phosphate 300 kg ha^{-1}	10,64 ab	11,49 ab	307,93
super phosphate 50 kg ha^{-1} + bio-phosphate with 1 times	21,41 b	19,56 c	327,13
super phosphate 50 kg ha^{-1} + bio-phosphate with 2 times	14,34 ab	16,02 bc	343,13
super phosphate 50 kg ha^{-1} + bio-phosphate with 3 times	11,60 ab	16,92 bc	308,87
rock phosphate 150 kg ha^{-1} + bio-phosphate with 1 times	16,21 ab	16,48 bc	292,40
rock phosphate 150 kg ha^{-1} + bio-phosphate with 2 times	5,26 a	12,64 abc	309,53
rock phosphate 150 kg ha^{-1} + bio-phosphate with 3 times	7,86 ab	14,48 abc	318,20

Statistical analysis showed that a bio-phosphate application and type of fertilizer P no real influence on yield of maize in Ultisol (Table 1). The result of experiment showed that application of bio-phosphate yield of maize up to 15.58% on Ultisols. This is presumably due to the provision of PSM can increase soil P content due to the dissolution mechanism P caused the organic acids of the PSM (Fitriatin et al., 2013). According to Rao. (1994) due to the level of grow than dsoil microbial activity is influenced by abiotic factors that include the physical and chemical properties of soil and biotic factors (presence of other microbes and absorption of higher plants).

4 Conclusions

Based on the experimental results it can be concluded that the application of the PSM inoculant as bio- phosphate (*Pseudomonas mallei*, *Pseudomonas cepacea*, *Penicillium* sp .and *Aspergillus* sp.) increased the content of soil phosphate growth and yield of maize. The application of bio-phosphate in the early planting has been able to increase the P content of the soil and plants. Bio-phosphate fertilizer with super phosphate as P fertilizer with dose 50 % recommendation gave better effect on soil P and yield of maize on marginal soil.

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Effect of green manure on chemical, physical of soil and yield of millet

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1 Introduction

The green manure incorporation is the environmental friendly agriculture cultivation technologies which could reduced the use of chemical fertilizer, micro-flora of soil. The leguminous green manure which is incorporated in soil would fix the N2, and release the fixed nitrogen to soil. The hairy vetch and green barley are the winter survival crop and the higher biomass among green manure corps, and hairy vetch has the fixation nitrogen ability. The use of living mulches required new cropping system (Feil, 2001), and suppressed weed occurrence (Lee *et al.*, 2011). It was reported that the effect of green manures which were incorporated in soil were evaluated the growth and yield of millet, and the physical characteristics of soil.

2 Materials and Methods

There were 3 green manure crops treatments which are hairy vetch, green barley, hairy vetch + green barley, and 1 control treatment which is chemical fertilizer. Millet is only cultivated green manure, excepted chemical fertilizer plot. Hairy vetch, green barley, hairy vetch + green barley were incorporated in soil, and plowed and incorporated under soil depth 25~30cm, and then soil was prepared with rotary tillage. The green manure and the chemical nitrogen fertilizer were incorporate to soil May 16. Millet was planted at two weeks after incorporation of green manures and chemical fertilizer. Stalk height was measured at milky stage. Chlorophyll contents were collected using SPAD (Minolta corp., Japan) were taken at central point between the margin and the mid-rib from era leaves of 30 millet plants. The characteristics of grain were measured from 30 plants at physiological maturity when black layer was formed below kernel. Grain yield were adjusted to 15% moisture content. Chemical and physical characteristics of soil were measured bulk density, rate of liquid, air, solid and void state after harvesting.

3 Results – Discussion

Fresh biomass of green manure was harvested before 15days of transplanting and weighed in 3 square meters (3 replications). The amount of hairy vetch, barley and hairy vetch mixed barley were incorporated in soil (Table 1). Fresh weight of hairy vetch, barley and hairy vetch + barley were 12.9, 31.5 and 22.8 t ha^{-1}, respectively. So, nitrogen rate of hairy vetch, barley, and hairy vetch +barley were 0.829, 0.339 and 0.469 %, respectively.

Table 1. Fresh weight, nitrogen rate and N supply of hairy vetch and barley at soil incorporation as green manure.

Green manure crops	Date	Fresh weight (t ha^{-1})	N % of Fresh manure	N supply (t ha^{-1})
Hairy vetch	May 16	12.90	0.829	0.107
Barley	May 16	31.52	0.339	0.107
Hairy vetch + barley	May 16	22.78	0.469	0.107
Chemical fertilizer	May 16	-	-	0.100

Chlorophyll contents collected using SPAD was measured at three growth stages, booting, heading and maturity stages (Table 2). Chlorophyll contents of booting and heading stage were not different among treatments. But at maturity stage, the range of SPAD were in 38.0 ~62.5, and the hairy vetch was considered low than other three treatments. It was considered that the nitrogen amounts in hairy vetch was insufficient to produce millet grain, it was reported that proper nitrogen concentration of leaf was 2.75%(Larson & Hanway, 1997), and SPAD value of hairy vetch was slight low among green manure, and also its trends were more clear at dough stage than other stage by plant nitrogen transfer of nitrogen from leaf to ear (Seo *et al.*, 2000)

Table 2. Chlorophyll contents collected using SPAD at three growth stages

Green manure crops	Boosting stage	Heading stage	Maturity stage
Hairy vetch	50.3±1.0	54.3±2.5	38.0±4.9
Barley	55.3±0.2	58.7±1.3	54.9±1.7
Hairy vetch + barley	52.4±0.9	59.0±0.9	62.5±0.3
Chemical fertilizer	54.3±0.8	58.8±1.3	55.4±4.9

Differences in soil chemical properties between before planting (May 16) and after harvesting (Nov. 16) was shown (Table 3). Soil pH was slightly higher in hairy vetch and chemical fertilizer than that of soil incorporated barley. Green manure crops seemed to increase slightly soil total carbon and total nitrogen than that of chemical fertilizer plot. It was similar to report which green manure improve on soil chemical as pH and EC of soil (Lee *et al.*, 2011), and green manure crops also improved bulk density (Kang *et al.*, 2014)

Table 3. Changes of chemical properties of soil.

Green manure crops	Before planting (May 16)			After harvesting (Nov. 16)		
	pH	T-C (%)	T-N (%)	pH	T-C (%)	T-N (%)
Hairy vetch	6.0±0.4	0.81±0.09	0.07±0.01	6.8±0.2	0.83±0.05	0.08±0.01
Barley	5.5±0.3	0.73±0.09	0.07±0.01	6.2±0.1	0.91±0.04	0.08±0.01
Hairy vetch + barley	5.6±0.2	0.80±0.06	0.09±0.01	6.6±0.2	0.85±0.02	0.09±0.01
Chemical fertilizer	6.0±0.3	0.85±0.02	0.08±0.01	6.5±0.1	0.83±0.02	0.08±0.01

1000 grains weight, culm weight and yield of millet were shown (Table 4). 1000grain weight of hairy vetch was highest among treatments, but culm weight and yield of hairy vetch+barley were highest other treatment. The N supplement by hairy vetch+barley was seem to be sufficient to grow millet. It suggested that corn absorbed enough nitrogen from hairy vetch (Seo *et al.*, 2000), and corn yield more increased with cropping system with winter legume hairy vetch (Torbert, 1996). Physical characteristics of soil were measured bulk density, rate of liquid, air, solid and void state (Table 5). Soil air state of was increased by incorporation with green manure as hairy vetch, barley. It was similar to the report that improved soil structure and water infiltration (N.L. Hartwig & H.U. Ammon, 2000)

Table 4. 1000 grains, culm weight and yield of millet

Green manure crops	1000grain wt. (g)	Culm wt. (ton/ha)	Yield (ton/ha)
Hairy vetch	18.9±0.9	7.87±0.18	3.45±0.44
Barley	16.7±2.2	8.22±0.23	4.03±0.04
Hairy vetch+barley	16.4±1.2	10.4±1.00	4.40±0.31
Chemical fertilizer	17.9±1.1	9.59±1.62	3.93±0.22

Table 5. Bulk density, rate of liquid, air, solid and void state of soil after harvest

	Bulk density (mg m^{-3})	Liquid state (%)	Air state (cm)	Solid state (%)	Void (%)
Hairy vetch	1.29±0.14	28.5±1.1	22.7±5.8	48.8±5.2	51.2±5.2
Barley	1.31±0.02	29.4±1.8	21.3±2.5	49.3±0.9	50.7±0.9
Hairy vetch+barley	1.15±0.02	30.8±0.7	25.8±0.5	43.4±0.9	56.6±0.9
Chemical fertilizer	1.29±0.05	34.0±1.5	17.4±0.7	48.6±2.1	51.4±2.1

4 Conclusions

The results of trials were that the leaf color and 1000 grain weight by green manure were increased than chemical fertilizer trial. The soil physical characteristics as the percent of void were lowest in chemical fertilizer treatment. The green manure treatment were not decreased the yield of millet. The results suggest that the green manure incorporation in soil can cultivate millet without the chemical fertilizer

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Application of Organic Fertilizers for pesticide degradation from Agricultural Soil under Controlled Conditions

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1 Introduction

The intensive utilization of pesticides as a strategy to improve agricultural productivity induces environmental and toxicological risks, groundwater contamination and serious health problem to the population. Metribuzin is a selective systemic herbicide used for control of many broad-leaved and grasses weeds in soya beans, potatoes, tomatoes, sugar cane, and cereals at 0.07–1.05 kg a.i./ha (Tomline, 2000). It is well known that organic amendments may under some conditions enhance the retention, persistence, and mobility of herbicide in the soil profile, and under others decrease them (Singh, 2008; Kravvariti *et al*., 2010). In this present study the effect of different organic amendments on the degradation of metribuzin was carried out by high performance liquid chromatographic method.

2 Materials and Methods

Soil was obtained from the upper layer (0-10 cm) of soil, air dried at room temperature, passed through a 2-mm mesh sieve and mixed with organic amendments (poultry manure (PM) and cow manure (CM)) in 2.5 percent rate (w/w). Then treated with an aqueous suspension of commercial formulation of metribuzin to give a final concentration of 5 mg kg^{-1} of air-dried soil. The moisture content of soil samples had been adjusted to 70% of soil water-holding capacity and transferred to glass jars, and incubated in the dark at 20 °C for 120 days. Sub samples (20 g) were taken for herbicide analysis one day after addition of herbicide and then 5, 15, 30, 50, 90 and 120 days, and frozen at -20 °C until Analytical procedure. Final soil samples (10 g) were extracted twice with methanol (20 mL) on a horizontal shaker for 90 min. After equilibration, the tubes were centrifuged for 10 min at 10000 rpm in a centrifuge maintained at 20°C. 10 mL of the supernatant were filtered and the extract was diluted with 5 mL of methanol (HPLC grade) and stored in 5 °C before analyzed by HPLC (Shimadzu model 10A) equipped with a Spectrophotometric UV detector. The reverse phase column was a 25 cm × 4.6 mm i.d. Adsorbosphere C18. The mobile phase was 80% methanol and 20%: water. The flow rate was 0.5 mL min^{-1}. The wavelength was set at 290 nm, and the retention time of metribuzin was 9.53 min. A 20 µL injection volume was used. Metribuzin dissipation curves in original and amended soil samples were fitted to first-order kinetics ($C = C\text{i}\ e^{-kt}$) and half-lives ($t_{1/2}$) calculated.

3 Results – Discussion

Calibration graph and the peak results of HPLC analysis of metribuzin standard (1 mg kg^{-1} soil) are presented (Fig. 1). Metribuzin content were decreasing progressively in soil amended with organic amendments. However, this decrease depended on organic amendment type applied. At the end of the experimental period and compared with the unamended soil, metribuzin content significantly decreased with application of PM and CM.

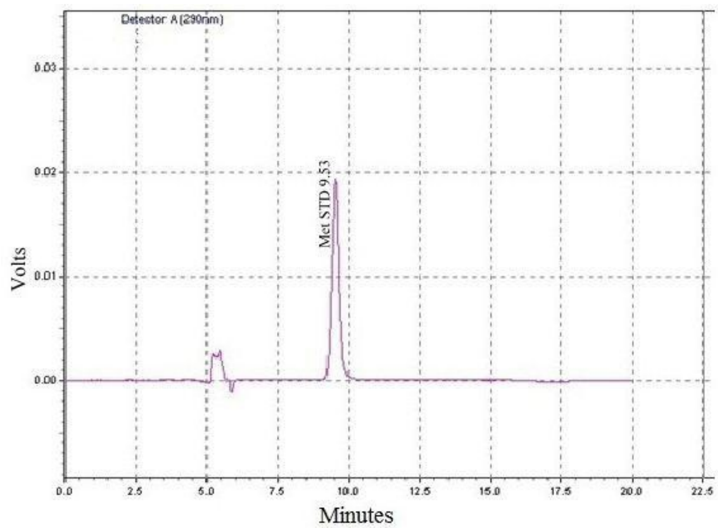

Fig. 1. Calibration graph of Reversed-phase HPLC separation of metribuzin standard (1 mg kg^{-1} soil).

Metribizin degradation coefficients (K) in PM and CM treatments were 1.29 and 1.22 times NF treatment respectively. Metribuzin half life in mentioned treatments was 92 and 97 days respectively, that were significant lower than NF treatment (119 days). Dissipation of metribuzin well described by first-order kinetics with regression coefficients (R^2) ⩾0.94. The obtained first-order rate constant and half-lives are presented (Table 1).

Table 1. Observed speed constants (K) and half-life values (DT_{50}) of the kinetics of metribuzin degradation in soil with different organic amendments.

Organic Amendments	K (±σ)(Day^{-1})	DT_{50} (days)	DT_{90} (days)	R^2
NF	0.0058 (0/0002)	119.48	396.89	0.98
PM	0.0075 (0.0004)	92.40	306.93	0.99
CM	0.0071 (0.0003)	97.60	324.22	0.97

Although addition of organic manures has been an integral part of sustainable agriculture practices, the earlier findings give a new dimension of its utilization for removal of persistent pesticides (Kadian *et al*., 2007). Degradation of metribuzin was enhanced by 0.5% manure, 5% peat, and 5% cornstalk amendments compared to non amended soils (Mooram *et al*., 2001). Organic amendment is a rich source of nitrogen, carbon and other nutrients, which make it well suited for supporting the soil microorganism growth.

4 Conclusions

In this study the effect of organic amendments on the half-life of metribuzin were investigated. It seems that the application of organic amendments favored microbial development and consequently accelerated the degradation process. The results indicated that microbiological soil properties were responsible for metribuzin dissipation. Study suggests that organic amendments certainly enhanced degradation of metribuzin in soil. These results have implications in managing the persistent soil residues of metribuzin. However, to get a more realistic picture study under actual field conditions is advised.

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Designing innovative strategies of nitrogen fertilization by coupling diagnosis of the uses of existing tools and participatory workshops.

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1 Introduction

In France, for all the arable crops, N fertilizer rates are planned at the beginning of spring, based on the balance sheet method (Hébert, 1969) and splitting is planned, depending on calendar dates and crop stages. This strategic planning aims at adjusting N fertilizer to soil supply in order to fulfill crop requirements (Meynard *et al.*, 1997). The balance sheet method is a rigorous and scientifically approved model that makes consensus in French agricultural R&D. Since the 80's, progress in nitrogen fertilization followed a typical way of rule-based design (Meynard *et al.*, 2012): R&D organisms gradually improved N fertilization through refining the estimation of the balance-sheet equation parameters. Dynamic modeling of soil mineralization is considered as one important step of progress to improve the precision of the method (Justes *et al.*, 2009). Further evolution focused on the ways to divide the whole rate on the crop cycle in order to improve N use efficiency and on the development of monitoring tools, always targeting the objective of non-limiting nitrogen nutrition all over the crop cycle. However, we question this strategy regarding the evolution of the context: issues related to environmental pollution, resources management, production (yield stagnation, grain protein content), farmers' difficulties to appropriate the method (Cerf & Meynard, 1987; Felix & Reau, 1995) and unused knowledge on N dynamics (that do not fit into the conceptual framework of the balance sheet method).
We assume that the consensus on the balance sheet method may have limited the exploration of alternative strategies, which could have similar or improved results. There is a need to shift toward new paradigms, to think about strategies that could satisfy new expectations such as achieving both environmental, agronomic and economic objective or including advancement in knowledge and technologies. Following the approach proposed by Cerf *et al.* (2012) for the design of decision support tools; we coupled diagnosis of the uses of existing tools and participative workshop to design prototypes for new strategies.

2 Materials and Methods

Diagnosis of uses of existing tools

The diagnosis of uses was carried out based on two complementary sources of information. (i) Official report of the regional working groups on the implementation of the balance-sheet method, mandated by the Ministry of Agriculture. Within the fifth Action Program of the Nitrates Directive, twenty regional groups of experts (GREN) have been created to agree on an equation for the calculation of the total rate and its parameterization in each region. We analyzed the controversies occurring when stakeholders confronted their perceptions and ways of using the balance sheet. (ii) Interviews of farmers and technical advisors on their practical use of the balance sheet method. We choose four regions of France with diversified agricultural systems and climatic contexts (Normandie, Bourgogne, Bretagne, Provence).

Design framework

The objective of the design process was to explore new concepts for fertilization, based on the involvement of new knowledge, in order to unlock the current paradigm. To move forward from rule-based to innovative design for management of nitrogen fertilization we choose an innovative theory: the C-K theory (Hatchuel & Weil, 2009). Based on a dual expansion of concepts (C) space and knowledge (K) space, it can be used to overcome fixation effects in design (Le Masson *et al.*, 2011). During workshops that gather different stakeholders with various background, it is a practical guideline to structure exchanges. The diagnosis of uses helped us to define the basis of new concepts to be explored and we used the C-K framework to lead the workshop and explore the potential design paths of innovative fertilization strategies.

3 Discussion

The diagnosis of uses showed that some principles of the method such as the estimations of the target yield and of the available soil nitrogen were controversial and potentially source of difficulties for the implementation of the balance-sheet method. In the equation, crop requirements are estimated with a target yield and a requirement per unit of production (Coïc, 1959). The target yield is source of controversies because it is unpredictable, due to inter-year climate variability. While the target yield should be based on the mean of yields obtained during the 5 previous yields (standard rule), farmers tend to estimate the target yield as the desired yield, close to the highest value ever reached (Box. 1). The debates about the standard rule clearly show that the concept of fixing a target yield is source of difficulties. From the report of the GREN, we found various arguments: the failure to achieve the potential yield in favorable years, the failure to enhance the genetic progress, the risk of strengthening the trend of yields' stagnation or the fact that an insufficient nitrogen nutrition could lead to low protein content. This shows that there is still no consensus on rightfulness of the standard rule and on the fact to strictly frame the way to fix the target yield. The model also requires estimating soil supply. Several GREN members thought that using a soil analysis to estimate the soil N content at the end of winter may be replaced by modeling, due to the improvement of knowledge on soil N cycling. The measurement is considered as time consuming and presents a number of sources of uncertainties such as a sampling procedure or extrapolation of measures.

Those controversies contribute to give ideas to formulate new concepts. For instance, regarding the target yield, we suggest to think of strategies that move forward from a planned fertilization to a more adaptive one. From the controversies on the soil analysis, we came out with ideas such as looking for plant indicators that could replace it.

Box 1. Extracts from interviews that illustrate the perception of the target yield as the desired yield.

"Farmers are entrepreneurs, we can not ask people to reason this logic to target an average result" (Advisor Bretagne).

"My yields are around 70 to 80 q.ha-1, 90 for some plot [...], I often use 90 (as target yield), I already did it » (Farmer, Bourgogne)

"I take 100q/ha-1 where I know I can do it" (Farmer Normandie)

"My average is about 60 q.ha-1, but I did not take that on my "provisional fertilization plan, I based it on 80". (Farmer Normandie)

"Target yield, it's an average value for a group of plot which is equivalent to the expected yield, the one of good years". (Farmer Provence)

The design workshops were organized based on new concepts to be explored. Those initial concepts result from both the diagnosis and the need to integrate recent knowledge not taken into account in the current paradigm. For the first participatory workshop we established two initial concepts:

1)"Strategies of nitrogen fertilization based on pathways of plant nitrogen status".

This concept was formulated to explore adaptive management without fixing a target yield and to integrate the knowledge on nitrogen deficiency to optimize NUE. With this concept, thinking of strategies of N fertilization that include periods of N deficiency is a shift with the current paradigm which is based on an objective of non limiting N nutrition. The exploration was fruitful and led to two main concepts: a regular monitoring of plant and a strategy based on anticipation of soil N supply. Various knowledge were discussed to make concrete those fertilization strategies such as an early monitoring based on nitrogen nutrition index and crop biomass; weather forecast; plants' N uptake capacity and soil humidity at the moment of N application to provide a triggering threshold to apply N fertilizer.

2)"Taking account of farmers' ability to learn". The idea was to explore tools that enable farmers to assess their fertilization strategies (rate and timing) at the end of the crop cycle, to adapt next year their fertilization strategy (adaptive management). The exploration led to imagine a collaborative tool based on a post harvest assessment. Then it would provide specific indicators to observe the next year regarding what could be improved in the current strategy.

4 Conclusions

We highlighted how the current paradigm is flawed regarding the objective to achieve both environmental and agronomical issues. Some principles of the method are sources of controversies and uncertainties. Incremental improvement of the model is called into question to achieve current and future nitrogen issues. We emphasized the need to investigate new strategies of N fertilization to comply with news expectations. Introducing the workshops with the diagnosis of uses created good conditions to explore concepts of innovative management strategies that we provided. The two first concepts will further be explored and tested with farmers and advisors in contrasted regions of France.

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Impacts of crop rotation, soil tillage and irrigation on yield and agroecological parameters: an assessment of different energy cropping systems in Northeast Germany

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1 Introduction

In the global context of population growth, socioeconomic development and food security, dealing with land use change and trade-offs posts a great future challenge. Growing demands for land and freshwater decrease the availability of adequate resources - a trend that is further aggravated by climatic changes and negative ecological side-effects of current agricultural practises. Energy cropping systems for biogas production are one of the currently omnipresent agronomic issues in Germany, with silage maize meeting the claim of high-yield yet low-price co-ferments while providing reasonable profi ts (Schittenhelm *et al.*, 2011). However, continuous maize cropping bears a considerable risk of ecological impacts such as humus depletion, biodiversity loss, and nitrate leaching (Bauboeck *et al.*, 2014). Our objective is to identify novel strategies that are both, ecologically sound and economically profi table in the long term. Therefore, we systematically assessed the productivity of alternative cropping systems in a 7-year fi eld trial in the federal state of Brandenburg (Germany) including continuous maize with cover crops and a diverse crop rotation, both under irrigation and rainfed conditions as well as under ploughing and no-tillage. Since Brandenburg is particularly affected by climate change due to light soils and summer droughts climate change adapted cropping systems are needed. We hypothesize that (1) irrigation significantly increases biomass yields in all treatments, (2) no-tillage with direct seeding reduces biomass yields substantially, and (3) the average biomass produced in the diverse crop rotation (CR) equals the biomass produced under continuous maize cropping (CC).

2 Materials and Methods

The field trial was established at the experimental farm in Muencheberg using a 3-factorial split plot design. The site is characterized by a mean annual precipitation of 562 mm, a mean annual air temperature of 8.8° C, and an average growing period of 170 days. The experiment included 8 cropping systems, represented by different combinations of 3 management factors: crop rotation type (continuous maize cropping with cover crops vs. a diverse 4-year crop rotation), water management (irrigated vs. rainfed), and tillage operations (plough vs. no-tillage with direct seeding) (Table 1). The experiment started with year 1 in 2008. In this paper we analysed data from 2008 (year 1) to 2014 (year 3).

Table 1. Experimental design of the 7-year field trial

Treatments	Year 1	Year 2	Year 3	Year 4
Continuous maize cropping (CC)	Maize (*Zea mays*, cultivar Francisco S270), harvested in September/October Cover crop: Winter rye (*Secale cereale*) for soil conservation, only rainfed cropping, eradicated end of March			
Diverse crop rotation (CR)	1st crop winter rye (*Secale cereale*), harvested in May 2nd crop forage sorghum (*Sorghum bicolor*, cultivar Rona1), harvested in September	1st crop winter triticale (*xTriticale*, cultivar Talentro), harvested May/June 2nd crop lucerne-clover-grass mixture (*Medicago sativa*, cultivar Plato + *Trifolium pratense*, cultivar Milvus + *Lolium perenne*, cultivar Lilora)	Lucerne-clover-grass mix (*Medicago sativa*, cultivar Plato + *Trifolium pratense*, cultivar Milvus + *Lolium perenne*, cultivar Lilora), harvested with 3 cuts	Maize (*Zea mays*, cultivar Francisco S270), harvested in autumn
Irrigation	irrigation (only sorghum) + rainfed	rainfed	irrigation + rainfed	irrigation + rainfed
Primary tillage	plough vs. no-tillage with direct seeding			

Irrigation demand was computed using the BEREST/IRRIGAMA.net model (Mirschel & Wenkel, 2004). For all tillage operations of maize a Becker Aeromat drilling machine was used and for the other crops an Amazone rotary cultivator (ploughing) and a John Deere seed drill (direct seeding). Whole crop silage was harvested to determine productivity (aboveground dry matter biomass yield). Cover crops in the CC treatment were not harvested. Standard amounts of mineral fertilizers were applied but no organic fertilizers. Statistical analysis with SAS was performed for yield data from 2008 to 2014 using Tukey´s HSD statistical test. Where appropriate, we used mean averaged values over time and/or treatment variants (tillage, irrigation) for comparative purposes, which may include more than one crop type per year in case of the diverse crop rotation.

3 Results – Discussion

Irrigation significantly increased biomass yields and yield stability in CC in all years with on average 3.7 t ha^{-1} (22 %). In CR irrigation only significantly increased biomass yields of sorghum. On the contrary, no-tillage with direct seeding did not significantly reduce biomass yields of CC except for two years (2012, 2013) (Fig. 1). However, plough-based yields were on average 1.2 t ha^{-1} (7 %) higher than under no-tillage. In CR no-tillage did not reduce biomass yields except in one year of winter rye and one year of winter triticale.

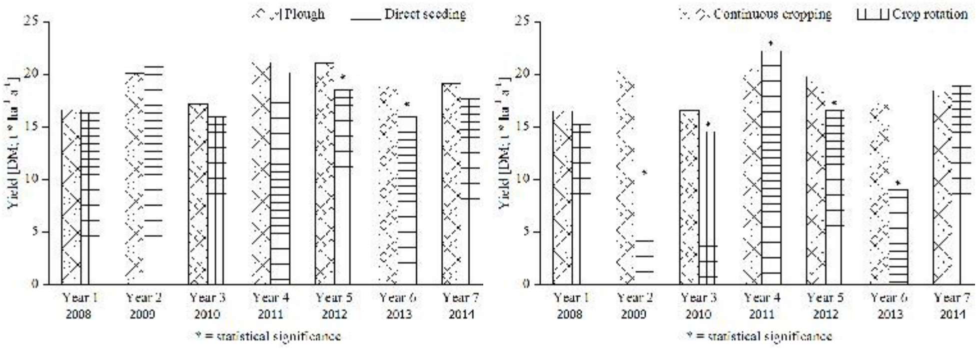

Fig. 1. Results for yield comparisons «Tillage vs. No-till of CC-maize» (left) and «CC system vs. CR system» (right).

During the 7-year-experiment CC resulted in higher biomass yields than the cereal crops in CR. Only biomass yields of the legume-grass mixture were comparable with those of maize. Over the whole period, CR reached 82.3 % of total biomass yield achieved with CC but with high annual fluctuations due to the different crops in CR (Fig. 1). In 2011, maize was cultivated simultaneously in both systems with an average yield increase of 6 % in CR across the treatments. This can be explained by the positive pre-crop effects of legume-grass mixtures as preceding crop before maize.

4 Conclusions

In only two out of seven years, no-tillage reduced maize productivity, which is a relevant finding for soil conservation matters as well as with respect to agronomic efficiency. Interestingly, this contrasts results from other similar studies (Anken *et al.*, 2004; Gruber *et al.*, 2012) and points out the hydrologic and pedological heterogeneity of the agricultural landscapes in Northeast Germany. On the other hand, the position of both these years at the end of the time series may also indicate that yield reducing effects under no-tillage develop over time. In our study region, irrigation can be a relevant option to increase biomass yields in maize but seems less relevant in diverse crop rotations. Continues maize with irrigation and ploughing was the treatment with the highest biomass production. Statistically, irrigation led to significant improvements of CC in all years. For an overall evaluation of the different systems an economic analysis is necessary to account for costs and revenues. An integrated approach also considering agroecological interdependencies and presumed climatic changes could improve process understanding and help to design sustainable farming systems.

Acknowledgements. The work was financed through the Federal Ministry of Food and Agriculture (BMBF), Germany; the Brandenburg Ministry of Sciences, Research and Cultural Affairs (MWFK), Germany and the BMBF funded FACCE-ERA-NET+ project Climate Change Adaptability of cropping and Farming systems for Europe (Climate-CAFÉ; Grant PTJ-031A544).

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Decline of rice grain yield under delayed transplanting in wheat-rice double cropping system in South Korea

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1 Introduction

The southern plain area is the wheat-rice double cropping possible region in South Korea (Yoon *et al.*, 2011). To meet increasing food security within the limited croplands, double cropping is required in much of the paddy field. However, wheat harvesting is sometimes delayed due to rainy weather condition in June. These events often result in delayed rice transplanting that reduce grain yield (Kim *et al.*, 2013). When late transplanting occurs, heading date also delayed and cumulative temperature for grain ripening decreases significantly. Consequently, farmers decide whether to select to cultivar to minimize the yield loss (Timssima & Connor, 2001). The objectives of this experiment were to determine whether delayed transplanting influenced the agronomic responses of japonica rice cultivars to planting date, and to suggest rice cultivars that are suitable for late transplanting.

2 Materials and Methods

Experiments were conducted at the experimental field of National Institute of Crop Science (NICS) in Iksan (35° 57'N, 126° 57'E) in 2013 and 2014. The experiment was laid out in a split plot design with three replications, where transplanting dates were in the main plot and rice varieties were in subplots. Three transplanting dates were applied, starting in June 5, and occurred on approximately 20 and 30 days thereafter. The recommended date for rice single cropping is around June 5, and the latter two transplanting dates on June 25 and July 5 were regarded as delayed transplanting. Total 10 japonica rice varieties were used including early (Geumo2, Geumo3, Jopyeong, and Unkwang), medium (Suan and Dongbo), and mid-late (Nampyeong, Sodami, Sukwang, and Chinnong). Cultivation practices were managed properly for optimum growth following standard cultivation protocol of NICS.

3 Results – Discussion

Average heading date of 10 cultivars was August 12 in the control, August 23 in the second, and August 28 in the third transplanting (Table 1). These delays in heading dates were resulted in decrease of cumulative temperatures for 40 days from heading. The accumulative temperature in the last transplanting was below 880°C that is insufficient for grain ripening of japonica rice. The heading date of the 10 cultivars responded differently to delayed transplanting, with greater cumulative decreases occurring with mid-late maturity cultivar.

Table 1. Effect of delayed transplanting on heading date of japonica rice cultivars and cumulative temperature during ripening stage (40 days from heading).

Transplanting date /Maturity	Heading date	Days to heading	Cumulative temperature (°C)	Average temperature (°C)
		Transplanting date		
June 5	Aug 12	69a	945a	23.6a
June 25	Aug 23	62b	883b	22.1b
July 5	Aug 28	56c	852c	21.3c
		Maturity group		
E	Aug 15	56b	930a	23.3a
M	Aug 23	64ab	881b	22.0b
ML	Aug 26	67a	863bc	21.6bc
CV (%)	-	14.6	7.6	7.6

* and **: Significant at 0.05 and 0.01 probability levels, respectively. ns: Non-significant at 0.05 probability level. Within a column, means followed by different letters are significantly different by Duncan's multiple range test.

Average milled rice yield across 10 cultivars was declined from 5.70 t/ha in the control to 5.32 t/ha in the last transplanting (Table 2). Yield was not affected when planting was delayed 20 days, but was 6.6% lower when planting was delayed 30 days. Yield loss due to late planting was associated with decreases in panicle and spikelet and no change in grain weight. The grain yield was higher in the mid-late maturity group compared to early maturity.

Table 2. Effect of delayed transplanting on grain yield and yield component of japonica rice cultivars.

Transplanting date/Maturity	No. of panicles (m^{-2})	No. of spikelet per panicle	1000-grain weight (g)	Ripened spikelet (%)	Milled rice yield (t ha^{-1})
		Transplanting date			
June 5	310a	95a	21.6a	89.5b	5.70a
June 25	291b	91b	22.8a	92.1ab	5.50ab
July 5	270c	89b	22.9a	94.0a	5.32b
		Maturity group			
E	298a	87b	22.4a	90.8b	5.35b
M	295ab	85b	22.9a	94.8a	5.41ab
ML	280b	99a	22.3a	91.6b	5.66a
CV (%)	9.7	13.2	5.3	5.2	7.4

Among the early maturing cultivars, Jopyeong (5.30-5.62 t/ha) and Unkwang (5.51-5.72 t/ha) showed the highest milled rice yield in the delayed transplanting dates (Fig. 1). In mid-late maturing cultivars, Sukwang (5.55-5.77 t/ha) and Chinnong (5.55-5.77 t/ha) showed higher grain yield in the delayed transplanting. These four varieties would be the option for the farmers who are considering wheat-rice double cropping in Honam plain area.

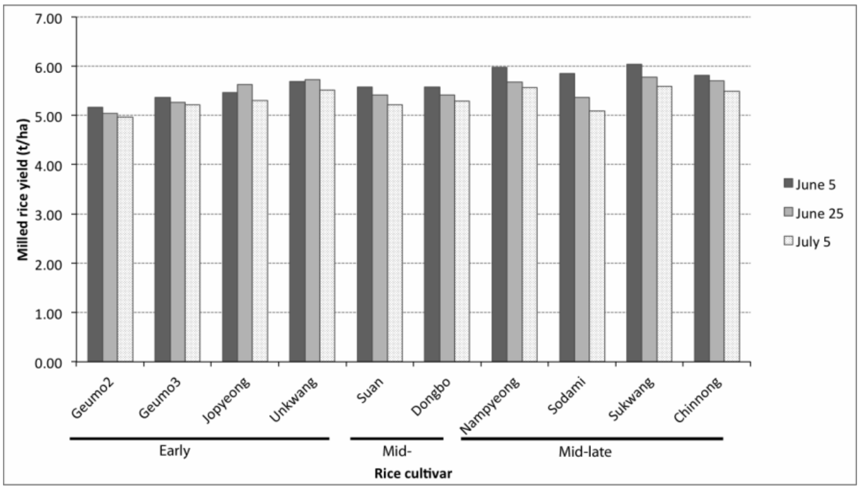

Fig. 1. Milled rice yield of 10 japonica rice cultivars in optimal and delayed transplanting dates in Honam plain area.

4 Conclusions

In this study, we identified the decline of rice grain yield in wheat-rice double cropping in South Korea due to delayed transplanting. To meet the high yield in rice and maximize benefit from the double cropping cultivation, suitable rice cultivars and adequate transplanting are required. Although the promising two early mature cultivars were selected in this study, new early- and medium maturity rice cultivars are needed for flexible cropping system design.

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Improvement of vineyard sustainability according to biogeochemical cycle of nitrogen in field

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1 Introduction

Good and yield wine production implies a well-balanced biogeochemical cycle of nitrogen (BCN) at field level e.i. in soil and in plant (Guilpart, *et al.,* 2014). Nitrogen is very important for grape quality and quantity and field sustainability. The mineralization of organic nitrogen, depending on soil microbial activity which is lincked to soil cover crop management, is the main source of mineral nitrogen for the vine (Barlow *et al.*, 2009; Ingels *et al.*, 2005; Raath and Saayman, 1995; Thiebeau *et al.*, 2005). This paper is focused on a useful indicator fulfilling a sustainability assessment method: functional microbial populations implicated in BCN in vineyard field.

2 Materials and Methods

An experimental network with 6 platforms gathering 45 fields located in Atlantic coast (Loire valley and Bordeaux) and in North-East (Alsace) of France has been set up since 2012 (extract presented in Table 1). These vine sites represent a diversity of environmental factors (i.e. soil and climate) and the same method is used to assess them: agricultural, environmental, social and economical. The tested prototypes are tested according to the following goals: same yield, harvest quality, working time and production costs. The added value approach is based on assessing nitrogen dynamic in soil, i.e. nitrogen mineralization, regarding microbial biomass and activity.

Table 1. Alsacian sites-system characteristics.

Name	Site	Designed system	Vine age	Variety	Soil
Ribeau_AB	INRA-Ribeauvillé	Organic	16	Riesling	Loamy, sandy and clayey
Ribeau_PI		Integrated	16		
Rouff_PI	Rouffach agriculture school	Integrated	32	Pinot Gris	
Rouff_Piopti		Integrated-Rate-sprayingreduction	32		
Chaten_AB	OPABA-Chatenois	Organic and Biodynamic	17	Riesling	Sandy silty and clayey
Inger_AB	OPABA-Ingersheim		26		Sandy loam

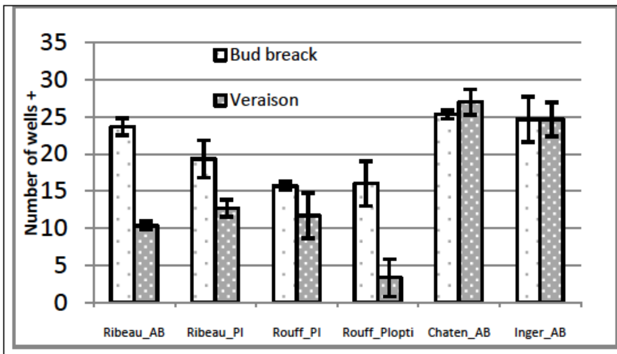
3 Results – Discussion

For all AB-systems, functional richness (Fig.1A) at bud-break is very much higher than for all PI-systems (respectively 24-25 and 16-19). For sites Ribeauvillé and Rouffach, functional richness is not significantly different between designed systems at bud-break, whereas, for both sites, it is significantly different at veraison. Comparing all sites according to designed-systems, functional richness is significantly different between designed-systems at the two vine vegetative periods.

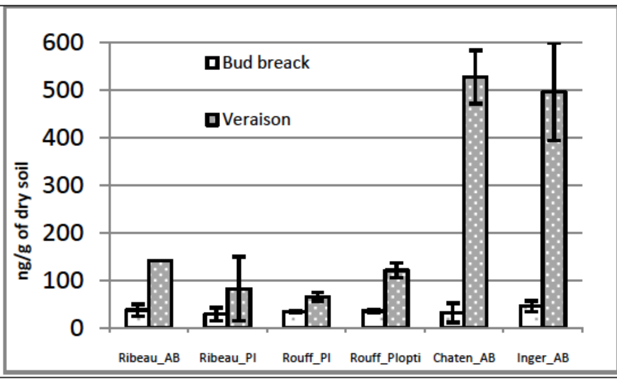
For all Designed-systems in a same site, bacterial abundance (Fig. 1B) is never significantly different between. At bud-break, bacterial abundance is between 28 and 45 ng/g of dry soil. For sites-systems Chaten_AB and Inger_AB, bacterial abundance is statistically different than the others sites-systems (respectively between 496-527 and between 65-141 ng/g of dry soil during veraison vine). One reason may be the number of years of organic farming in Inger_AB and Chaten_AB (more than 10 years) against less than 10 years for Ribeau_AB, and the others PI_Designed_system. Comparing all sites according to designed-systems, bacterial abundance is significantly different between designed systems only for veraison period.

Nitrogen mineralization kinetic (Nmin-kinetic) does not allowed to separate either PI and AB designed-systems, neither sites-systems (Fig. 1C).The top Nmin-kinetic is for Ribeau_PI site-system whereas the slowest one are for Ribeau_ABand Rouff_PI sites-systems.Rouff_Piopti, Inger_AB and Chante_AB sites-systems have touchily the same

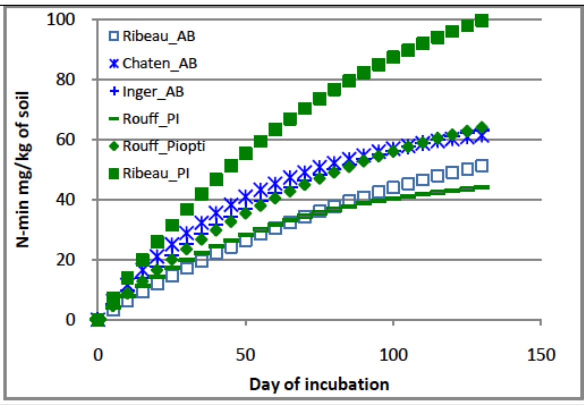
Nmin_kinetic.
It possible to separate PI and AB designed-systems according to PC2 axis of the PCA (Fig.1D): AB-systems under zero and PI-systems up to zero. Ribeauvillé-site is just on the y-axis for both systems AB and PI, i.e. there is no such difference between the two designed systems on this site. Inger_AB and Chante_AB are mainly explained by variables functional richness at bud-break and at veraison, whereas Rouff and Ribeau systems are mainly explained by bacterial abundance.



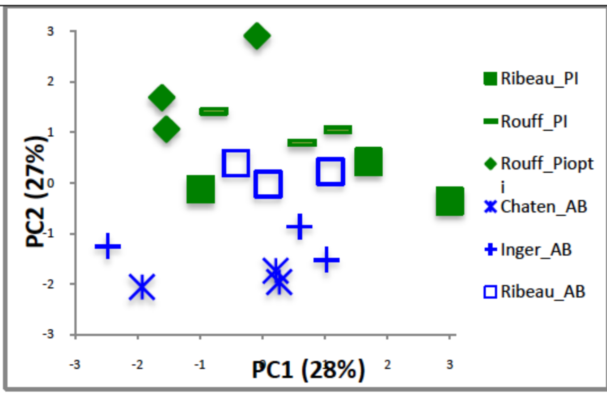
A. Functional richness at *bud break*and *veraison*of vine.



B. Bacterial abundance at *bud break*and *veraison*of vine.



C. Kinetics of nitrogen mineralization, under controlled conditions.



D. Bacterial biomass.

Fig. 1. Multicriteria results for all the sites-systems in Alsace, for 2014vintage (France).

4 Conclusions

In this paper, we show that some of the analyzed BCN indicators are interesting to assess new designed-systems in different vineyard.

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Silobag Storage: A Novel Technology for Modern Farming Systems

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1 Introduction

Argentina exhibits a storage capacity deficit of about 30% of the average harvest of wheat, corn, soybeans and sunflower. This deficit limits the ability to store and wait for higher prices after the harvest season and increases the fees of elevator services. Additionally, the grain hauling fleet is insufficient and during harvest time combine work have to be interrupted to wait for available hauling trucks. In recent years, the widespread silobag adoption alleviated Argentina's inefficiencies in the production, marketing and exporting channels of the main commodities. The silobag technology overcomes many of the limitations of traditional on-farm storage facilities – such as steel bins. In general, investing in permanent storage facilities is not affordable for most farmers with the main constraints including high initial outlay, scarce, expensive and short maturation loans and high levels of economic and productive uncertainty. Instead, the silobag requires a minimal initial outlay, its use can be increased, decreased or stopped completely according to productive and economic conditions and it can be set at a different location each year. This last feature turns critical in a country with a constantly increasing proportion of tenant farming that switches plots every year according to the level of rental fees. Moreover, if the bag integrity is preserved, the storage environment reduces moisture losses and insect proliferation which reduces storage maintenance costs (Young, Parker, and Klose 2009).
Beyond the described advantages, preliminary evidence suggests that an additional advantage of the silobag is the ability to return control of grain sales to the grower and improving marketing opportunities and increasing farm returns (Darby and Caddick 2007; Taher et al 2013). The silobag provides the farmer the ability to competitively choose among different buyers which results in a higher selling price. Without the silobag, farmers would store the grain at a commercial elevator, and would be limited to the price bids from that elevator resigning bids from other potential buyers – other elevators or industries. On-farm bins provide similar incentives, but at a much higher cost. The economic mechanisms that improve the value of this technology over other forms of grain storage have not been thoroughly analyzed. In particular, the role of increased marketing opportunities at one point in time –i.e., cross sectional price differences- has been largely overlooked and are modelled explicitly in this paper to understand the full value of this technology. This paper develops a dynamic programming model of soybean storage that quantifies the value of the silobag to a farmer in comparison with the traditional elevator storage.

2 Materials and Methods

The model represents a farmer who has to decide at harvest whether to sell his production inmediately or whether to store it using one of two storage alternatives: a silobag or a commercial elevator. If storage is initiated, the selling decision is made once a month (in 12 decision nodes) with the objective of maximizing net returns, i.e., revenue which is a random price times quantity sold minus selling commision, hauling and storage costs. Soybean prices follow a random markow process transitioning from a given state in the current time period to another state in the next time period according to a probability transition matrix of 12 intervals conditional of the grain sold in each period. The transition matrix is estimated using a series of deflated detrended soybean prices, centered at mean price of 250 u$s t^{-1}, to represent current conditions. The cost of setting the silobag is a single quantity paid at the begining of the storage, while the cost of the elevator storage is a monthly fee paid at the time of marketing the grain. Selling commission and hauling costs are the same for the silobag and the elevator. The silobag increases the bargaining capacity of producers allowing them to negotiate either lower marketing costs or higher prices. For silobag users, such effect is modelled as cross-sectional price differences that represent a set of bids from different potential buyers that the producer can choose from. For each decision node, cross-sectional differences are generated sampling 5 prices from a normal distribution whose mean is the soybean price of that node and a standard deviation of 1 u$s t^{-1}, as a base for comparisons. The model is solved and 500 Monte Carlo simulations are run to represent the different price paths.

3 Results - Discussion

The optimal strategy under the two storage alternatives differs substantially. Using the silobag, it is optimal to store for a longer time period than using the commercial elevator (Table 1). For the low harvest price scenario and storing in the silobag the weighted storage length is of 9.8 months, while storing at the elevator the storage length is of 6.6 months. This is expected since storing in the silobag requires a fixed upfront cost to set up the bag, while the elevator charges a monthly fee per stored ton. Therefore, with the silobag a long storage has no additional costs compared to a short storage, which allows waiting for prices to increase later in the year. For both storage alternatives and for the low and medium low price scenarios (the price intervals occuring more often at harvest time), it is better to store longer than for the intermediate price scenarios. This occurs because the lower the price, the higher the probabilities that the price increases through the year. For intermediate and higher harvest prices, it is better not to store and selling all the production at harvest. This occurs because the expected price change conditional on the intermediate price levels is either negative or positive but too small to offset the costs of storing under either technology. Because the silobag allows long storage at low cost, using this technology permits capturing higher prices several months after harvest which results in higher selling price and higher net benefits (Table 1). With the silobag, the ton-weighted selling price is up to 2.3% higher and the net benefit is up to 2.8% higher than storing at a commercial elevator.

Table 1. Comparison of Storage Strategies using the Silobag and the Elevator Storage for Different Price Scenarios and Producer Bargaining Power.

		Price at Harvest	Storage Length (months)	Selling Price (u$s/t)	Mean Net Benefit (u$s/t)
Panel A: Same Price	Silobag	Low	9.8	234.4	194.0
		Medium Low	9.0	246.8	206.1
		intermediate	0.0	246.7	212.3
	Elevator	Low	6.6	232.9	188.8
		Medium Low	1.8	241.3	204.2
		intermediate	0.0	246.7	212.3
Panel B: Higher Silobag Price	Silobag	Low	8.8	249.3	208.5
		Medium Low	6.8	259.7	218.7
		intermediate	5.7	263.8	222.8

When the producer is able to negotiate lower marketing costs or higher selling price, the optimal storage strategy, the final selling price and the net benefit change. It is now optimal to store during a shorter period of time for the low and medium low price scenarios and it is convenient to set up the silobag and store under the intermediate price scenario (Table 1, Panel B). When the producer can improve the average selling price by 1 u$s t^{-1}, the weighted selling price increases by about 7% for the three price scenarios compared to the elevator storage and the net benefit increases by 10% and by 4.9% for the low and intermediate price scenarios, respectively.

4 Conclusions

This paper develops a dynamic model of soybean storage quantifying the value of the silobag to a farmer in comparison with the traditional elevator storage. The model considers that the use of silobag can generate higher bargaining power by which producers can obtain higher selling margins. Results presented indicate that the use of silobag provides more flexibility to wait for higher prices during the storage season and can generate higher economic benefits, even if no extra bargaining power is considered. When lower marketing costs or higher selling prices are obtained the silobag's economic benefits increase considerably.

Beyond the described economic benefits, the use of silobags is able to generate advantages that can enhace the whole farm operation and extend its benefits to regional- and national-level logistics. First, the silobag provides storage capacity requiring minimal capital investment in facilities and equipment. Making this technology apt to high-uncertainty environments. Second, the silobag use reduce harvest delays and provides variable storage capacity that can be varied from year to year and set in different places every year. Thus, alleviating regional- or national-level storage and hauling capacity deficits. Third, if the silobag integrity is preserved, the storage environment reduces moisture losses and insect proliferation. Because of these advantages, the silobag is being rapidly adopting by producers and grain processing industries througouth the world, both in developed and developing countries.

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The effects of different tillage methods on soil temperature, water content, bulk density, and yield of winter wheat in southern Henan of China

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1 Introduction

No-tillage can promote soil porosity and improve infiltration, soil structure and decomposition of organic matter. Its soil biological activities were regulated by earthworms (Edwards, 1992; Hendrix, 1992). Soil tillage by soil disturbance or straw cover changed the soil surface, thereby affected the heat flux condition of the soil (Mark & Mahdi, 2005). No-tillage and its impacts on root distribution of winter wheat and soil temperature were studied in arid and semi-arid regions (Chen *et al.* 2009). The objectives of this study were to explore the effects of different tillage modes on soil temperature and root system, realize the innovation of regional application and technology and provide feasible theoretical basis for agricultural production.

2 Materials and Methods

The experiment was conducted at Xiping, China, from 2007 to 2014. The content of total N , available-phosphate, available- potassium and organic matter were 0.94 g/kg, 89 mg/kg, 105 mg/kg and 1.19 mg/kg, respectively. Zhengmai 366, a strong gluten wheat cultivar, was used in this study. Five treatments including with different tillage methods were conducted (Table 1).

Table 1. Experiment treatments

Treatment	T_1	T_2	T_3	T4	T_5(ck)
Specific measures	Straw mulching and pre-sowing deep plough for corn + straw mulching and non-tillage for wheat	Pre-sowing deep plough for corn + non-tillage for wheat	Straw mulching for corn + non-tillage for wheat	Straw mulching and non-tillage for wheat	Traditional cultivation

3 Discussion

Table 2. Effects of different tillage methods on soil water content and bulk density

Treatments	Before sowing						Harvest		
	soil water content(%)			soil bulk density(g/cm³)			soil bulk density(g/cm³)		
	0-10cm	10-20cm	20-40cm	0-10cm	10-20cm	20-40cm	0-10cm	10-20cm	20-40cm
T1	23.2	22.0	20.3	1.41	1.41	1.44	1.29	1.40	1.44
T2	20.8	20.5	17.9	1.30	1.38	1.47	1.44	1.44	1.47
T3	19.4	19.5	20.3	1.45	1.41	1.54	1.49	1.55	1.64
T4	20.6	22.6	21.2	1.48	1.52	1.56	1.20	1.55	1.57
CK	19.4	19.5	20.3	1.34	1.40	1.41	1.32	1.35	1.46

There were about 25-30 days from maize harvest to wheat seeding in southern Henan of China. The results showed that soil water content before sowing was 2% higher in straw mulching treatments (T1 and T4) than that of other non straw mulching treatments (Table. 2).

As it was shown in Table. 2, straw mulching treatment has a significant impact on the bulk density of the soil from 0-10cm soil layer. Deep plough treatments significantly reduced the bulk density of the soil from 0-40cm soil layer.

The difference of the average temperature of the soil among different treatments was less than 0.3 °C during the wintering stage, and was less than 0.6 °C during turning green stage(Fig. 1). The soil temperature of the treatment T1 and T2 were 0.1 °C and 0.2 °C higher than that of the control, respectively. The soil temperature of T3 and T4 was 0.1 °C and 0.3 °C lower than that of control respectively. There were no significant difference in the soil temperature in wintering and turning greening stage of winter wheat among different treatments.

As it was shown in Fig. 2, the root dry matter density of control (CK) in soil layer 0-10cm in wintering period, turning green stage and filling stage was the lowest, but that of which in soil layer 10-20cm was the maximum. Compared with control (CK), the root dry matter density of the soil layer 0-10cm in the treatment of T1, T2, T3 and T4 at filling stage.were increased by 0.12kg/m³, 0.13 kg/m³, 0.11 kg/m³ and 0.09 kg/m³, respectively. And the root dry matter density of the soil layer 0-20cm on T1, T2, T3 and T4 treatments were increased by 7.0%、9.3%、7.0%、4.7%, respectively.

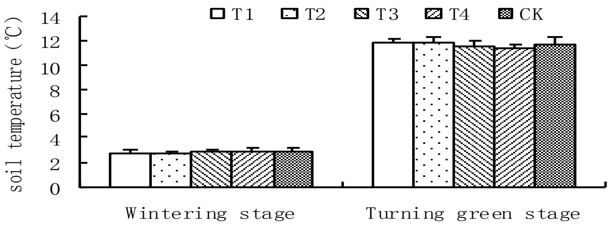

Fig. 1. The average soil temperature during wintering stage and turning green stage

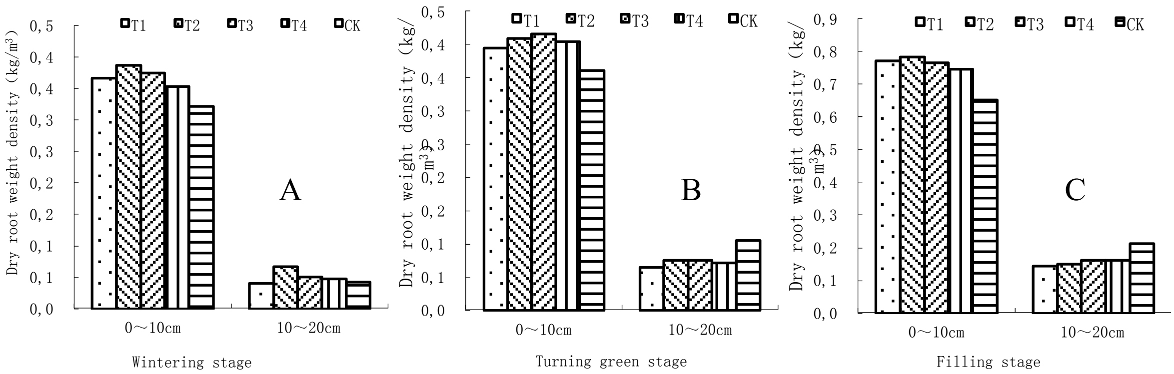

Fig. 2. The distribution of root system

From 2007 to 2013, the average yields of T1, T2, T3 and T4 were 1.44%, 4.20%, 5.50% and 3.99% lower than that of CK, respectively (Table 3). The yields of T1 treatment was increased by 2.02% compared with that of control in 2010-2011. Compared with control, from 2010 to 2013, the yields of T1 was 2.02%, 2.83%, 10.93% higher than that of CK, respectively. With the increase of the experimental years, no-tillage and straw cover technology can slightly improve the yield. At the same time, the cost reduction and ecological effect is obvious.

Table 3. Yield under different treatments

Treatments	Yield(kg·hm^{-2})					
	2007-2008	**2008-2009**	**2009-2010**	**2010-2011**	**2011-2012**	**2012-2013**
T1	7315.5a	7480.5a	7124.5a	9033.0a	8172.0a	4367.7a
T2	7374.0a	7225.5b	6729.5b	8779.5ab	7671.0bc	3413.0c
T3	7125.0a	7243.5b	6657.0b	8479.5b	7354.5c	3677.3bc
T4	7233.0a	7122.0b	6994.5ab	8800.5ab	7483.5c	3502.7c
CK	7465.5a	7545.0a	7230.0a	8854.5ab	7947.0ab	3937.5b

4 Conclusions

Better soil moisture was provided by straw mulching in the sowing period of winter wheat. Deep plough reduced the soil bulk density. No-tillage technology increased root dry matter density of the soil layer 0-10cm in filling stage. For no-tillage and deep loosening, one or two seasons of straw returning have influenced the distribution of root system.

There were no significant difference of the changes of the soil temperature under turning green and jointing stage between no-tillage and conventional tillage treatment. The difference of the soil temperature was not sufficient to affect the growth and development of the winter wheat.

The seeding quality still needs to be improved to improve seed germination rate. Compared with control(CK), No-tillage treatments reduced the yield slightly at the first three years, but slightly increased yields in the later years.

Acknowledgements. This work was financially supported by the National Key Technology R&D Program (2011BAD16B07 , 2012BAD14B08 and 2012BAD04B07), and Special Fund for Agro-scientific Research in the Public Interest (201203033), and Special Research Development Fund Project of Henan Academy of Agricultural Sciences(201218301).

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T2. Assessing performances and services of farming systems (farm level surveys and databases)

Chair: Jean-Marc Barbier, INRA
Co-chair: Wei-li Liang, Hebei Agricultural University

Adaptations of farming systems to cities: periurban farms beyond the short food-supply chains

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1 Introduction

There is an increasing attention to periurban agriculture, mainly related to the services provided by maintaining agriculture nearby the city (Zasada, 2011) and to the conflicts related to the use of the resources (Darly & Torre, 2014). However, few attention is given to the farm management in periurban areas (Aubry & Soulard, 2013), looking more on its environmental impacts or on the contribution of farmers to the development of short food-supply chains. Following Nahmia & Le Caro (2012), we defined periurban farms as all the farms that are located within an urban planning area, *e.g.* urban municipalities or inter-municipalities. This means that all these farms, besides their farming systems and their way of marketing their produce, are under the influence of the city. This influence has been considered as a factor of adaptation of different farming systems (Soulard & Thareau, 2009; Houdart *et al.*, 2012) including those which are not oriented short food supply chains (Capillon & David, 1996). In this research, we aimed at identifying the main types of periurban farming systems to highlight their different adaptations to city.

2 Materials and Methods

We study the adaptation of periurban farming systems to cities through the elaboration of a statistical-based farm typology according to Landais (1998). We applied our method to the urban region of Pisa (Italy), a medium-sized city leading an inter-municipal area of almost 200,000 inhabitants which experienced a diffuse urbanization since the eighties (Marraccini *et al.*, 2013). The input data for the typology have been acquired through on-farm surveys on a sample derived from the individual Land Parcel Identification System database according to the dominant land use, the farm size and the farmland distance to the city. Starting from this sample, 55 farms were selected and surveyed using a semi-structured interview. The main items of this interview were the farm location and history, the land tenure, the management of crops, livestock and semi-natural habitats, the commercial practices, the farmer and its family and the farm perspectives. The variables used in the typology described the farm territory and the farm management, the land use intensity and the individual farmer characteristics.

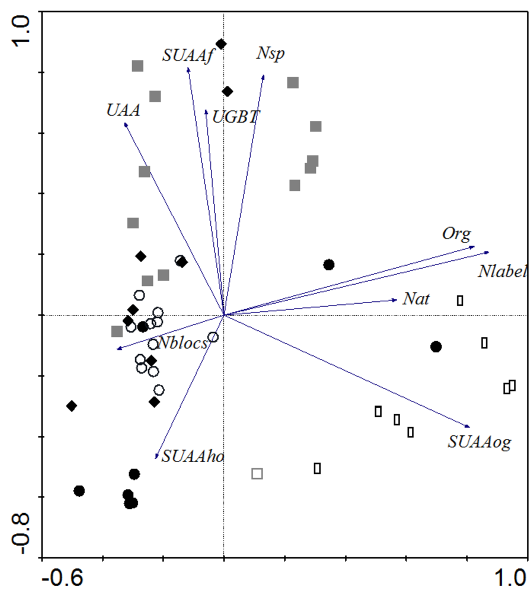

Fig. 1. PCA of the set of variables (see codes in the text, UBGT= livestock units, Org=organic farm, Nat=presence of SNH). Each symbol represent a farm with a dominant land use type, e.g. empty circles are the industrial crop farms.

These variables were selected on an initial set of 48 static and dynamic ones using a descriptive analysis followed by a PCA and explained 65% of the farm sample variance (Fig. 1). Finally, a non-hierarchical cluster analyses (CA) on the final set of 10 variables and on the 51finally considered farms allowed obtaining 7 different farm types (Ward's method, Euclidean distance). All the variables used appeared significantly different among the farm types (Kruskal-Wallis test).

3 Results – Discussion

Seven types were identified on our sample of 51 farms (data not shown). Three types (T1, T2 and T4) are composed of cereal farms differing on farm size (UAA), farmland fragmentation (Nblocks) and crop rotation length (Nsp), whereas two of them (T5 and T6) are forage and livestock-oriented farms differing for the farm size (UAA), the share of forage surface (SUAAf) and the marketing of produce in alternative or conventional food chains (Nfc). One type concerned organic olive groves farms (T7) and the last one (T3) little and conventional market-oriented vegetable farms. Our results underlined that 1) the farm types are not always linked to the main productive orientation of farms, except in the case of the specialized farms (olive groves and vegetables) and 2) not all the farm types located in the urban region have functional relationships to the city, e.g. the big conventional arable farms. These functional relationships are revealed not only by the local marketing of farm products but also by the fragmentation of land tenure, the bonds of the farmer, the multifunctionality of the farm, the intensity of the agricultural practices (Fig. 2). Through a spatial analysis of the farm types field blocks' location (data not shown) we found a statistically significant negative correlation between types having a functional relation to the city linked to short food-supply chains and the distance of the farm to the city, suggesting that the farms mostly oriented to urban market find their farmland farer from the cities than the other farms were there are less constraints and conflicts for their activities.

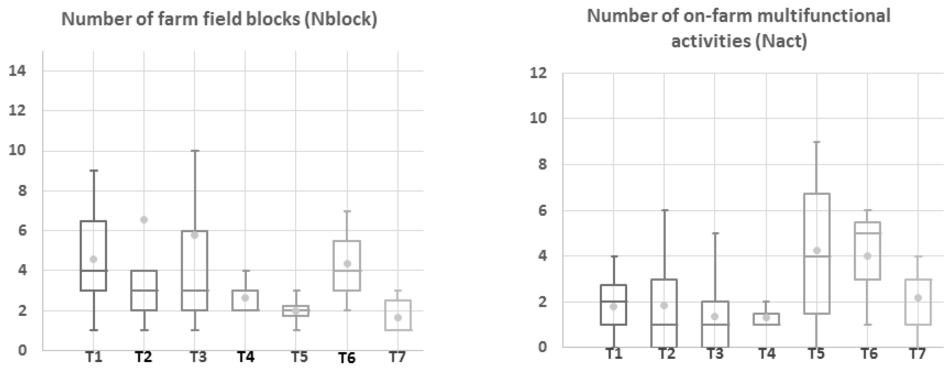

Fig. 2. Examples of features of the periurban farm types (T1 to T7, see text) in the urban region of Pisa (Italy).

4 Conclusions

By studying the farm types in periurban areas, we showed 1) the high diversity of farming systems even though within a same dominant land use type and 2) the different adaptations of these farms to the city. Understanding these points can contribute to a better understanding of the resilience of farming systems in periurban, linked to the main issues at stake in this area: the protection and management of water resources, agricultural land and of the local food system.

Acknowledgements. This work has been carried out within the research project DAUME (Durabilité de l'agriculture urbaine en Mediterranée) funded by the French National Research Agency under the contract n°ANR-2010-STRA-007-01.

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Food security, income and agriculture in the new ruralities of Central America

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1 Introduction

Family agriculture in the sub-humid tropics of Central America faces multiple challenges that jeopardize the sustainability of rural livelihoods. Increased climate risk, high pressure on land, relatively expensive inputs and low agricultural profits, among others, are major threats to food security and income generation of smallholder farming in the region (FAO *et al.*, 2012). Rural households experience and face these challenges to ensure their food and income in different ways depending on their socio-ecological context, objectives and resources. In Central America, many rural societies have moved from a completely agriculture-based to more diverse society where migration and rural-urban exchanges have shaped their current livelihoods and farming systems, the so-called new rurality (Grammont, 2004). The aim of this study was to understand the diversity of farming systems in the region, their main agricultural activities and performance, as well as their main sources and levels of income and food.

2 Materials and Methods

A short survey was conducted in 2014 with local partners to almost 800 farm households in five sites in sub-humid regions in Nicaragua, Honduras and El Salvador. Sites represented a gradient of market development and agroecology. Around 160 farmers were randomly selected accounting for 20-30% of the total rural households in each site. The survey contained 14 questions including information on household structure, cropping systems, livestock component, perceived food security, income and potential future strategies. Each survey was answered in ca. 40 minutes. Descriptive and statistical analyses were conducted to quantify the diversity of households between sites, as well as within sites using a structural household typology simply built on access to land (i.e. farm size). A balance was calculated to assess the level of self-sufficiency of the household in terms of energy in their diet based on their structure (i.e. demand of energy of the household), and the food produced in the farm and consumed by the household (i.e. availability). Preliminary results of the survey were presented to 10-20 participants from local organizations and rural population for discussion and validation and to identify potential future options for family agriculture in each site.

3 Results – Discussion

Analyses of the house hold survey data highlighted intra site diversity of the rural population in terms of their resources and livelihood activities (Table 1). For example, households in two sites in Nicaragua tend to have available less farming area per person with relatively larger farms and less area used for growing grains (i.e. maize and beans) than in the other sites. In contrast, households in the site in El Salvador tend to have more farming area available per person reflected in smaller farm sizes and higher maize yields. Animal husbandry tends to be more common among rural households in Nicaragua compared with the other two sites. Household total income tends to be the lowest in the site in Honduras compared to the other sites, while at least half of the households in one site in Nicaragua, Honduras and el Salvador obtain most of their salary (>80%) from off-farm activities. This reflects a strong diversification of household activities as a common feature of these small holder farming systems (Grammont, 2004).

Table 1. Median values for some key household and farm indicators

Site	People per ha	Farm size (ha)	Grains (% area)	Maize yield (t ha^{-1})	TLU	Annual income (USD)	Share off-farm income (%)
NI-Terrabona	1.4	3.5	50	1.2	0.7	973	49
NI-Somotillo	1.8	2.8	67	0.7	1.0	881	29
NI-Condega	2.9	1.4	100	1.0	0.6	1246	81
HN-Candelaria	3.8	1.3	83	1.0	0.2	428	100
SV-Chalatenango	5.7	0.7	100	1.3	0.2	1040	100

Diversification of household activities and farming systems can largely differ within sites. Fig. 1A illustrates differences between household strategies in one site in Nicaragua (NI-Terrabona) where more households owning farms less than 3,5 ha ensured a large part of their income (>50%) in 2013 from off-farm activities compared to households with larger farms. This confirms that although most households combine both on- and off-farm economic activities to ensure their

livelihoods, households with smaller farms tend to rely more on non-farm activities.
Diversification of activities and farming systems can also relate to the vulnerability of rural households in terms of poverty and food self-sufficiency. Fig. 1B shows that between 75-80% of households with farms smaller than 7ha earned less than 1.25 USD per person, while ~30% neither produce enough energy to fulfil the household needs in terms of food. For households with farmers larger than 7ha, these numbers drop to 63% and 12% respectively. This suggests that although households with larger farms tend to be less vulnerable in terms of income generation and food dependency than smaller farmers, most house holds still largely depend on their own food production.

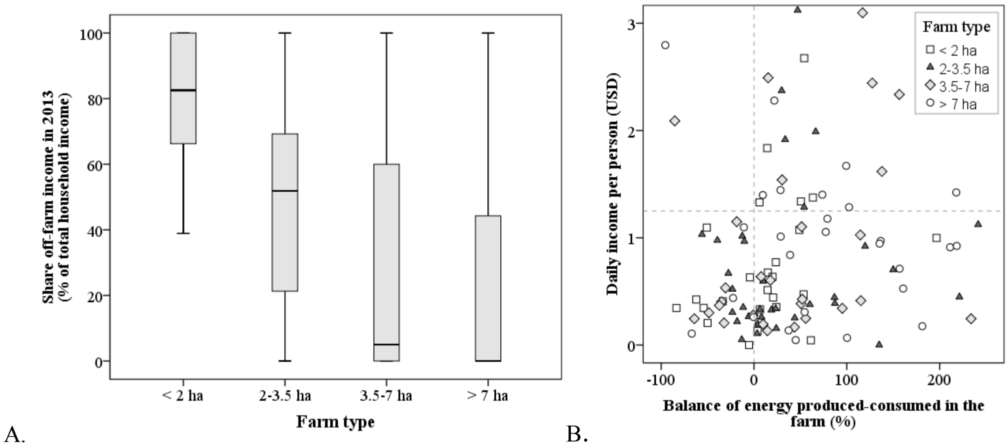

Fig. 1. Households and farming system diversity among households with different farm sizes in NI-Terrabona, including: household distribution of the share of off-farm income of the household total income in 2013; B. comparison between balance of energy and daily income per person in 2013.

Discussions with local partners confirmed these major differences between households within the same site. While diversification and intensification of home gardens seems to be a key option for the food and nutrient security of households with limited access to land, vegetable production for smallholder farming systems and agroforestry systems for more sustainable extensive production represent potential future development pathways. This reinforces the need to look for more integral research and development programs that account for the agricultural and non-agricultural components of the current and future rural societies.

4 Conclusions

The results of this approach combining short survey and discussion with farmers and local organization is a step forward to analyze and explore the interactions of food security, income and farming systems in the sub-humid tropics of Central America and to propose more contextualized future options for family agriculture in the region. Particularly, we need more integral research and development programs to better combine the agricultural and non-agricultural components of the new ruralities in Central America.

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Ecological intensification in Río de la Platagrasslands

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1 Introduction

Understanding existing agro-ecosystems in which food production is based on intensive internal resource use might provide inspiration for re-designing external input based systems. The livestock production systems in the *Río de la Plata Grasslands* (RPG) in southern South America represent a good example of such model. Animal production in this vast region, which includes parts of Brazil, Uruguay and Argentina, co-evolved with plant biodiversity on semi-natural grasslands that received negligible amounts of external inputs since the introduction of domesticated livestock in the 16th century (Soriano, 1992), constituting a feasible form of land-sharing. During the last 15 years, high prices of grains (mostly soybean and wheat) prompted conversion of grasslands to arable land (Paruelo *et al.*, 2006). Overgrazing due to high stocking rates on the remaining land caused loss of valuable grassland species (Overbeck *et al.*, 2007), low grassland and meat productivity (Carvalho & Batello, 2009) and negative environmental impacts on soils and climate due to erosion and losses of soil carbon and high greenhouse gas (GHG) emissions (Modernel *et al.*, 2013). This change in land use endangers the unique and 400 year old model of land sharing (Garnett *et al.*, 2013) in which meat production is sustained by natural grassland biodiversity. Two intensification strategies can be distinguished in the region. The first one (conventional intensification) proposes to increase meat yields through replacing natural grasslands by ley and feed crops (Cohn *et al.*, 2014). The second one(ecological intensification) proposes to increase meat yields by adjusting forage allowance[1] to animal energy requirements in time and space through smart use of species diversity (C3 and C4) in native grasslands (Soca *et al.*, 2008). The first strategy aims to intensify production to be able to save land and separate production and nature conservation areas (land sparing), while the second one aims to preserve the diversity of native grasslands while using them (land sharing)(Green *et al.*, 2005). In this paper, we analyse the ecosystem services provision of both intensification pathways, compared to the traditional system with low productivity.

2 Materials and Methods

Environmental indicators were calculated based on the production of one steer slaughtered at 500 kg. Farms that produce this animal can specialize, or combine three production activities: calving, growing and fattening. Specialized farms include three types: cow-calf (produce 150 kg calves), backgrounding (receives 150kg steers and sells them at 350 kg) and fattening (fattens steers from 350 to slaughter weight). Intensification strategies can differ depending on farm specialization.

The impact of the intensification process on the ES provision was estimated from a review of published studies in the region. Meat productivity and GHG emissions were estimates from nine farm case studies in Uruguay (Becoña *et al.*, 2014; Montossi, 2014; Picasso *et al.*, 2014). Calculations on the impact on biodiversity and carbon sequestration of current and ecollogically intensified systems was made from Brazilian experiments that evaluated the grazing pressure on natural grasslands on the soil carbon stock, considering 4% forage allowance (FA) as the traditional system and 12% FA for ecological intensification and crop-ley rotations for conventional intensification (Carvalho *et al.*, 2009; Conceição *et al.*, 2007; García Préchac *et al.*, 2004). Fossil energy reduction, pesticide use reduction, GHG emissions reduction, erosion risk reduction and water use efficiency were calculated using published farm data (Picasso *et al.*, 2014; Ran *et al.*, 2013). In order to standardize the different impact categories, the system with the most positive (or least negative) impact on an indicator was considered as the reference and set to 100%; the other systems were expressed as fractions of the reference.

3 Results and discussion

While conventional intensification would increase meat yields and reduce greenhouse gas emissions compared to the ecological intensification strategy, the also occurring negative environmental consequences question this option for the RPG farming systems (Table 1 and Fig. 1). Production cycles in conventionally intensified systems produce meat in less time than the other two, resulting in greater productivity per hectare.

Ecological intensification shows synergies among a number of indicators by improving meat productivity, biodiversity conservation, carbon sequestration, GHG emissions reduction and water use efficiency. The use of fossil fuels, pesticides and erosion risk is higher than in the traditional low productive system, but (sometimes substantially) lower

[1] *Weight of herbage per unit of animal live weight at a point in time (Allen et al., 2011).*

than under conventional intensification.

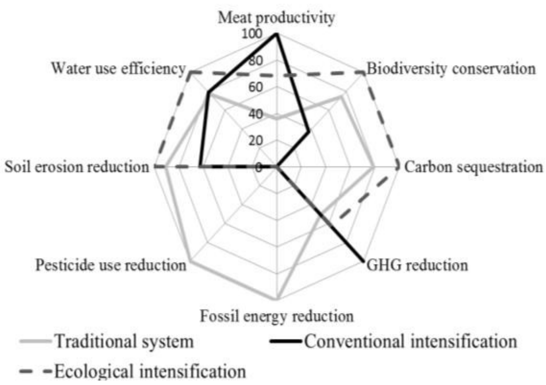

Figure 1. Impact of traditional, conventionally intensified and ecologically intensified livestock systems on the ecosystem services provided by natural grasslands in the RPG. Higher values (closer to 100) indicate better performance.

Table 1. Indicators and their values considered for each farming system.NG: Natural grasslands; L: Ley; GR: Grains.

Indicator	Traditional	Conventional intensification	Ecological intensification	Units
Diet composition (dry matter %)	100% NG	32% NG; 37% L; 31% GR	70% NG; 30% L	ha
Stocking rate	0.7	1.6	1.3	Livestock Units·ha^{-1}
Meat productivity	124	342	233	kg LW ha^{-1}yr^{-1}
Biodiversity conservation	2.6	1.3	3.5	No unit
Carbon sequestration	113	0	143	t C ha^{-1}yr^{-1}
GHG emissions reduction	20	10	16	kg CO_2 eq kg LW^{-1}
Fossil energy reduction	0.0	12.1	3.4	MJ kg LW^{-1}ha^{-1}
Pesticide use reduction	0.1	14.9	1.7	No unit
Soil erosion reduction	11	16	14	kg soil kg LW^{-1}
Water use efficiency	0.052	0.053	0.067	L kg LW^{-1} yr^{-1}

4 Conclusion

The evidence presented in this article shows that the RPG is a region where combining agriculture and conservation of biodiversity is possible (land sharing), but under threat of change from use as grassland to soybean. Given the long history of land sharing, preserving livestock production systems based on native grasslands is key to the maintenance of regional biodiversity and the associated array of ecosystem services. The unique combination of production and resource conservation under ecologically intensive methods of producing meat should be further investigated to understand its benefits and promote low-input technologies that are adapted to the specific farming conditions.

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OPTIMIZING MILK AND BEEF PRODUCTION SYSTEMS ON FARM LEVEL

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1 Introduction

Within the EU KP 7 project CANTOGETHER innovations are developed and explored to integrate plant production and animal production in mixed farming systems with the overall aim to design innovative sustainable mixed farming systems with crops and animals. This requires detailed knowledge about the advantages of mixed farming systems and the factors influencing their environmental performance. In our analysis of two existing farm data networks the environmental impacts of mixed and specialized farms were compared, and the factors responsible for a high or low environmental performance were explored to derive driving factors for an environmentally successful farming.

2 Materials and Methods

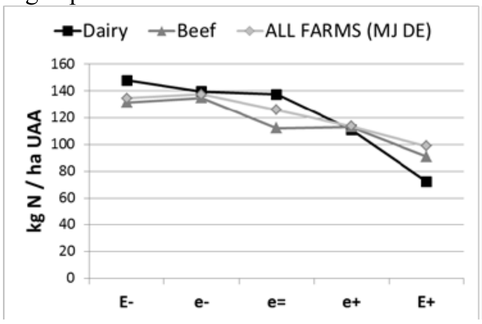
Data were derived from the network INOSYS of the French Institut de l'élevage (Idèle) and the LCA-FADN network of Agroscope (Hersener *et al*., 2011), containing farm management data, economic figures and results on environmental impacts on farm level for 622 and 87 milk and beef producing farms, respectively.
To ensure the comparability of the results, common environmental indicators were identified and used for the analyses: energy demand, global warming potential, eutrophication and acidification. For comparing the environmental impacts, reference units both related to the area and to the production were used: ha usable agricultural area (UAA) and kg milk and beef produced for both networks, as well as MJ digestible energy produced only for the Swiss farms.
As different inputs were considered and sometimes differents methods were used to calculate the environmental impacts in the two farm networks, the absolute numbers of the impacts calculated could not be compared. Therefore, a simplified method based on the formation of groups was used. For each indicator analyzed, the sample was divided in three groups: (1) the best third with 33 % of the farms with the lowest impact; (2) the worst third with 33 % of the farms with the highest impact; (3) the middle third with the remaining farms.
A score from 1 to 3 was attributed to each group, to lowest score being attributed to the group with the highest impact, the highest score to the group with the lowest impact. At the end, all indicators were aggregated and the scores of each farm were summed up. The final scores ranged between 4 and 12, the latter being attributed to farms located in the best third for all four indicators analyzed. Those farms were classified as "best farms" for the respective reference unit.
In the first step the different reference units were analyzed separately. For identifying the most successful farms, the results related to the area used were crossed with those related to the production. The resulting scores ranged between 8 and 24. As the number of farms with per score was limited, five groups were formed from the least (score from 8 to 10) to the best performing farms (score from 22 to 24) and used for the comparison. To evaluate whether mixed farming systems perform better than specialized systems, three different definitions of mixity, proposed in the Cantogether working groups, were applied and compared with regards to their environmental impacts (results not shown).

3 Results

For Switzerland, the best performing farms per ha usable agricultural area (UAA) were more extensive farms with a lower use of external inputs. Typically they were organic suckler cow farms with a low stocking rate at rather higher altitudes. They had a high share of grassland and a low economic performance. Also in France the best performing farms per ha UAA were more extensive farms with a low use of external inputs such as concentrates, fertilizers, pesticides and fuel. They had a larger agricultural area, with more grassland and less maize and generally a lower productivity than the farms with high impacts.
Per kg milk produced, the best performing farms in Switzerland were rather larger, more intensive farms at lower altitudes, which combined milk and plant production. They had a higher share in open arable land, a higher stocking rate and milk yield per dairy cow than the less performing farms. Besides, their total return and income per family work forces was higher as well. The best performing farms per kg beef produced had a significantly higher stocking rate and less suckler cows than the less performing farms. They used more external inputs such as diesel and concentrates and had a higher overall return. As for the best farms in milk production, they tended to be larger with regards to UAA. In France the best performing farms per kg milk produced had a similar UAA as the less performing farms, with less maize and grassland, but more arable crops. The beef producing farms had a larger UAA with more maize and a higher meat production. They generally used less external inputs (nitrogen, concentrates for example) than the best performing

farms, except for the pesticides, where no difference between the groups was recorded. Combining the results per ha and per production unit allowed to identify the farms which performed well in both reference units. In Switzerland, one to eleven farms (depending on the reference unit used for productivity, kg meat, kg milk or MJ DE) reached a score of 22 to 24. In France, 12 farms reached a score of 24.

In Switzerland, the best performing farms overall were generally at lower altitudes and had a larger usable agricultural area. For all combinations analyzed the stocking rate declined with augmenting environmental performance (Figure 1). The best performing farms generally purchased less feedstuffs and concentrates than the less performing farms. Also the nitrogen fertilization decreased with the environmental performance. The least performing groups had a total nitrogen fertilization level of around 140 kg nitrogen per ha UAA, the best performing groups exhibited clearly lower values of 80 to 100 kg nitrogen per ha UAA.



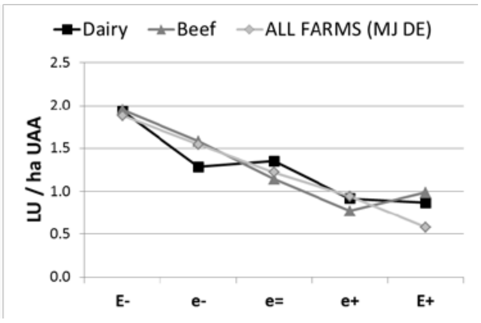


Fig. 1. Nitrogen input and stocking density of the aggregated environmental performance groups in Switzerland

In France, the best performing farms had a larger UAA with less silage maize. They also had a lower nitrogen fertilization level and a showed lower productivity in terms of milk yield, beef production and cereal yields. The best performing dairy farms exhibited a higher feed autonomy than the less performing farms. Organic farms were often among the most efficient farms, environmentally and economically.

4 Discussion

The factors important for a good environmental performance depend on the reference unit used. For low impacts per ha UAA the amount of inputs, i.e. the intensity of a farm, is decisive. Related to the production, i.e. kilogram of milk or beef produced, the amounts of inputs used seem to be less relevant. It is rather the efficiency of the production and therefore the farm management which is decisive.

In designing sustainable production systems it is therefore important to clearly define the goals of a system: a beef system in alpine areas for preserving the landscape has to be defined differently from a system in the plain region of Switzerland. Additionally, the recommendations should depend on the product in question: for milk and beef production different factors were important for a good environmental performance. The mixity of a farm plays a decisive role in the environmental impacts if there is (1) a good optimization of the external inputs in the farming system and (2) a better integration between crops & animals (more self-produced feed, more manure recycling and more legumes). A problem was that no general definition of mixed farming existed. Depending on the definition applied, different conclusions were drawn. Therefore it is more constructive to concentrate directly on production data when defining a production system because they reflect a farmer's strategy in relation to its environment, and not economic data which are dependent on market fluctuations. An important factor seems to be the stocking density: for all combination analyzed in both countries, the best performing farms had a stocking density of around one, whereas the stocking density of the least performing farms was rather at two. This could be explained by the impact of the stocking density on many other factors: A higher stocking density leads to higher nutrient load and requires more feedstuff import to the farm, because the amount of feedstuff needed cannot be produced any more on the farm.

5 Conclusions

This study gives important hints on what to consider when designing sustainable milk and beef production systems. Rather than thinking in categories such as mixed or specialized, one should directly focus on the descriptive parameters of a system. Amongst them the stocking rate could be identified as a crucial factor influencing many others. The product in question influences the importance of the single parameters and should be considered designing a system.

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Farming system models for supporting farm resilience: research needs, gaps and promising approaches

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1 Introduction

It is important to increase the resilience of food production systems in the face of a changing climate, land scarcity, and changing demographics and market conditions. As farm resilience is a high-level system property emerged from social-ecological interactions, its direct measurement is difficult because it requires measuring the thresholds or boundaries that separate alternate stability regimes of the farm system. However, systems' modeling for supporting agricultural resilience is still in an early stage. Through critical review of state-of-the art literature, this study aims at highlighting the new requirements of agricultural system modeling as they apply to management for farm resilience, limitations of contemporary agricultural systems modeling approaches, and promising directions for future research on the field.

2 Materials and Methods

By review of previous conceptual works on socio-ecological systems' resilience, we conceptualized 11 criteria for evaluating models' suitability for farm resilience studies, which include the capability of the modeling approaches to (1) represent social-ecological complementariness, (2) have long-term perspective, (3) manage uncertainty, (4) capture global-local linkages, (5) mediating participation, (6) capture cross-scale feedback loops, (7) explain human behavior including (8) social learning and adaptation, (9) capture farm heterogeneity, (10) anticipate multiple farm performance allowing trade-off assessment, and (11) sensitive to biophysical, economic and social drivers. Using these criteria we evaluated a mass primary literature on farming systems models to assess strengths and weakness of six main farming systems modeling approaches, and conducted comparative analysis across the methods.

3 Results - Discussion

Farm nutrient balance model accounts farm nutrient balance based on the consideration of major material inputs and outputs. As several of these fluxes are difficult to measure (e.g., leaching, erosion), transfer functions are commonly used. Internal nutrient flows between farm production units are also measured (Smaling and Fresco, 1993; Den Bosch *et al.*, 1998a; Den Bosch *et al.*, 1998b; Lesschen *et al.*, 2007), the popular nutrient balance accounting framework, produces farm nutrient balances and some farm agronomic and economic indicators. However, due to practical difficulties in measuring nutrient flows tied with soil processes, balance of soil nutrient reserve are still poorly considered. By capturing farm nutrient balance as a snapshot in time only, the analysis offers no long-term perspective. This ignores the residuals effects of fertilizer uses, long-term soil carbon cycling, and livestock or tree production cycles. Although human components exist as system entities and are connected to farm environment via nutrient flows and management activities, no decision making mechanism is included.

Farm system dynamics model deals with internal stocks (production units of the farm) and flows (nutrients and water), associated feedback loops and time delays that affect the behavior of the entire farming system. The substantive nature of feedback loops can be either material or information links, thus create multi-directional cause-effect relationship between biophysical and social observables (Shepherd and Soule, 1998; Sendzimir *et al.*, 2011). These models can mimick the actual farm components and interinfluences, thus is perceivable by stakeholders. The models are able to perform nonlinear behavior and dynamic complexity of the farm in sensitive to change in values of observables. However, the structures of stock-and-flows and feedback loops are predefined and fixed during simulation runs, ignoring the adaptive farmers' decision on modifying the nutrient network structure to utilize subsidiary effects among farm components. Thus, the modeling approach cannot model structural adaptation of the farm to change that is essential in farm resilience. The model also can operate the system dynamics at one aggregated scale and less capability to capture heterogeneity within and between farms.

Fixed-structure integrated farm modeling frameworks couple the sub-model of static farm nutrient stock-and-flows with those of soil-crop dynamics and socio-economic processes that allow information exchange for forming feedback loops between farm nutrient cycles, crop and livestock productivity and socio-economic dynamics (Giller *et al.*, 2006; Giller *et al.*, 2011). However, its limitation to understanding farm resilience is that: the within-farm interactions and feedback loops are not the subject of farmers' adaptive decisions; they are rather fixed and unspecific to nutrient cycle management/design context. Thus, farm's structural adaptive behavior to major change in external drivers is not endogenous explained by this modeling type. Multi-agent system (MAS) models represent the coupled human-environmental system is described through autonomous 'agents', which can be defined to represent actors and acted-upon entities such as households, farm production units, offer a system tool for understanding the complexity of energy, nutrient and material flows that result from rich interactions and feedback among social and natural processes (Bousquet and Le Page, 2004; Gaube *et al.*, 2009). As separate loci of control in the human-environment system, agents act autonomously, and interact with other agents, in an ever-changing system. MAS is strong in supporting interdisciplinary between natural and social sciences. MAS is based on complex adaptive system theory that is nowadays well-suited for representing ecological systems, social systems, and human-environmental systems; thus it becomes a paradigm shared by ecological and social sciences (Bousquet and Le Page, 2004; Scholz, 2011). By mimicking actual entities in the real human-environment system, MAS allows for an intuitive representation of the environment and of the embedding of human actors in a socially, ecologically, and spatially explicit setting. As MAS displays large-scale outcomes that result from interactions and/or learning among individual entities, it allows an adequate representation of micro-macro relationships and a strong ability to model social learning and adaptation (Kelly *et al.*, 2013). However, MAS models for understanding farm resilience and transition scenarios is still in a very early stage of development. To be able to assess farm resilience and support farms' transition to resilience, MAS models developed have to meet the following key requirements, which have not been addressed by current MAS research community: (1) *capture resilience-relevant properties* (i.e. buffering capacity, critical thresholds and tipping points), (2) *model change in slow variables as the endogenous processes*, (3) c*apture social-ecological feedback loops at different levels*, (4) *explain farming practices, which create subsidiary linkages between production units, or between farms as the subject of farmers' decisions*, (5) *parsimonious representation of socio-biophysical processes, (6) appropriate model validation* and (7) *better contextual robustness* (i.e., less dependent on site-specific assumptions, more applicable to a wide range of contextual variation and management options).

Table 1. Comparative assessment of contemporary farming system modeling approach with respect to criteria for farm resilient research. Note: detailed narrative insights of the table cells do not show.

Criteria	Nutrient balance models	System dynamics models	Bayesian Network models	Bio-economic models	Coupled component models	Multi-agent system models
Interdisciplinary	weak	strong	medium	weak	weak	strong
Long-term perspective	no	strong	no	weak	strong	strong
Uncertainty management	no	weak	strong	no	unclear	medium
Local-global perspective	no	no	no	weak	strong	strong
Participation mediation	weak	strong	strong	weak	unclear	strong
Multi-scale feedback loops	no	no	no	no	unclear	strong
Actors' behavior	no	weak	strong	medium	no	strong
Social learning and adaptation	no	no/weak	no	no	no	strong
Farm heterogeneity	medium	medium	no	weak	strong	no
Multiple farm performance	strong	strong	no	medium	strong	strong
Driver sensitive						
- Biophysical	weak	weak	weak	weak/medium	strong	weak
- Economic	weak	strong	medium	strong	weak	strong
- Social	no	medium	strong	weak	weak	strong

4 Conclusions

Agro-ecosystems modeling has gone through more than 40 years of development. Although a great deal of knowledge and tools about economic and biophysical processes exist, agricultural system modelling science hardly ever seeks to develop modelling frameworks and tools to support farm resilience management. The result of our meta analysis found that none of developed farming system models are sufficient for supporting farm resilience regarding all criteria. The results can serve as a reference matrix that helps identifying research directions towards supporting the resilience of agricultural systems. Multi-agent systems (MAS) modeling has appeared as a promising approach for model farming system resilience. Using the above-mentioned criteria we also analyzed the current limitations of this model family and elaborate possible future developments as subjects of follow-up studies.

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Factors influencing the flexibility of farming systems – Case study of the Flemish beef farming sector

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1 Introduction

In Western countries, most farming systems are highly specialized with a strong focus on increasing productivity, maximum biological control and technological optimization. Nonetheless, these farming systems experience economic and social difficulties and are confronted with the ecological boundaries of their environment. As a response, there is increasing attention for a shift in agricultural focus from optimization and control to one on resilience and adaptive capacity.
Flexibility is seen as an important aspect of a farm's resilience (Darnhofer *et al.*, 2010) and can be defined as the room for change or the degrees of freedom (Lev & Campbell, 1987). It enhances the possibility to react to environmental changes and is part of the farm's adaptive capacity. These concepts are well described and operationalized in management science, but agricultural science focusses mostly on theoretical and conceptual aspects. There is a need to translate this theoretical knowledge into practical knowledge, so that flexibility can be used as an evaluation criterion over and above traditional concepts such as efficiency and productivity. The first step is to provide insight in the factors influencing the farmer's choice set. In this paper we present preliminary results regarding this insight, investigating the case of the Flemish beef farming sector.

2 Materials and Methods

We started this research with a comprehensive review of literature, both from the management and agricultural science domain, to understand the different interpretations and approaches on the concept flexibility. We selected the Flemish beef farming sector as case study because it is known for its heterogenic characteristics of management systems. This heterogeneity is assumed to result in a diverse range of flexibility strategies.
Based on literature research concerning flexibility aspects, we constructed a guide book for conducting semi-structured interviews (Evers, 2007). This type of interview allows you to focus in more detail on interesting aspects that emerge during interviews. Currently these interviews are being conducted and analyzed, resulting in a first indication of important factors influencing flexibility.

3 Results – Discussion

There is no scientific consensus on the definition or methodology to analyze flexibility in agricultural production systems. Authors make distinctions between different types of flexibility or focus on a specific aspect (Astigarraga & Ingrand, 2011; Ingrand *et al.*, 2004; Lev & Campbell, 1987; Wauters & van Winsen, 2004; Weis C.R., 2001). Furthermore, different sources of flexibility are distinguished, ranging from input, output, technological and income flexibility (Wauters & van Winsen, 2004).
In the first phase of this research we do not focus on a single definition or source of flexibility, but approach the topic from a broad and general perspective. From the first analyses, we were able to extract a range of factors that significantly influence the flexibility of farm systems. These factors are presented in the first column of Table 1. The second column briefly illustrates how these factors influence the flexibility of farm systems.

Table 1. Overview of the factors influencing flexibility.

Factor	Illustration / explanation
Governmental policies	In the Flemish beef farming sector this is currently a much debated topic. A considerable amount of farmers has to reduce nitrogen deposition in the context of Natura 2000, influencing their management options.

Subsidies	Trying to qualify for subsidies requires complying with certain conditions, limiting the farmers choice set.
Financial resources	Loans from banks usually imply a large amount of money for one type of investment, favoring scale enlargement. Having own financial resources provides the farmer more decision freedom.
Income diversification	Focusing on only one income source or product makes farms more vulnerable to external influences. Diversification increases the range of possibilities to react to these changes.
Marketing channels	Having plural marketing channels enlarges choice options and possibility to react to price or market changes. There are also several gradations of autonomy in the marketing strategy.
Soil type	Type of soil determines for a large part which crops and fodder can be grown, influencing the flexibility in feeding strategy.
Infrastructure	Infrastructure is an important factor for the livestock sector, as it requires large investments. Overinvestment and -specialization of stables can reduce adaptive capacity.
Machine set	Machinery can either be very specialized or more general, determining the flexibility of the production process.
Cattle breed	Depending on the cattle breed animals are more robust, less susceptible to diseases, require less supervision and less concentrates. Especially the common Belgian Blue is a breed that requires specialized management, reducing flexibility.
Family situation	The family situation affects available labor force and possible succession. These factors influence management options and future investments.
Attitude farmer	Some farmers are very aware of the market situation, try to react proactive and handle risks by diversification. Others may react more conservative and are rather opposed to innovation.

Interpretation of these preliminary results show that factors are interrelated. For example, the choice of cattle breed may depend on available subsidies and/or the attitude of the farmer, in turn influencing the infrastructure. Through the construction of cognitive maps we will gain more insights in these relations. Cognitive maps are qualitative models of a system, consisting of variables and the causal relationship between these variables (Özesmi & Özesmi, 2004).
Typically the revealed factors are not straightforward reducing or enhancing flexibility (Table 1). Their effect is mostly the result of how farmers deal with these factors. An interesting application of these results is the characterization of different livestock management models by the way they cope with the different influencing factors.
In the second phase of this research we will compare the gained insight in the interdependencies of the emerging factors with the scientific literature. As written above, there's no consensus on how to analyze flexibility. By looking at our results from these different perspectives we will gain insight in the origin and the different types of flexibility. From the characterization of management models practical knowledge can be derived, as farmers can learn from more flexible systems and change their strategies.

4 Conclusions

In this paper we presented an approach to analyze the flexibility of the Flemish beef sector and the factors influencing this flexibility. We illustrated our approach by some preliminary results. Results showed that factors are interrelated and that we need a systems approach to analyze flexibility of farming systems. We also concluded that the effect of influencing factors mainly depends on the coping strategy of the farmer in question, which may lead to a characterization of different management models. In the next phase we will construct individual cognitive maps of the factors influencing flexibility for each of the interviewed farmers. Through qualitatively analyzing these maps and comparing them between different management models, we will gain insight in the origins and the different types of flexibility.

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Methods for designing farms that include a coal seam gas extraction enterprise.

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1 Introduction

Over 24,000 km^2 of the Surat Basin in southern Queensland, Australia, has been approved for coal seam gas (CSG) development (Huth *et al.*, 2014) and this is driving significant landscape change. While regional scale economic benefits of CSG development are acknowledged, few studies have evaluated the impact on farmers that must now coexist in a "shared space" with large-scale resource extraction enterprises (Huth *et al.*, 2014). Much of this land is used for a broad range of agricultural purposes ranging from grazing, irrigated and dry land cropping and horticulture. Incorporation of a resource extraction enterprise into these farm lands requires the addition of extensive road networks, wells, pipelines, electricity transmission lines, water storages and processing facilities (Fig. 1a). To date, the design of these mixed gas-farm systems has been undertaken via negotiations between individual farmers and CSG companies looking to install infrastructure on their farms. Little information has been available to assist farmers in planning and implementing these significant changes to their farming enterprises. We outline ongoing research that provides insights on the farm redesign process that looks to maximize the benefits arising from CSG development (e.g. improved cash flow, investment into the asset base) whilst minimizing the costs (e.g. lost land, decreased yields, impacts on machinery efficiency).

2 Materials and Methods

Techniques used to evaluate costs and benefits include remote sensing, soil survey, farm economic and production modelling, GIS and participatory farmer discussions. Information on the impact of CSG infrastructure on machinery operations has been derived from tractor GPS logs (Fig. 1b). From these, changes in machinery efficiency (Ramin and Wan Ishak, 2012) have been calculated for well pads inserted into different locations within fields. Imagery from the ZY-3 Chinese Earth Observation Satellite has been used to study patterns in Normalised Difference Vegetation Index (NDVI) which can indicate impacts on crop and pasture production due to compaction or site disturbance (Fig. 1c).
Aerial photogrammetry was used to produce a digital elevation model at 20 cm pixel size for a 1200 km^2 focal region. From this, a detailed map of water flows around CSG infrastructure has been developed and tested using ground-based measurements (Fig. 1d, Poulton *et al*, 2015). Simulation of farm production and cash flow are being undertaken with a farming systems simulation model (Holzworth *et al*, 2014). These simulations include reduced production from reduced cropping area or soil damage from CSG development. Simulations are also used to evaluate possible farm improvements that could be funded through increased income from CSG compensation payments. These data sets have been studied in consultation with landholders to understand areas of concern for farmers involving impacts of surface water flows and erosion, impacts on farm operations and safety, production losses and soil damage.

3 Discussion

Several lessons have risen from the various monitoring efforts and subsequent discussions with farmers. Many of these involve appropriate ways to position or re-use certain parts of the CSG infrastructure to minimise costs and grasp opportunities. The detail of these cannot be considered in this brief communication. However, some of the broader lessons can be summarised as follows:

1. Farmers need to develop a farm or business plan prior to CSG development to drive the CSG farm re- design processes.
2. Farmers need to be aware of their own values (e.g. financial, family, environmental, agronomic, place identity) and preferences and understand that the CSG company negotiators may not understand or share these values. They will need to clearly explain these during negotiations.
3. Individual farmers vary greatly in their values, goals and farm design preferences and so no single design approach will be suitable. Every farm will need to be designed individually.
4. Spatial information such as those used in this study is useful for informing farmer's designs, but also in communicating their ideas or concerns to CSG companies. For example, issues of surface water flows can be hard to demonstrate apart from during certain weather events. Maps of water flow or crop yields help communication with CSG staff who may have little experience with a particular farm.
5. Spatial data gathered in this study suggest that negotiations between farmers and CSG companies to date seem to

have been successful in positioning CSG infrastructure effectively within farms. Most infrastructure has been positioned in areas of reduced production and with reduced impact on farm operations. This shows that sufficient flexibility exists in CSG design negotiations to place infrastructure in ways that it minimises impacts on agriculture.

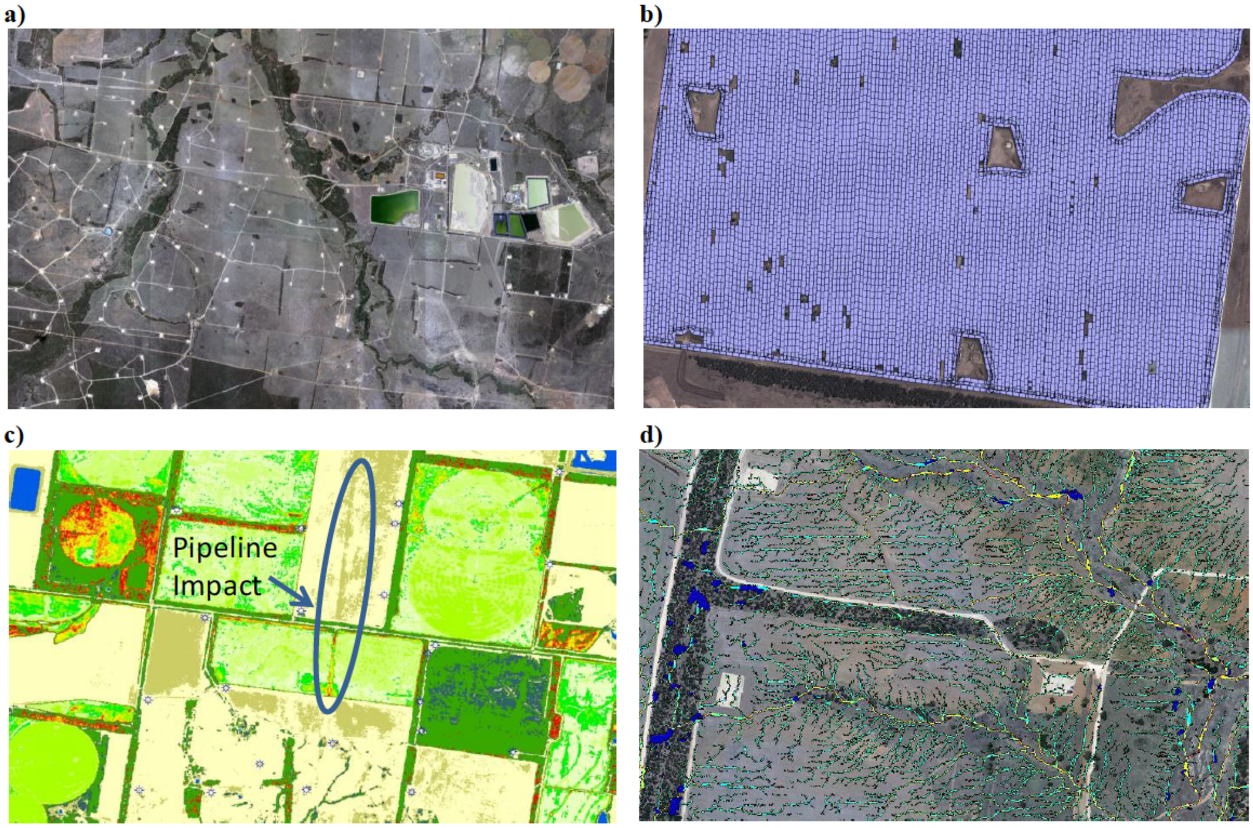

Fig. 1. (a) Aerial image of a CSG development area. (b) Map of tractor movements around CSG well pads within a field (c) Map of NDVI for fields in a CSG development area showing pipeline impacts on yield. (d) Modelled accumulated water flow paths indicating low (cyan) to medium (yellow) to high (red) accumulation overlaid on aerial image.

4 Conclusions

These techniques and the design principles derived from these studies will be of use in other agricultural landscapes which include a gas extraction industry. Future research will focus on 1) integrating these lessons into a simple series of design principles that can be used by landholders and 2) identifying areas within the CSG tenements where improved cash flow from CSG payments could be used to assist in farm improvement.

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Interview-based structuring of operational decision-making by farmers

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1 Introduction

Farm management is a dynamic decision problem that requires a series of more or less independent decisions by the farmer about how to operate the farm system to achieve his goals. Such operational decision-making is difficult because it is highly dependent on uncertain factors such as weather, crop and disease development, prices, etc. Other sources of difficulty are the presence of time gaps between decisions and their resulting impacts, as well as the multiple side effects of each decision (e.g., preventing or delaying the execution of other decisions). Unlike in the manufacturing industries, strict production planning in agriculture is therefore not really possible. Operational Decisions (OD) daily decisions about which actions to carry out next and which modifications should be made to activities intended in the future are thus essential in farm management. It is our belief that by analyzing these decisions, we can better understand how farmers perceive operational management and cope with uncertainty, which explains, to a large extent, why performances differ among farmers.

More than only understanding farmer's reasons for a given choice, we must understand the mental process that leads to this choice, i.e., the decision-making process. Indeed, performance heterogeneity is observed among farmers even if farm systems are similar. This variability can be explained by differences in the mental process leading to the decision. Global knowledge of such a mental process is not available although many structuring features such as beliefs, goals, plans and preferences have long been identified by philosophers and artificial intelligence researchers (Pollock 2006) who have investigated decision-making foundations.

An initial fundamental step that is reported here concerns the use of interviews with farmers about their decision-making practices. The analysis of these interviews makes it possible to highlight the aspects that spontaneously arise from the farmer's discourse and those that are ignored or that remain implicit. On the basis of these outcomes, we plan to develop a refined interview-based survey to explore the decision behaviors of a larger panel of farmers and to focus on the aspects that were missing in the first phase.

2 Materials and Methods

Our analysis is based on a systematic examination of interviews to identify the decision-making features that appear determinant for the farmers, which information sources are looked at, and how they are used in the decision process. We conducted six interviews of grain crop producers located in the vicinity of Toulouse (in southwestern France). Each interview lasted from 2 to 5 hours and was recorded and transcribed. Content analysis, using Nvivo software, enabled us to systematically identify main themes and topics that emerged and to make a frequency analysis of the keywords used.

The interviews are divided into three parts. A comprehensive part based on semi-directive interviews allows farmers to talk about their farm, their activities and management decisions, their sources of information, their constraints, and the risks and difficulties experienced in their work. Then, in a more directive part, farmers have to more precisely describe the nature and timing of their farming practices thanks to calendar-based positioning of management operations. The final part aims at investigating the role of events (e.g., incidents) in the dynamics of the decision process.

3 Results – Discussion

The interviews confirmed that regardless of the farm and its location, plan-based management, and actual situation monitoring are essential practices in operating a farm business (Martin-Clouaire and Rellier 2009). Farmers need to adopt plans for the future in order to allow their reasoning about what to do to extend beyond the present moment and to coordinate their activities with each other and with those of other farmers in the case, for example, of equipment sharing. Planning enables rough scheduling of the necessary time, materials and labor through anticipation of crop needs and threats.

The interviews also showed the need for flexibility and adaptability of the plans. Farmers form and commit to partial plans that roughly specify the activities that they intend to perform. Flexibility takes different forms. It may lies in the temporality of the activities declared in the plan. At most, timing is defined with windows of earliest starting time and latest finishing time (e.g., for sowing activities). The timing of activities may also be limited by temporal relationships of precedence (weeding before fertilization) or parallelism of execution. Plans may be logically complex; e.g., they can include conditions that provide them with additional flexibility. For instance, a farmer explained that he usually sows rapeseed the first week of September with a given technique, but if weather conditions are bad, he switches to an alternative technique or delays sowing by two weeks. In this illustration, the flexibility also concerns the resources and means involved in the realization of the intended sowing activity and the fields potentially targeted by the activity. Tuning the execution of an activity to the actual situation is a common practice. Indeed, plans are partial because they concern intended activities in an uncertain future. Thus making a detailed plan at the beginning of the sowing season would simply be impossible. Having a partial plan makes it necessary to expand and revise it continuously. Expansion is needed to determine the executable actions that are appropriate in the current situation. Then, revision is triggered by events recognized as having an importance for management.

A structuring feature of the decision-making process thus concerns the identification and processing of these events. An event can either be a significant change in state (e.g., beginning of a new crop stage) or the occurrence of an incident that is external to the farm system (e.g., climatic event) but that affects it. Events are major drivers of change of intentions, including changes that result in actions to be executed immediately. Events constitute hazards as well as opportunities. On the basis of the interviews, we identified six types of events primarily defined with respect to: calendar or management landmarks (e.g., completion of winter wheat sowing), weather (e.g., wind), pest outbreak, crop development (e.g., harvesting stage), resource unavailability (e.g., the farmer is ill, equipment failure, etc.) and legislation (e.g., irrigation ban). For example, in the case of nitrogen fertilization activity that requires repeated applications of fertilizer separated by a time interval, if the first application has been delayed for some reason (e.g., bad weather), then the subsequent ones must also be delayed in the plan. These events are observed by farmers or reported to them (e.g., by an adviser) and can be more or less anticipated (e.g., with weather forecasts).

The farmers make operational decisions on the basis of their beliefs about both the current and predicted situations. These beliefs can result from direct observations or from indicators formed by making inferences from one or several observations. More generally, farmers process information given to them (e.g., by advisers), acquired through monitoring activities or available in their memory in order to evaluate the ongoing and upcoming situations. Most farmers also include this observation (or monitoring) of activities in their plans. The farmer's decision-making may consist in selecting the next action to carry out or in formulating or revising a plan and committing to it on the basis of the situation perceived. But the evaluation is highly subjective and uncertain; it partly relies on uncertain information but also depends on farmers' expertise, constraints, goals and preferences. Then, action selection requires resolving conflicts among competing goals, identifying alternative actions that contribute to the goals and that are coherent with the plan involved. At this stage, we need a better understanding of the role of farmers' characteristics (e.g., expertise, preferences, goals) in operational decision making.

4 Conclusions

By analyzing empirical data from qualitative surveys, we obtained a preliminary view of how grain crop farmers deal with operational decision-making. Using this information, we identified areas that require further investigation through subsequent interviews that we plan to carry out. Expertise role, goal reasoning and preference characterization and manipulation in an uncertain context are our next investigation priorities.

The motivational role of goals has long been recognized as a driver of decision-making behavior. Surprisingly, goals often remain implicit in the farmer's discourse, even if the farmer's problem is to frame future actions so as to achieve some desirable outcomes within a relatively short term. Actually, the justifications provided by the farmers indirectly point to goals that can be organizational (avoiding labor bottlenecks later on, having winter crop tillage activities completed by a predetermined date), agronomical (having pests under control), or circumstantial (saving money by having inputs be replenished before a predetermined date). The dynamics of creation and revision of goals is still to be examined.

Farmers often have more tasks to perform than they can do immediately. They have multiple information to consider, numerous goals and wishes to take into consideration, and several ways to move towards the goals. The various goals and wishes may be in conflict with each other (e.g., relaxing and meeting deadlines). The conflict may be between the short-term and long-term consequences that have opposite values in terms of their attractiveness, or because some goals are highly desirable but hardly feasible. Therefore, farmers have to somehow prioritize, which means mobilizing dedicated knowledge about preferences of various types. Such knowledge and the mental processes that can process preferences while taking matters of risks and urgency into account are poorly understood at this stage.

Ultimately, understanding how the various decision features are processed to yield operational decisions will require the exploration of the farmer's bounded rationality (Daydé *et al.* 2014) that accounts for limitations in the farmer's information and reasoning powers. The role of farmers' expertise in this context also needs further investigation.

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Strategies to manage crop planning complexity in very diversified direct selling farming systems: the example of organic market gardeners

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1 Introduction

Crop diversification and direct selling can be efficient ways to improve social, economic and environmental benefits of farming systems (Feenstra, 1997; Ponisio *et al.,* 2014). However, they can increase the complexity of the farming system management and especially the cropping plan (Aubry *et al*., 2011, Lanciano *et al*., 2010) which can be defined as the acreage devoted to each crop and the spatial and temporal allocation of crops within the farming land along the production season (Dury *et al*., 2011). Small size organic market gardens often combine a high level of diversification and direct selling (Navarette, 2009). The aim of our work was to study the strategies they developed to deal with the complexity of crop planning.

2 Materials and Methods

We carried out a multiple-case study (Yin, 2009) on 12 organic market gardens in northern France producing from 30 to 80 plant species on an acreage going from 0,5 to 2 ha. These farms sold their vegetables directly to consumers through different commercial forms: vegetables baskets paid beforehand with a yearly subscription according to the principles of Community Supported Agriculture (10 farms), vegetables baskets retailed without any subscription (6 farms), vegetables retailed piece by piece on-farm or in producers markets or shops (8 farms). 8 farms combined 2 or 3 of these channels. The common characteristic of all these selling channels is that the market gardeners have to provide from 5 to 10 vegetables species every week all along the commercial season which lasts from 7 to 12 months depending on the farm. We carried out semi-directive interviews with market gardeners about their objectives, situations and practices in order to get a first global and systemic view of the farm and then we focused on the strategies implemented by farmers to manage crop planning complexity. We realized an inductive qualitative analysis of the rich collected material (Miles & Huberman, 1984).

3 Results – Discussion

Among the 12 market gardens, crop planning decision making is a systemic challenge because it has to satisfy simultaneously 3 main objectives: (i) matching selling requirements, (ii) limiting the complexity of technical intervention, (iii) respecting rotation criteria to maintain health and fertility of plants and soils. These objectives are related to commercial, technical and ecological aspects of the farming system. To manage the complexity of this systemic challenge, market gardeners have implemented organizational strategies at the same 3 levels of their system.
Strategy A is to adapt their selling methods. It relies on the fact that in direct selling channels the producer controls the way he commercializes his vegetables. Selling vegetables baskets requires to produce every week a precise quantity of vegetables in right proportions to satisfy the customer whereas in retail selling systems the quantity of vegetables available every week and their proportion has not to be as precise. Some market gardeners choose to sell only through retail selling systems to be more flexible. Other use a retail selling system as a commercial buffer in combination to a vegetables baskets systems. In this case they can be less precise about proportions and quantities of vegetables sold in baskets because excess vegetables can be sold through the retail selling system. Some farmers use the heterogeneity of consumer's tastes to get more flexibility in planning species proportions in vegetables baskets systems. Instead of selling all baskets with the same proportion of vegetables, they can make baskets with different vegetables and different proportions and ask consumers to choose between them. They also can promote exchanges of vegetables between consumers if some of them wish a bigger or a smaller proportion of some vegetables.
Strategy B is to differentiate planning requirements in relation to the commercial function of the crops. Some crops are considered as "key vegetables" because they are strongly expected by consumers at different times of the year. The sowing or planting of these vegetables is therefore planned before the production season with safety margins. On the other hand, some vegetables may be not specifically expected by consumers but bring diversity to the commercial offer. These "complementary" vegetables can be planned with less safety margins and some of them may be planned not before but along the production season depending on opportunities. It is especially the case of short cycle species vegetables which can be sown/planted when there is an available surface area between two long cycle vegetables. When required these short cycle vegetables can also be sown/planted in multicropping with long cycle vegetables. The proportion and nature of vegetables considered as "key" or as "complementary" vary among farmers and have an

impact of the level of flexibility they can get from this strategy.
Strategy C is to aggregate crops in similar management groups. It involves the determination of aggregation criteria to create groups of species which will be grown in the same space. Instead of thinking the spatial allocation of every species, the farmer has only to think the spatial allocation of a few groups. In the studied farms, the market gardeners use various grouping criteria: botanical family, cropping season (spring, summer, autumn or winter crops), irrigation or fertility needs (high demanding, medium demanding and low demanding). These criteria make both spatial allocation of crops and technical management easier.
Strategy D is to differentiate the importance of phytosanitary criteria in rotations according to species and other ecological technics at the farm level. It consists in being strict in the rotation criteria for some crops considered as "sensitive" for sanitary reasons and to be more flexible or even not to use any rotation criteria for other crops considered as "less sensitive". The market gardeners can release the pressure on rotation criteria because they implement a lot of other ecological technics at the farm level to promote the global immune function of the agroecosystem: high diversity of species and varieties on a small farm, use of resistant and locally adapted varieties, growing green manures with sanitary properties, multicropping, creation and management of ecological infrastructures such as ponds, hedgerows, woodlands, grass stripes, agroforestry. The nature and proportion of plants considered as "sensitive" or "less sensitive" vary among farmers and have an impact of the level of flexibility they can get from this strategy.
These 4 organizational strategies are not implemented and combined the same way among the farms (Table 1) but have been mentioned by farmers as allowing them to reduce the complexity of crop planning.

Table 1. Combination of crop planning strategies among the 12 studied farms (X means "presence")

		Farm											
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Strategy	**A**	X			X	X			X	X	X	X	X
	B	X	X			X			X	X			
	C	X	X	X	X	X	X	X	X	X	X	X	X
	D	X	X	X				X	X	X		X	X

In this study we have not associated these strategies with the economic, social and environmental performances of the farms. A multi-criteria assessment and more interviews could be carried out in order to determine in what extent certain strategies or combinations of strategies impact the performances of the farming system.

4 Conclusions

Innovative strategies have been developed on very diversified direct selling market gardens to manage the complexity of crop planning. These strategies can be combined and are implemented at different levels of the farming system: commercial, technical and ecological. They are mainly based on the opportunity farmers have to control their commercial methods in direct selling systems and on the sanitary advantage that a high level of plants diversity can bring to the farming system when associated with other ecological technics. This multiple-case study show that crop planning complexity has to be addressed as a systemic level and describe 4 strategies developed in the specific field of organic market gardening. Further investigation would be required in order to see in what extent these strategies could inspire the design of other types of farming systems such as cereal cropping or breeding farms.

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Labour Productivity Analysis in Mixed Family Farm Systems to support a Co-Innovation Process

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1 Introduction

Viability of family farming is strongly linked to labour productivity and opportunity costs of labour in the wider economy. Increasing labour productivity is as important as increasing land productivity in order to ensure the quality of life of family farmers (De Schutter , 2011). Labour productivity of most Uruguayan family farm systems is lower than could be achieved with their current resource availability. In some cases, it is even lower than the opportunity cost of labour, estimated as the cost of temporary hired labour in the region. A wide variability in labour productivity can be observed between farms with similar resource endowment. Quantifying and understanding the main causes of the gap between current and attainable labour productivity, and its variability among family farms is crucial to support the development of more sustainable family farm systems.
The **objective** of this work is to develop a method to study labour productivity in the framework of a co-innovation project. The *specific objective* is to identify and to analyze the main causes of low labour productivity in family farms, in order to propose strategies to increase it. This is an on-going project.

2 Materials and Methods

The co-innovation project involves a systemic process of characterization, diagnosis, redesign, implementation and evaluation (Dogliotti *et al*., 2014), of fourteen case studies selected to represent the variability on farm resource endowment present in a specific region in Uruguay. The method proposed to study labour productivity is part of the characterization and diagnosis phases of the co-innovation process and it integrates different hierarchical levels of analysis: the whole farm system, the production activities and the operational tasks. Data on labour allocation at each of these levels was collected by semi –structured interviews to farmers and their families, complemented with direct observations during specific moments of the production process. Based on this data plus the rest of the farm data collected during characterization, we built a 'problem tree' for each farm, explaining the main causes of actual labour productivity. All the farms studied combined vegetables and livestock production. During the interviews we identified the type of work (routine or seasonal) and the key questions asked to understand the organization of the work were when?, how much time?, who does the work? and in which way the task or activity is done?

3 Results & Discussion

Low labour productivity and high workload are common problems among family farmers in south Uruguay. We found that nine of the fourteen farms studied had in 2013-14 a labour productivity equal or lower than the opportunity cost of labour (4 U$S hour^{-1}), and the maximum estimated was 8 U$S hour^{-1}. We selected farm number 3, with a labour productivity of 6.4 U$S hour^{-1}, to illustrate here the method proposed, summarized in three steps.
First step: characterization of the farming system. Farm size is 10 ha with 5.7 ha grown with field vegetables (0.5 ha irrigated), 1 ha of alfalfa, and the rest is used for cattle grazing. The cattle load is 0.8UG[1]ha^{-1}. Family is composed by a middle age couple (44 and 48 years) and their two daughters (17 and 20 years) who study and work occasionally at the farm. The level of mechanization is medium (tractor, crop sprayer and basic tools). The family contributed 5000 work hours per year and they hired 650 hours of temporary labour. Most of the labour was allocated to onion and sweet potato crops followed by sweet maize and melon. We found that 28% of available labour was allocated to general activities such as maintenance of infrastructure, repairs, buying inputs, etc. including time allocated to a carrot crop that was lost before harvest.
Second step: the 'labour productivity tree'. Based on the data collected during characterization phase, we calculated the technical coefficients for each crop and animal production activity in the farm. We calculated indicators for the different hierarchical levels of the system and drew the problem tree (Fig 1).
Labour productivity in vegetable crops (8.9 U$S hour^{-1}; 67% of available labour) was higher than in cattle (5.1 U$S hour^{-1}; 5% of available labour). The prices obtained for the products sold were similar to other farmers in the region, and the quality of the products was considered good, so this 'branch' of the tree was not developed. The yields of onion and sweet potato were 39 and 15% lower than top yields achieved by farmers in the region with similar resource

[1] *Cattle Unit: 1 UG equivalent to 1 cow of 400 kg live-weight.*

endowment. Low yields were explained by deteriorated soil quality, timing of operations, low plant density and weed incidence. Low labour productivity in vegetable production was not only due to low yields but also was explained by excessive hours spent in some tasks.

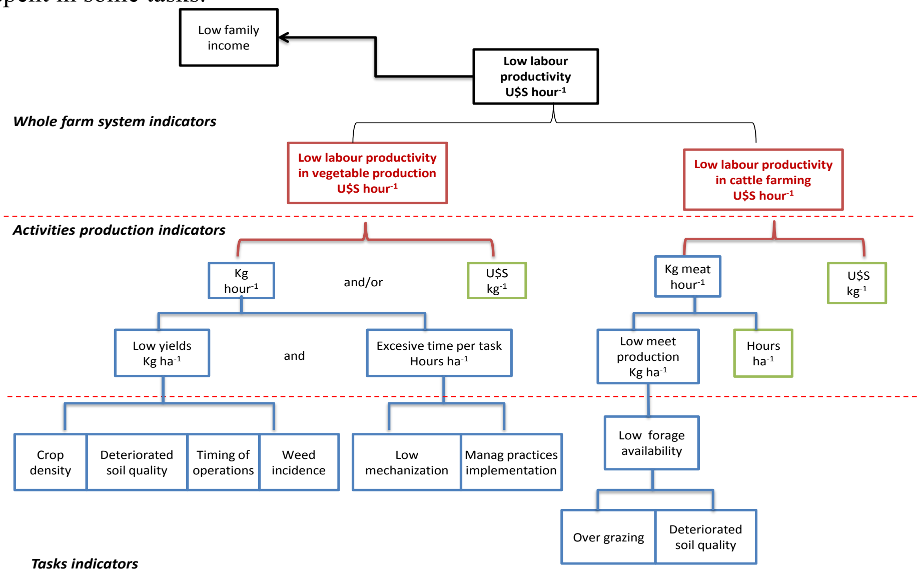

Fig. 1. Labour problem tree of farm number 3

We compared the time spent in this farm to perform the main tasks for each crop with data provided by the extension service of the MGAP[2]. Taking all crops together, the results showed that the time spent in direct operational tasks on crops was 33% higher in this farm. Classification and packing of products, and the sweet potato harvest were the most time consuming tasks at this farm and they were both done with low efficiency. Low labour productivity in cattle was explained by very low production of meat per hectare (45 kg live-weight ha^{-1}), due to low forage availability. The farmer sold part of his alfalfa bales, and over-grazing combined with deteriorated soil quality explained low forage production. The incidence of meat production in overall labour productivity was very low because time allocated to this activity was minimal.

Step 3: quantifying the impact of improving labour productivity. We estimated which could be the attainable labour productivity values in two different scenarios. The first scenario supposed increasing yields by adjustment of some crop practices (timing of operations, plant density and weed control) and by reducing 10% the vegetable crop area improving crop-pasture rotation. For the second scenario we added to the first scenario the effect of reducing 620 hours of labour through mechanization of classification and packing of products, and by improving sweet potato harvest practices (Table 1). The impact of increasing crops yields was much higher (43%) than reducing labour (14%). The labour productivity of cattle farming increased more than vegetable production (84 and 36% respectively) because the yield gap was significantly higher in the cattle production (Scenario 1, Table1). It seems feasible to increase family income and labour productivity, in a first step by increasing yields adjusting crop management and without investments. In a second step workload could be reduced and labor productivity further improved by investing in post-harvest machinery and harvest tools.

Table 1. Labour productivity indicators

	Actual	Scenario 1	Scenario 2
Family income (U$S $year^{-1}$)	31752	45277	45277
Labour productivity (U$S $hour^{-1}$)	6.4	9.1	10.3
Labour productivity _vegetables (U$S $hour^{-1}$)	8.97	12.2	14.8
Labour productivity_cattle (U$S $hour^{-1}$)	5.1	9.4	9.4

4 Conclusions

The method proposed to study labour productivity at farm level was useful to aid the re-design step of the co-innovation process, because it allowed to identify the key factors to enhance labour productivity.

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Evaluation of sustainability of peasant farming systems in VallesCalchaquíes (NW of Argentina)

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1 Introduction

Peasant faming systems of VallesCalchaquíes have different problems: low productivity, limited water availability for production, environmental degradation, scarce infrastructure and limited bargaining possibilities. They mainly produce vegetables, fruits plants, maize, alfafa and goat milk for cheese production. They also produce: sheep, cows, pigs and chickens. In general, all the family relies on the farm and off-farm work for living. A question related to the sustainability of these farming systems strongly arises.

The concept of sustainable development was originally proposed by the World Commission on Environment and Development in 1987. That report support the idea that a sustainable development is a development that satisfies current generation requirement without affecting future generations needs and it includes the responsibility of preserving the environment and the consideration of a social dimension (WCED, 1987; Cáceres, 2004). A broad conception of sustainability is adopted in this study; sustainability implies an interdisciplinary view which includes economics, social-cultural and environmental aspects which help to a better understanding of the functioning of a farming system; they are a useful tool for designing policies and strategies for action in territories. To evaluate sustainability the productive unit and the family performance are included as a whole system. The objective of this work is to select and evaluate appropriate sustainability indicators to evaluate the sustainability of peasant farming systems of the VallesCalchaquíes. This knowledge will contribute to design research to develop practices to improve farming systems sustainability and to guide environmental and productive policies according to the situation of the territory.

2 Materials and Methods

This research focuses on farmers that live in a place called “La Aguadita”, located in Molinos department (25º 08´10” and 25º 58´ 20” Southern latitude and 66º 01´30” and 66º 58´10” Western longitude), in Salta province in the Northwest of Argentina. Molinos department has many mountains of 2000 to 5000 m and limited fertile area (Department Geography of Salta). The data for this study come from a questionnaire made to 15 farmers carried out in 2014 (INTA-SAF). Variables show information about characteristics of the family group, the area under production, production activities, labor, family income, social nets and problems of the farming system.

The use of specific indicators for each of the dimensions (economics, social-cultural and environmental) to measure sustainability is considered as a useful tool to show the functioning of a production system. The indicators synthesize, condense, quantify and communicate complex and complicated information (Singh *et al.,* 2009). Indicators should be specific variables to reflect the situation of peasants producing for own consumption and selling. Different indicators are selected for each dimension. The indicators are expressed in different units depending on the variable to be quantified (economic, social-cultural, and environmental). A way to skip the problem of different expression of the units is to build a scale with 4 or 5 values (Sarandon & Flores, 2009). In this research we use 0 for the less sustainable category and 3 the most sustainable. Indicators were selected based on the availability of data from the questionnaire.

In Table 1 the selected indicators for each dimensions and the meaning of each category are presented.

3 Discussion

This research was the first step to explore the sustainability of peasant farming systems of the Northwest of Argentina. The use of a simple scale from 0 less sustainable to 3 or 4 more sustainable allows a direct quantification of the indicators and the comparison among different farming systems of different regions (Sarandon & Flores, 2009).

A broad idea of sustainability was adopted in this research. A limited number of indicators were selected based on available data and they were quantified following a scale. To get the value of an indicator the average of the questionnaire were used. A better evaluation requires to evaluate each indicator for each observation and to make a ranking of the most sustainable farming system to the worst. Moreover, in this study all the indicators were given the same weight; however the relative importance of some of them can be defined. Peasants' opinion can be included in giving values of indicators that should contribute to their sustainability. Still, there is place for getting an overall evaluation of sustainability which means to combine all the indicators in a sustainability function (Van Calker, 2006).

Table 1. Indicators for each dimension, scale and quantification

Dimension	**Indicator**	**Scale meaning**	**Quantification of the indicator**
Socio-cultural	Familiar continuity	0 = high age farmer without successor 2 = high age farmer with successor 1 = medium age farmer without successor3 = medium age farmer with successor	3
	Formal education	0 = primary school incomplete2= secondary incomplete 1= primary school complete3= secondary complete or higher incomplete	0
	Ownership of the land	0 = not owner2= owner in process of legal possession 1= owner without legal possession3= own with legal possession	3
Economic	Income diversification(1)	0 = one source of income2= three sources of income 1= two sources of income3= more than three sources of income	2
	Monthly total family income (2)	0 = up to 1000 2= 1501-2000 1= 1001-15003= more than 2000	1
	Self consumption diversification	0 = two products2= four products 1= three products3= more than four products	2
Environmental	Natural pastures management	0 = grazing all the year without supplementation 1 = grazing all the year with supplementation 2 = grazing part of the year without supplementation 3= grazing part of the year with supplementation	0

(1) sources of income include income from: selling products, working outside, retirement, subsidies and remittance
(2) per capita. Argentinian pesos

4 Conclusions

The methodology used in this research allows seeing the weakest and strongest points of the farming systems with respect to different dimensions of sustainability. A limited number of indicators for social-cultural, economic and environmental dimensions were included. Social-cultural dimension indicates a good performance for family continuity and ownership of the land; however an improvement of education is needed. Farmers have in average three sources of income, improving the sustainability of the system. Total income per capita is low, so there is place for improving quality of life in this aspect. Policies may be oriented to increase subsidies or credits to improve the production of the system. The management of natural pastures among farmers is poor, and probably it shows some kind of soil degradation. More and better indicators for environmental dimension are required; any other suitable one arises from the available questionnaire. In general terms, it seems that farmers systems have a better performance in the social-cultural dimension than the other two. There is still place to improve research in all the dimensions.

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Development of a trajectory to support sustainable choices at farm level

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1 Introduction

Agriculture is more and more faced with extreme challenges such as climate change, scarcity of natural resources and specific demands from society. Both on farm and agricultural sector level, stakeholders express their need to evolve towards more sustainable farming practices to guarantee their future. To face these challenges many initiatives to identify, measure, evaluate and communicate sustainable development arise. The use of sustainability assessments is seen as an important instrument to move towards sustainability (Pope *et al*., 2004). Many definitions of sustainability assessment exist. It can be seen as "a range of processes that all have as their broad aim the integration of sustainability concepts into decision-making" (Pope, 2006). Sustainability assessment is "a process by which the implications of an initiative on sustainability are evaluated" (Pope *et al*., 2004). The initiative can range from an existing policy, a plan, programme, project or a current practice or activity. Hugé *et al*. (2011) describe it as a process that aims at operationalising sustainable development as a guide for decision-making by identifying the future consequences of current and planned actions.
Literature on sustainability assessment and sustainability assessment tools to support decision making is still rapidly growing (Gasparatos & Scolobig, 2012; Marchand *et al*., 2014). However, despite this growing interest in sustainability assessments and the existence of numerous assessment tools, opinions differ on how to define, plan and measure the progress towards sustainability (Gasparatos & Scolobig, 2012). There is a lack in literature regarding tool choice, use of tools and use of specific methodologies in assessments (de Ridder *et al*., 2007). Not only the selection of a tool, but also its implementation plays a major role in the success of a sustainability assessment. Previous research on the implementation of assessment tools which support the decision making process of a farmer have led to multiple insights (Coteur *et al*. 2014; Marchand *et al*. 2014; Triste *et al*. 2014). Ownership, monitoring results over time, the attitude of the tool-users and the organization of discussion groups need to be taken into account when implementing an assessment tool. Nevertheless, insights on how various assessment tools can be used in a complementary way to support the needs of a farmer are lacking. We developed a two-dimensional assessment framework to support sustainable farm choices. The framework allows the farmer to follow a trajectory towards more sustainable farming making use of a set of complementary tools.

2 Materials and Methods

To develop the assessment framework, we have based our analysis on insights from empirical research and lessons learned from two other cases in which we were involved. This enabled us to identify what is important when implementing an assessment and which needs stakeholders have concerning the assessment of a farm.
First, Boerenbond, the biggest farmers' organisation in Flanders, requested the authors of this paper to design a sustainability assessment framework applicable to different agricultural sectors. This demand enabled us to set-up a participatory research and clearly grasp the needs of the stakeholders concerning the sustainability assessment and its implementation. In our research, we define the participatory approach as the collection and analysis of information on sustainable development of farming practices involving scientists, advisors, farmers and experts in all development steps of the assessment framework. The development steps included a context-specific assessment tool development phase, a reflection of this tool development phase (Coteur *et al*., 2014) and discussion meetings with experts, advisors, farmers and other stakeholders for the fruit production sector, the dairy sector, the meat production sector and the greenhouse horticulture sector. Concerns and needs were systematically written down in notes and reports during meetings. Second, we analysed lessons learned and reflections from two other cases in which the authors of this paper were involved. The first case is the development and implementation of the Monitoring Tool for Integrated Farm Sustainability (MOTIFS) (De Mey *et al*., 2011; Meul *et al*. 2011; Triste *et al*., 2014) and the second case is the Public Goods Tool (PGT) (Gerrard *et al*., 2011, Gerrard *et al*., 2012 ; Marchand *et al*. 2014).

3 Results – Discussion

The analysis resulted in five different needs regarding sustainability assessments. First, the sustainability assessment needs to be embedded in the surrounding context. Second, the framework should allow us to approach every agricultural sector differently. Third, communication about the sustainable development of an agricultural sector and their specific efforts needs to be possible. Fourth, the sustainability assessment framework needs to focus on the farmer and on the encouragement of sustainable practices on farm level. Fifth, the sustainability assessment framework needs to accommodate the goals of a farmer as every farmer should be able to set his own path during his decision process. There is a need for different types of tools as the function of a tool needs to reflect the goal of the farmer at a specific time. These five needs are incorporated in a two-dimensional assessment framework to support sustainable farm choices.

The first dimension of the framework describes five steps of the assessment. The first step involves the implementation and use of an assessment tool to gain insights on the sustainability of multiple farm aspects. After completing the assessment, the results are interpreted in a second step. To enhance the sustainable development of a farm, improvement strategies are developed based on the interpretation of the results. These improvement strategies will be implemented in a fourth step. The fifth and last step is the monitoring step. During this step the farm will be monitored over a longer period of time by for example completing the same assessment every year. In that manner a farmer can see if his farm is progressing towards a more sustainable farm system. The second dimension of our framework describes three levels of complexity of assessment tools. The first level contains basic tools, which consist of mainly sustainability measures a farm can implement. This is a very quick and easy way to assess a farm without the use of quantitative data. In level two both qualitative and quantitative data are used to assess a farm. Indicators used to measure sustainability can be simple or complex, but the data collection itself stays rather simple. In this level, the use of benchmarks allows us to compare farms within a specific agricultural sector. Level three consists of a more complex, time consuming and often more expensive data collection. To assess a farm at level three, expert judgment and/or specific monitoring are necessary.

Different combinations of an assessment phase and a specific level of a complexity form a farm specific trajectory. It is defined as a sequence of steps throughout the assessment framework. The steps a farmer chooses to follow have a different impact on the decision making process as different steps impose different insights in farm sustainability. The framework is flexible and each farmer can choose a specific trajectory within the framework.

4 Conclusions

The two-dimensional assessment framework enables us to support sustainable farm choices by fulfilling the needs of farmers and other stakeholders. It takes into account the general context in which each farmer operates, it can approach every agricultural sector differently, every farmer can choose its own path, communication about sustainable development is an option and different types of tools can reflect the goals of a farmer at a specific time. The flexibility of the framework allows a farmer to choose a farm specific trajectory which may change over time. Our future research will specify the farm specific trajectory for each combination of assessment phase and level of complexity.

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Evaluating the sustainability of urban agriculture projects

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1 Introduction

There is currently an important increase in urban agriculture (in and around the cities) in the North countries, including France and the Ile de France region (AC. Daniel, 2013). This development is greatly supported by Paris and by the Paris region policies (announcement of 33ha of productive agriculture on roof and walls in Paris for 2020 in the city council roadmap of September 2014, regional calls for projects in 2013 and 2014).
At the same time, the Agricultures Urbaines team has been organizing meetings for project holders in urban agriculture (UA) in the Paris region. The intra-urban projects involved in these meetings, projects either currently existing or in development, are very diversified and use different technical and economic models to take into account the constraints of an urban context. Among the reasons given for the necessity of developing UA are the services it provides to the city, such as biodiversity (Madre *et al.*, 2014), food and social links (Pourias, 2014), waste recycling (Grard, 2013), climate change mitigation… (Lin *et al.*, 2015). In this context, it seemed important to study these projects, the circumstances of their development and to evaluate more precisely the kind of services they render to the city. To this end, we have created a study grid for these innovating farming systems.

2 Materials and Methods

Study grid
To our knowledge, there is no published study grid describing such urban farming systems and systematically measuring the services they render. However, these services are somewhat similar to those measured when evaluating the sustainability of farming systems.
We studied different indicators grids for evaluating the sustainability of farming systems at the farm scale: IDEA (Zahm*et al.*, 2008), FADEAR (2013), IBEA (2013), Masc 2.0 (Craheix*et al.*, 2012). We took note in these grids of which points were the most pertinent for our study, and of which indicators could be measured on urban farming systems. We then chose those most adapted to our context when several indicators were equivalent between methods, and added some indicators specific to UA and market gardening (which is the main production of these systems) using expert advice.
The indicators can be grouped in 3 categories (Table 1).

Table 1. Indicators retained for the study of urban farms.

Registration in the territory	Labelling and traceability
	Implication in the local community
	Marketing and exchange system
	Autoconsumption
	Waste management and recycling
	Spatial organization
Economic and human resources	Working hours and workforce management
	Origin of the income (sales, subventions, services…)
Cultural system	Cropped and wild biodiversity
	Crop rotation
	Fertility management
	Diseases and pests management
	Irrigation
	Energy consumption

Urban farming systems
We identified farming systems already in place or beginning in 2015 in the Paris region to evaluate the pertinence of our grid. The project managers of 8 diversified projects agreed to participate in this study.
These are:
- Agripolis: aeroponic project of 9 towers beginning in 2015;
- Ferme du Bonheur: association farming 4.5ha since 1995 on wastelands with a mixed production (plants and livestock);
- Ferme du Moultou: farm of 600m² belonging to the Resto du Cœur association (food assistance) in production since 2013;

- Paysanurbain: association beginning in 2015 the production of micro-greens in a 50m² greenhouse, for a 500m² production in the long term, supported by the Cocagne network;
- PlanèteLilas: association farming 2.5ha for vegetables in a public park since 2007;
- Pullman hotel-restaurant: roof vegetable garden of 60m², productive since 2014 and managed by the Topager company;
- Veni Verdi: association farming nearly 400m² since 2014 in a Parisian college;
- V'île fertile: association farming 600m² since 2014 in a public park.

In order to applyour grid on these projects, a regular monitoring (every 2 weeks) for a year is planned. All indicators present in the grid will be measured and every farming techniques applied on the production plots noted. Regular exchanges will also enable us to understand the reasons for the choice of techniques used and perhaps identify innovating practices if some are used.

3 Results – Discussion

Conventions have been signed with each project and in order to facilitate the monitoring, notebooks on 3 themes have been distributed to the project managers or to the person(s) in charge of the farming. These notebooks are: an activity notebook to study the share of each activity (cropping, trainings, interviews…) in the working schedule and the revenue when there is one; a harvest notebook to evaluate the production; a cropping notebook to note the management practices and cropping system.

4 Conclusions

The monitoring will begin in April and will enable us to measure the indicators on these urban farms and to study the operational and strategic levels of decision in these cropping systems. This monitoring is also an advice opportunity for the project managers from our team.
This monitoring and the analysis of the data acquired will enable us to evaluate our grid and its pertinence for the study of UA projects as well as its adaptability to other urban contexts.
The data from this year of monitoring will also help us clarify, qualitatively and quantitatively, the potential of urban farming in the Paris region.

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Improve Nitrogen use efficiency in mixed crop-livestock system in North China Plain

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1 Introduction

North China Plain (NCP) is one of the most important productive agricultural areas in China. In recent years, the intensive farming systems, from high-yielding agriculture and animal breeding to the segregation of crop and animal production at smallholder farm scale have led to a serious imbalance of the main nutrients (Oenema *et al.*, 1998; Aarts *et al.*, 2000) and limited the sustainable development of integrated agriculture. Linking cropping and animal production systems is an important to improve the nutrient use efficiency and reduce the resource use, and also an approach to sustainable development of agriculture in NCP.

Mixed crop-livestock system can provide the approach to construct the nutrition cycling and improve the nutrition use efficiency, thereby to increase the productivity of the whole farm, and is probably the most benign agricultural production system from an environmental viewpoint because it is at least partially closed to external inputs except energy (Egbert *et al.*, 2004).

Nutrient budgets provide information about nutrient losses and nutrient use efficiency, and the information generated is readily communicable to farmers and policy makers. Nutrient budgets can also provide guidance to improving nutrient management (Oenema, 2006).

This study uses a framework for mixed crop-livestock system to evaluate nitrogen flows in a model farm in NCP at the farm-gate scale. The objective is to analyze N flows between crops and animals, and to evaluate the nitrogen use efficiency in crop and animal system, and to explore of better management means to improve N use efficiency.

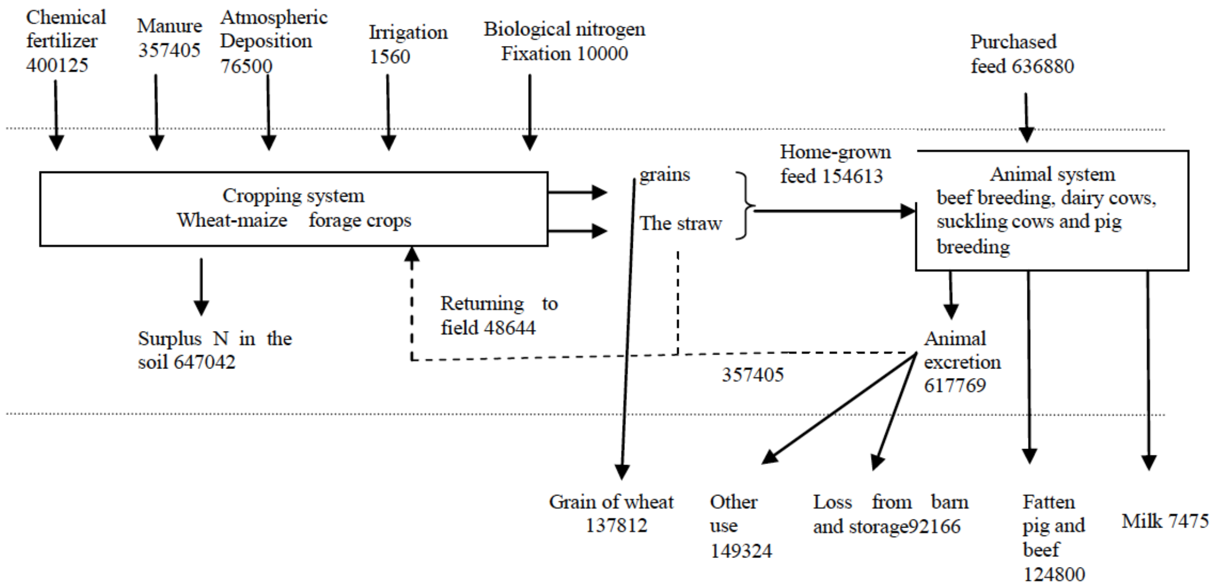
2 Materials and Data collection

We selected a farm (Jinglong Company) in Jingxian County (37°58′N, 115°99′E) of Hebei Province, which is located in the northwest NCP. This farm is considered representative of the region's large-scale farm. There are 1000 ha land in this farm, and the crop production is mainly winter wheat-summer maize double cropping system and a few forage crops. This farm is considered as the typical of the livestock farms in the region: beef breeding, dairy cows, suckling cows and pig breeding. In this farm, the grain of maize and the residues of maize were all feed to the animal feeding, the grain of wheat are sold on the local market. In addition to the forage produced in this farm, they also bought some maize grain and synthetic feed outside the farm. The excreta of the livestock was first collected to compost until apply to the farmland as organic fertilizer. In this study, we focus on the nitrogen flow and use efficiency between crop and livestock system on the whole farm.

All data on the inputs and outputs of the crop and livestock production system were obtained using verbal estimations based on crop and animal production in 2013 by the formal survey questionnaires from the farm manager and workers and field observations during June-November 2014. The information provided by the administrator and workers was considered reasonably accurate since they managed and worked on the farm with the current production mode for many years, and they provided clear information on each production step. The data included the N inputs and outputs of wheat and maize production and animal breeding. The N outputs from crop production included the harvested grain and maize staw.

3 Results and Discussion

In cropping system, the grain of wheat and maize is harvest, wheat is sold in the market and maize is as fodder, and the straw of maize is also harvested as forage for animals. In this system, the inputs of N in purchased fertilizer is 44.7% of the total input of N, and the N from animal manure is 40.0% of the total. The surplus N per unit area is 647.0kg/hm^2, and the surplus N is as high as 64.5% of the total inputs of N per year, indicating the environment impacts. In animal system, feed purchased are considered as the main source of N inputs, and this part of N accounts for 80.4% of the total N. The input of N from cropping system is only 17.0% of the total inputs of N in animal system. There are much manure due to the large quantity of pig, beef and dairy cow breeding, and this part of N amounts to 6.2×10^{5}kg/a, but the loss is 15.0% when storing in the barn and stack. 59.7% (3.6×10^{5}kg) N from manure flows to the cropping field and part of manure are exported as commercial fertilizer. In this system, we harvest the pork, beef and milk, the total N output in these products is only 18.0% of the total inputs. In crop-livestock the whole system, the N use efficiency is 21.0%.



(in cropping system, the unit is kg/hm^2 ; in animal system, the unit is kg/year)
Fig.1 The nitrogen flow in the crop-livestock systems at the farm level

4 Conclusion

It is concluded that the high surplus of N in cropping system are threatening the environment, and that is normal in the solo cropping system because of much fertilizer N. The N use efficiency is not satisfied in the whole crop-livestock system because of many young stocks and lacking of judicious feeding. So if the best ecotechnological means are combined in a balanced mixed farm system a multiple win situations will attain in terms of high food production capacity and environment quality.

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T3. Crop modeling and yield gap analysis for agricultural systems analysis and design

Chair: Sentold Asseng, University of Florida
Co-chair: Frank Ewert, Bonn University

ARE OUR MODELLING TOOLS READY TO COPE WITH AGRICULTURAL SYSTEMS EVOLUTION?

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1 Introduction

Agricultural systems are continuously changing to better cope with demands by society, environmental concerns, and changing climate. As a result, new concepts have been developed such as agroecology, ecosystem services, multifunctional agriculture, and climate smart agriculture. These new agricultural concepts require tools to help with the analysis, design and evaluation of new systems. However, modeling the evolution of farming systems is challenging both for computer scientists and agricultural modellers. This paper discusses how these evolutions require new modelling concepts, tools and approaches to help improving the analysis, design and evaluation of farming systems. The key question is how the modeling community can evolve our models from cropping system models to an integrated platform capable of handling a continuously changing farming system.

2 Scientific challenges

New biophysical knowledge
The first challenge is the new biophysical knowledge that has to be acquired in order to cope with change. This concerns different evolutions:

- Climate change: how to integrate new processes regarding the effects of extreme temperatures and responses to tropospheric ozone?
- Smart agriculture: how to better represent mitigation processes and related greenhouse gases emissions?
- Integrated pest management: how to integrate biotic regulation functioning? How to represent pest and pest natural enemies typically represented by different modelling approaches? How to predict potential spreading of alien pests and diseases facilitated by changing climatic conditions?

New practices
The second challenge concerns the development of new types of agricultural systems. Representing the decision process of these new agricultural systems and the impact of the agricultural operations on the biophysical system is therefore an important issue:

- How to represent new crop management as conservation agriculture, intercrops, agroforestry systems, mixed crops?
- How to represent interactions with the field environment that provides natural enemies such as hedges?

Integrating diverse production on the same farm
There is a general movement towards more diversified farming systems. More research focuses on integrating livestock and cropping systems together.

- How to represent an increasing diversity of production systems and related interactions?
- How to integrate flows of resources within the farm?
- How to share resources among competing activities?

Changes of scales
A big challenge in implementing new farming practices is to integrate the surrounding area of the farm either as a biological reservoir or in order to link it with the agri-food chain or to analyse complementarity within a territory.

- How can models deal with scales and change of scales for crop production, processing and management?

Working with farmers, resources managers andpolicy-makers
Agroecological farming systems target specific environmental and social conditions. There is a real need to work with farmers and to integrate specific local conditions:

- Do we have the tools to interact with stakeholders while developing and applying simulation models; how to create ad hoc models (library of modules, repositories of parameters)? Do we need web interfaces?
- How to integrate partial knowledge and stakeholder knowledge?
- How to represent simulation results in a meaningful way?
- How to run models in digitally-isolated rural areas?

Issues regarding data

Not only farming systems are changing, but also data acquisition. Data flow has increased dramatically during the last ten years due to the availability and use of remote data among others, and new options are made available even by smartphones.

- How to deal with large increases in the amount of data?
- How to integrate data from satellite images (from initialization to real-time process) in running processes?

3 Evolutions required in our modelling platforms

When checking the different scientific challenges, some general challenges for the modelling platforms emerge:

- Integrating new formalisms
- Integrating complex management options
- Integrating different production systems
- Integrating cross spatial and temporal scales
- Allowing on-site development or parametrisation
- Using real-time data

Some of these challenges will not require considerable modification of actual modeling platforms. For example, integrating new formalisms to take into account extreme temperature or CO2 impacts on crop production is not something that requires modifying the architecture of modeling platforms.

Some other challenges are more complicated such as representing complex management options and their impacts on the biophysical systems. Diversifying production systems or integrating pests is also complex as some modeling platforms are more or less dedicated to a specific type of agricultural production (e.g. cereals).

Other challenges may need much more substantial changes such as integrating hedges or landscape structures because this will require representing the system in a 2-D (or 3-D) dimension. The other important example is the use of the platform in a participatory manner and allowing for the integration of farmer's knowledge while developing the appropriate model.

We conclude that the main problem is not lack of scientific understanding in most cases, or lack of software architecture and approaches amenable to deploy the platforms and capabilities that are needed. What is lacking is more a concerted effort that brings together many disciplines, including software engineering, to create the conditions to make progress in this area.

We point to a common misunderstanding about the ease to develop and use of simulation tools. Resources are made available to produce specific analyses, but very rarely to develop new tools, infrastructure, and even for targeted data collection. In the same way as the demand for integrated simulation has grown, the complexity of tools required has increased as has the need for verifying quality and reproducibility of results. All of this cannot be performed without an articulated approach in which there are dedicated resources available to reconsider tools and modelling frameworks development.

Putting the coherence between crop processes and model inputs at the core of model development: a case study for water stress in intercropped systems

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1 Introduction

Modeling the dynamics of water stress is a recurrent issue for many crops, either for the quantification of yield gap due to water or for the management of Regulated Deficit Irrigation. The demand for such models increases especially for intercropped systems, but data required to build, parametrize and evaluate these models is limited. Moreover dealing with a diversity of agrosystems with one model highlights the questions of parametrization protocols and model uncertainty estimates. These aspects appear insufficiently handled by existing intercropped systems models.

2 A modeling approach putting the coherence between crop processes and model inputs

We put the biophysical processes conceptualization and parametrization at the core of the model development by following several principles. Firstly, each model input has a functional relevance and refer to a biophysical process. This coherence between crop processes and model inputs opens the possibility to use expert knowledge to estimate parameters in situations where data are lacking while knowledge on plants and soils are rich. Secondly, parameter calibration is excluded, this procedure being both particularly demanding in data and potentially delicate when evaluating the predictive quality of the model. Thirdly, several protocols specifying how to get each model input are defined. These protocols take into account different accuracy levels depending on data availability and allow to assess the associated uncertainty in model outputs (Roux *et al.*, 2013). Fourthly, some critical model concepts are integrative in order to cover a range various intercropped systems while trying to contain both the potential error resulting from using simplified hypotheses and the parametrization error coming from using more detailed descriptions of crop processes.

3 Illustration of the modeling approach through the BIS_Wat model development

We applied these principles to develop a new water balance model called BIS_Wat (Bispecific Intercropped Systems – Water balance model) built to simulate the dynamics of water stress experienced by each crop of an intercropped system. This new model extends to others types of bispecific agrosystems the WaLIS model (Celette *et al.*, 2010) developed for intercropped vineyard. BIS_Wat is a 2D bispecific tipping-bucket model working at a daily time step that is based on the Fraction of the Transpirable Soil Water (FTSW) concept (Sinclair & Ludlow, 1986) used as water stress indicator. The use of this generic concept allows to take into account both soil and crops characteristics for the transpiration regulation process. The soil is sampled into layers and columns with roots representation based on the effective rooting depth concept (Lacape *et al.*, 1998). Moreover, the model is based on three main hypotheses: i) homogeneity along the row and symmetry on either side of tree (useful to extrapolate results to field scale); ii) the four water fluxes which impact the water balance are soil evaporation, plants transpiration, surface runoff and deep percolation, implying that others water fluxes are neglected; iii) the evaporation and transpiration fluxes are directly driven by the intercepted radiation and by the soil water deficit experienced by plants, each plant of the association having its specific FTSW. Making explicit these assumptions allows to define a theoretical validity domain and ensure model transparency but evaluation on contrasted situations will lead us to define more precisely the model limits.
The use of integrative concepts allows to simulate both monospecific and bispecific systems for a wide range of crops in a Mediterranean climate. Consequently, it is theoretically possible to simulate with the model the water stress dynamics of contrasted agrosystems ranging from annual crop to intercropped orchards (Fig 1.). Two main concepts are at the core of the BIS_Wat parameterization: the Radiation Interception Efficiency (RIE) and the Total Transpirable Soil Water (TTSW) for each of the associated species. These model inputs have to be set or not, depending on which kind of scenario is modelled (Table 1.).

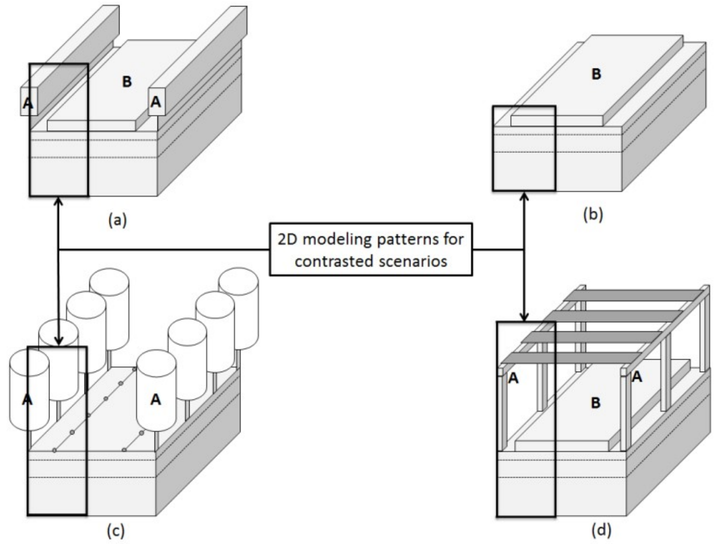

Fig. 1. Example of 4 contrasted scenarios where A is the dominant crop or structure and B is the dominated crop for the radiation competition: (a) intercropped vineyard (b) durum wheat (c) irrigated peach orchards and (d) food crops under photovoltaic panels. For each example, the 2D modeling pattern is highlighted.

Table 1. Illustration of BIS_Wat parametrization for 4 contrasted scenarios (0: model input not required; 1: model input required)

	Intercropped vineyard (a)	Durum wheat (b)	Irrigated peach orchards (c)	Food crops under photovoltaic panels (d)
TTSW (A)	1	0	1	0
TTSW (B)	1	1	0	1
RIE (A)	1	0	1	1
RIE (B)	1	1	0	1

4 Conclusion and future work

We have presented several modeling principles to build specific crop model and a new model of bispecific cropping systems named BIS-Wat, putting at the core of the model development the model inputs and their coherence with crop processes. A possible model use would to assess the level of water stress of each of the associated crop compared to a water stress target as defined for example in vineyards by (Pellegrino *et al.*, 2006). We have already verified that the model can be parametrized on various systems thanks to the choice of two central integrative inputs and made an evaluation on vineyards based on soil water content measurements. We are currently working on error level assessment on the four different systems described in Figure 1 (e.g. wheat, intercropped vineyard, salad and peach orchards) using quantitative metrics adapted to the diagnosis of water stress.

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How could yield gap assessment contribute to cropping system design?

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1 Assessing yield gaps at the cropping system level

Yield gap analyses have been used to estimate differences between yields achieved by farmers (Ya) and potential (Yp) or water-limited (Yw) potential yields. Yield gap estimates provide crucial information to evaluate scenarios of global food security given limited land suitable for crop production, the world population soon to exceed 9 billion, and the need to decrease the environmental footprint of agriculture (Van Ittersum *et al.*, 2013). A central issue is how to reduce the yield gap while maximizing efficiency in use of limited resources (e.g. water, nitrogen, phosphorus)(Van Noordwijk & Brussaard, 2014). Yield gap analysis assumes that Yp is achieved with optimum or recommended sowing dates, sowing density and cultivar, which determines growing period to maturity (Van Ittersum et al 2013). The focus of this approach is thus on single crops for a given cropping system. Cropping systems are defined by the temporal and spatial organization of crops. Cropping intensity can be below 1 (e.g. 0.5 in crop-fallow systems), 1 (i.e. a single crop per year) or greater than 1 in multiple cropping systems involving two or more crops per year that can be grown sequentially, or with some degree of simultaneity; the yield of multiple cropping systems thus needs to account for the time dimension, i.e. kg per ha per year (Evans 1993). Moreover, there is often a trade-off between cropping intensity and the yield of individual crops in the system (Table 1). Therefore, closing the cropping system yield gap may trade-off with closing the yield gaps of individual crops within the cropping system. Hence, developing a robust quantitative framework for evaluating biophysical performance of cropping systems involving new crops and/or new arrangements (in space and time) of crops would inform research on designing new systems (Gaba *et al.*, 2014) and help devising benchmarks to assess yield and efficiency gaps at the cropping system level.

Table 1. Publications documenting trade-offs between cropping intensity and yield of individual crops

CROPPING SYSTEM	CLIMATE	REFERENCES
A – Sequential(crops are not grown simultaneously)		
wheat-maize	temperate (Argentina, New-Zealand)	Monzon *et al.* 2007; Fletcher *et al.* 2011
wheat-soybean	temperate (USA)	Shapiro *et al.* 1992
maize-maize	semi-arid (Chile)	Meza *et al.* 2008
maize-soybean	temperate (Argentina)	Monzon *et al.* 2014
rice-rice-rice	tropical (Asia)	Evans 1993
B – Simulatneous (crops are, at least partly, grown simultaneously, e.g. intercropping)		
maize-barley	semi-arid (China, Gansu)	Li *et al.* 2011
maize-wheat	semi-arid (China, Gansu)	Li *et al.* 2011
maize-faba bean	semi-arid (China, Gansu)	Li *et al.* 2011
maize-pigeon pea	sub-humid (Brazil)	Balde *et al.* 2011
maize-soybean	temperate (Argentina)	Monzon *et al.* 2014
maize-cassava	tropical	Mutsaers *et al.* 1993
maize-potato	tropical	Wu *et al.* 2012
wheat-pea	temperate (France)	Bedoussac *et al.* 2010a,b
vegetable-vegetable	-	Yildirim and Guvenc 2005

2 How to focus on cropping system options more likely to be useful?

Despite the existence of cropping system level trade-offs as mentioned above, yield gap analyses have usually been performed on existing cropping systems under the assumption that farmers are good at allocating land, labor, and time (Van Ittersum *et al.*, 2013). But there may be barriers to adoption of crops not currently included in the cropping system due to lack of markets, infrastructure or information which could be overcome if a new crop or cropping system is well adapted to the environment in terms of yield and resource use efficiencies. However, the number of possible alternative crops and cropping systems for a given location is very large such that it is not feasible to evaluate all of them, even through simulation with crop models. Therefore we propose a framework, presented in Figure 1, to narrow the focus on those more likely to be useful. This framework is based on two principles: (i) new crops, if introduced, must have an existing market and be adapted to the target environment; (ii) the option of increased cropping intensity depends on the total growing period as constrained by photoperiod, temperature, light, and water. Enabling tools include reliable crop models to simulate the cropping system of interest (this will require further attention regarding intercropping) and a long-term weather database, or at least 3 years of observed weather data (Van Wart *et al.*, 2015) to quantify climate-related risks. Finally, the performance of the system is evaluated in terms of production and yield variability expressed per unit land and time (Egli 2011), as well as in appropriate metrics allowing comparisons of different crops, e.g. monetary value of the production, energy or protein content (Hochman *et al.*, 2014).At some point an economic assessment will also be required, but having estimates of yield and yield variation for the different cropping system options is essential to such an analysis.

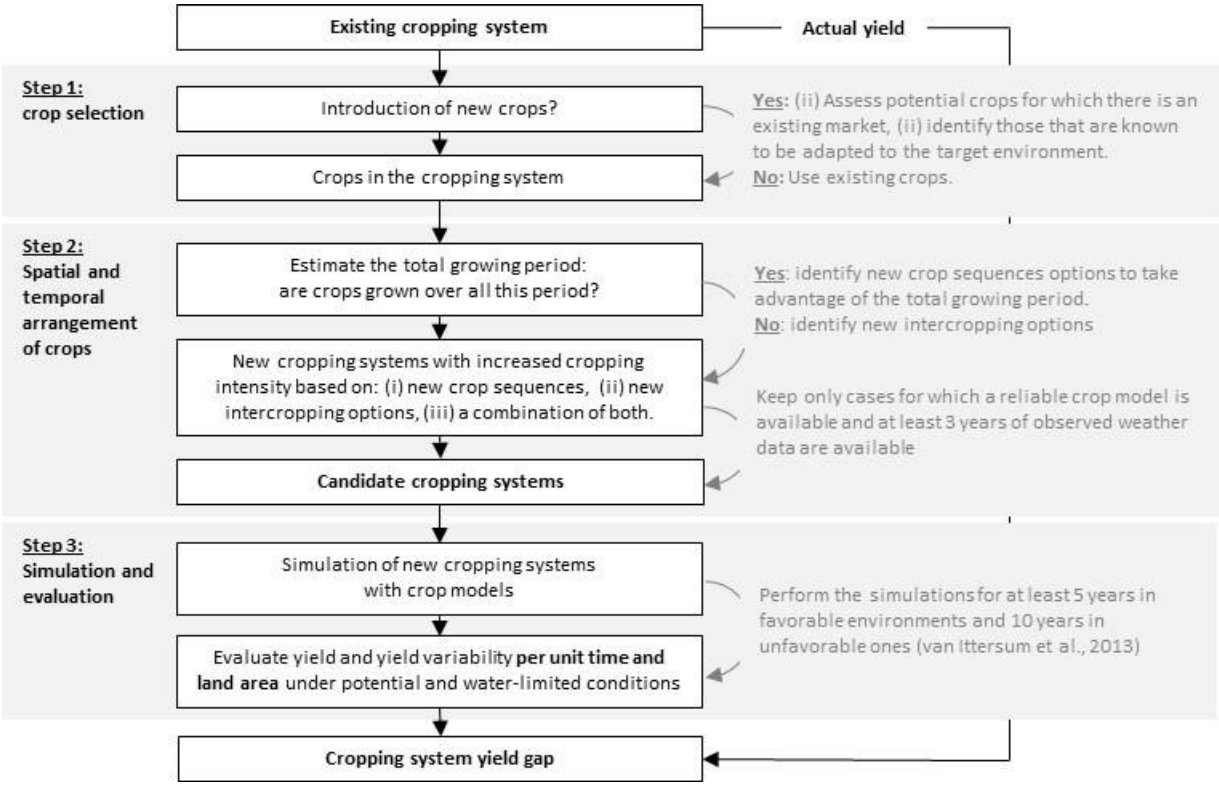

Fig. 1. A framework to assess yield gaps at the cropping system level.

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Explaining rice yield gaps at farm level in Central Luzon, Philippines: An application of stochastic frontier analysis and crop modelling

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1 Introduction

Large rice yield gaps have been reported for rice farming systems in Central Luzon, Philippines (Laborte *et al.*, 2012). Understanding the reasons behind rice yield gaps is crucial in identifying strategies to increase production of this staple crop in Central Luzon, to meet the demand of a growing population and to enhance resource use efficiency. The objective of this study is to introduce an innovative framework to decompose the rice yield gap into efficiency, resource and technology yield gaps (Fig. 1) and to explain those yield gaps at farm and farming system level using information related to crop management, farmers' objectives and production technology employed. The aforementioned gaps can be explained by integrating concepts of production ecology into methods of frontier analysis and applying this to individual farm level data.

2 Materials and Methods

Stochastic frontier analysis based on the specification of Battese and Coelli (1995) is used to compute and explain the efficiency yield gap for each farm. Rice yield (kg ha^{-1}) is used as output variable. Input variables include N, P and K application rates (kg ha^{-1}), seed rate (kg ha^{-1}), and herbicide and insectide use (kg a.i. ha^{-1}). In addition, 'dummy' variables are used to control for variety, season and year random effects. The effect of crop management referring to the timing of application of nutrients and pesticides on the efficiency yield gap is assessed in a 2nd stage multiple regression.
The resource yield gap is estimated from a production perspective based on the difference between highest farmers' yields (i.e. mean actual yields above the 95th percentile) and technical efficient yields computed with stochastic frontier analysis. Finally, ORYZA v3 (Bouman *et al.* 2001) is used to estimate the potential yield in Central Luzon and hence, the technology yield gap, which is defined as the difference between potential yield and highest farmers' yields.
We test the framework using the Central Luzon Loop Survey, an unbalanced panel dataset of about 100 farm households collected by the International Rice Research Institute (IRRI) every 4 to 5 years during the period 1966 – 2012. The dataset contains detailed information on rice crop management (input – output coefficients and timing of nutrient and pesticide applications), farm (e.g. land quality and tenure status) and household characteristics (e.g. off-farm activities and income) and it allows the analysis of changes in rice yield gaps over the past half-century.

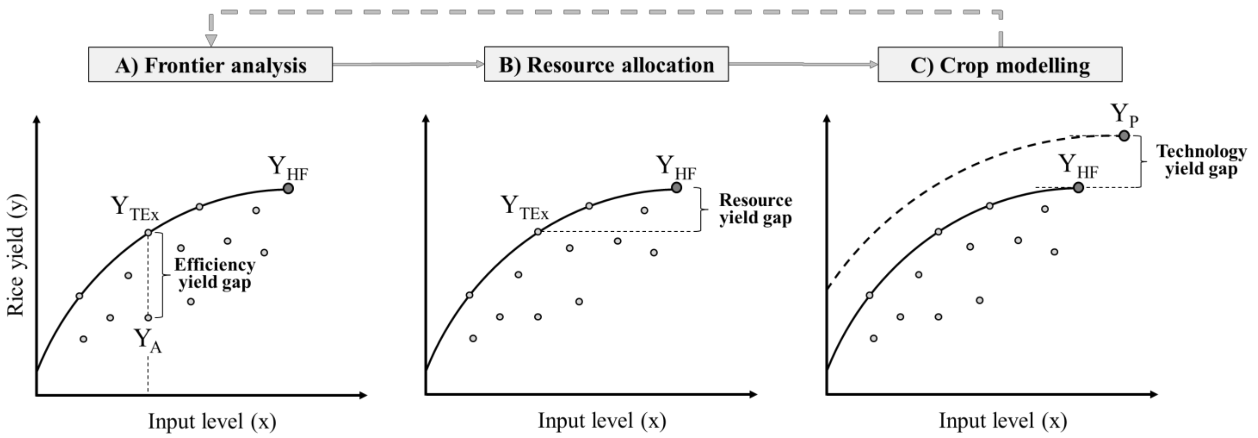

Fig. 1. Theoretical framework to explain rice yield gaps in Central Luzon, Philippines. Y_P is the potential yield as defined by van Ittersum & Rabbinge (1997). Y_{HF} refers to the highest farmer's yield in the farm survey, Y_{TEx} is the technical efficient yield at a specific input level, and Y_A is the actual yield observed in an particular farmers' field. Each dot represents an individual field in a well-defined biophysical environment. A single input-output relationship is shown for illustration purposes.

3 Results – Discussion

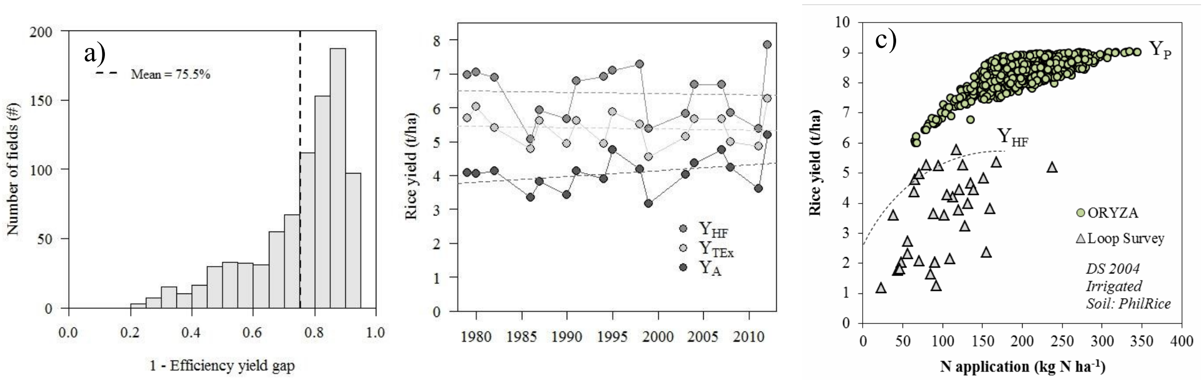

Fig. 2. Estimates of a) efficiency, b) resource and c) technology yield gaps for rice farming systems in Central Luzon. Dashed lines in b) refer to linear regressions fitted to the data and each year corresponds to one season (i.e. wet or dry season). See legend of individual figures and text for further explanation of the results.

Rice yield gaps of 5.0 t ha^{-1} were reported for the irrigated rice farming system of Central Luzon (Laborte *et al.*, 2012).

A mean efficiency yield gap of 24.5% was calculated for all the rice fields included in the Central Luzon Loop Survey (Fig. 2a). Although low efficiency yield gaps (< 20%) were estimated for the majority of the fields, large efficiency yield gaps (> 50%) still persist in many of the farmers' fields analysed. As shown in Fig. 2b, the mean efficiency yield gap (difference Y_{TEx} and Y_A) narrowed over the period of the analysis from about 1.5 t ha^{-1} to 1.0 t ha^{-1}. Efficiency yield gap and the timing of the first and second applications of fertilizers and pesticides (data not shown) have a statistically significant relationship highlighting the contribution of timeliness of crop inputs to prevailing yield gaps.

The resource yield gap over time is also shown in Fig. 2b. For most of the years, the pattern observed for Y_{TEx} and Y_{HF} is rather similar which results in a rather constant resource yield gap over time of about 1.0 t ha^{-1}. Such estimate indicates that approx. 1 t ha^{-1} can be gained in case all farmers would raise their input levels to the one resulting in Y_{HF}. Further analysis is required to analyse the opportunities and trade-offs offered by alternative farmers' objectives such as profit maximisation, risk minimisation or resource use efficiency maximisation.

An estimation of the technology yield gap is presented for the dry season of 2004 in Fig. 2c. Although N application rates in some of the farmers' fields are high enough (i.e. 150 – 200 kg N ha^{-1}) to realize the Y_P of ca. 9 t ha^{-1}, Y_{HF} remains 3 t ha^{-1} lower than Y_P. Such large differences are consistent over the years and tend to be larger in the dry season than in the wet season (data not shown). In order to fully understand and disentangle this technology yield gap it is important to further decompose it and assess whether such differences are caused by technologies (input combinations such as irrigation, nutrients and pest management) not analysed or not occurring in the farm survey.

4 Conclusions

In this analysis, the rice yield gap of 5.0-5.5 t/ha was decomposed into efficiency, resource and technology yield gaps which could be explained based on timing of application of fertilisers and pesticides (ca. 1.0 t ha^{-1}), farmers' objectives and constraints referring to resource use (ca. 1.0 t ha^{-1}) and current technologies (in the survey) not being able to exploit full climatic potential due to sub-optimal input use (roughly 3 t ha^{-1}).

Further research is required to a) explain the technology yield gap,b) assess the role of off-farm income and marginal returns to labour to prevailing yield gaps and c) quantify possible trade-offs among different farmers' objectives.

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Modelling the population dynamics of root lesion nematodes

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1 Introduction

The root lesion nematode *Pratylenchus thornei* (Pt) is a major pest of cereal and pulse crops on the heavy clay textured soils of the northern grains region of eastern Australia. *P.thornei* has a broad host range covering many cereals and pulses (Castillo and Vovlas, 2007; Nicol and Rivoal, 2008) highlighting its economic importance as a major pathogen of grain production worldwide. In Australia yield losses in susceptible varieties as a result of *P.thornei* have been estimated at between 44 and 80% (Thompson, 2008; Thompson *et al.*, 2012), resulting in an estimated annual cost to the industry of $38 million (Murray and Brennan, 2009). Genetic control by breeding tolerant and resistant varieties has been considered the best long- term approach for this pathogen (Thompson *et al.*, 1999). Wheat lines with superior tolerance have been developed, which has meant the regional wheat yield potential has continued to be achieved. However, tolerant varieties continue to increase the nematode population, creating high pathogen levels in the soil and creating a serious risk to other host crops that do not have tolerant and resistant lines available.

The grains region of north-eastern Australia is summer rainfall dominated and the majority of crops are rain fed, with winter crops being grown on stored moisture supplied from the heavy clay soils. A population model was designed and linked to the farming systems modelling framework APSIM to better understand the dynamics of *P.thornei* within this highly variable environment and to understand the interactions between the farming system, the environment and nematodes,(Holzworth *et al.*, 2014). This paper will focus on the survival of *P.thornei* between host crops, and the length of time required to reduce the population bellow the accepted damage threshold of 2 nematodes per cm^3. Previous studies have shown that the population of nematodes at the time of sowing has a significant impact on yield loss, with susceptible varieties suffering no significant yield loss when planted into low populations of *P.thornei* at the beginning of the season (Whish *et al.*, 2014b). Current rotations in the northern grains region aim to provide a break in the form of a long fallow to a non-host summer crop (sorghum or cotton) followed by a second long fallow back to a susceptible winter crop. However, when conditions are favourable the addition of a second crop to reduce the length of unproductive fallow is often favoured. An understanding of the rate of mortality and population decline of *P.thornei* in the absence of host crops will offer some insight into the trade-off between reducing the time between host crops and the decline in population numbers.

2 Materials and Methods

Observed data: Two consecutive susceptible wheat crops were grown in succession to increase the nematode population to high levels. The maximum nematode population was achieved just prior to harvest of the second successive wheat crop. The soil was then fallowed to a non-host sorghum crop and fallowed again, totalling 30 months duration. Over this period regular sampling of the nematode population determined the mortality rate of the nematode population. Nematode sampling involved the collection of soil samples and manual counting of nematodes following the methods described in Owen *et al.* (2010).

Modelling: A population model of *P.thornei* was constructed in the population-modelling framework DYMEX (Sutherst *et al.*, 2000). This model is focused around two lifecycles. The first lifecycle occurs in the roots of the host plant where reproduction occurs. The second lifecycle takes place in the soil where the nematodes survive between host crops. The model was linked to APSIM following the linking method described by Whish (2014a). The coupling point used to join the two models was at the root/soil interface with the nematode population reducing the water and nutrient uptake of the roots. This coupling point relates to the turgor reducers described by Boote (1983)and effectively reduces the supply of water and nutrient to the plant as observed by Whish *et al.*(2014b).The APSIM soil temperature model provided the environmental information to DYMEX. Simulations were initiated within the model with the highest population of nematodes measured in the field. The distribution of nematodes between life stages followed the ratio of 33% Adults, 33 % J4 juveniles, 17% J3 juveniles and 17% J2juveniles. Following the validation of the model a scenario analysis was completed to see how initial population influenced the time required to reduce the population below the damage threshold of 2nematodes per cm^3 soil.

3 Results - Discussion

The mortality functions within the DYMEX population model simulated the three years of observed data quite well (Fig. 1). The longest decay curve (Fig 1a) took 765 days before the population reduced below the damage threshold. Neither of the other two shorter curves managed to reduce the population below the damage threshold. The two longer cures (Fig 1a and 1b) reproduced the observed data well. However, the final curve (Fig. 1c) did not fit the data as well. This may be improved as more data is added, but it may also be a result of the drought conditions experienced before and after harvest. The observed predicted regression (Fig. 1d) shows the model accounted for 95% of the error with a RMSE of 3.9. The model appeared to slightly over-predict the rate of decline especially when the population was high, but generally improved the prediction at low population numbers.

The scenario analysis (Fig. 2) highlighted the importance of the initial population when reducing nematode populations below the damage threshold. High population of 80 nematodes per cm^3 took three years to reduce below the threshold. A moderate initial population of 50 nematodes per cm^3 took two and a half years and a population of 20 nematodes per cm^3 took 20 months. The long survival mechanisms of this pathogen highlight the importance of knowing the size of the population at the beginning and the end of each season. Once a population increases, non-host, or resistant crops or fallows are required to reduce the population below the damage threshold. Planting susceptible or tolerant crops within this time period will increase populations to higher levels that will take longer to reduce, thereby limiting cropping options, and potentially reducing the profitability of the overall farming system.

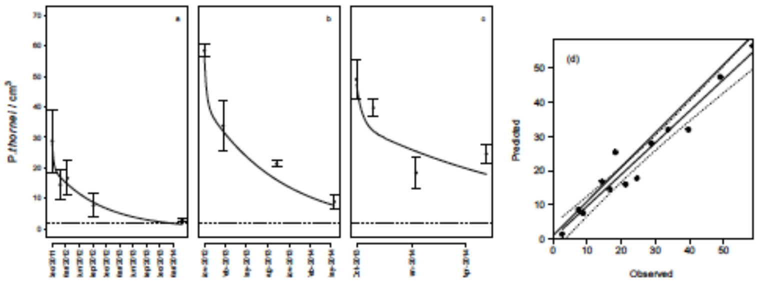

Fig. 1. The observed (points) and predicted (line) population data declining from maximum population at harvest of the preceding wheat crop and the decline over the break. The longest decay curve (a) included a non-host sorghum crop sown in October 2012. The shorter curve (b) commenced in November 2012 and there was no sorghum crop planted due to drought. The final curve (c) commenced in 2013 and had a sorghum crop planted in October 2014. The dashed horizontal line represents the damage threshold below which minimal yield loss will occur in a susceptible wheat crop. The observed predicted regression (Fig. 1d) shows good correlation between the observed and predicted data, y = 0.93x + 0.28, R^2=0.94.

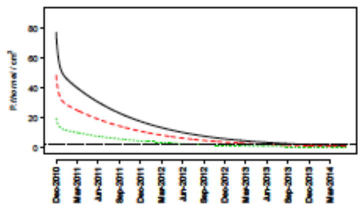

Fig. 2. The effect of starting population (80 pt/cm^3, solid black line;50 pt/cm^3, dashed red line; 20 pt/cm^3, dotted green line) on the time taken for the *P.thornei* population to reduce below the economic threshold.

The simulation model described works within a single 30cm soil layer, the maximum soil temperature is calculated at the centre of this layer and does not vary much outside the cardinal survival temperatures for *P.thornei*. However, surface temperatures of these soils will be hostile to nematode development and survival. A new model that works across these soil layers is under construction and will improve the prediction of nematode population dynamics within the soil.

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Combining yield gap and efficiency analysis to analyze farmers' fields network: a case study on nitrogen in durum wheat in Tunisia

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1 Introduction

In most Mediterranean regions, durum wheat yield is variable with time and location, depending on several factors, primarily water and nitrogen supply (Boussen *et al.,* 2005). Nitrogen (N) is one of the most important nutrients applied as a fertilizer and responsible to a great extent for the large yields obtained from high input agriculture (Latiri, 1998). However, the increased use of N fertilizer can affect farmers' margins, causes excessive losses to the environment and make agriculture dependent of non-renewable energy. The simultaneous increase in both yield and N-efficiency is at the core of eco-efficient agriculture which targets efficient and sustainable use of resources in agricultural production and land management (Keating *et al.*, 2010). It adds to the concept of ecological intensification (Cassman, 1999), the hypothesis of eco-efficiency frontiers that are determined by the genetic nature or by the agrobiodiversity of the cropping systems.
This study aims to analyze the efficiency of nitrogen supply on durum wheat and its drivers in different regions in Tunisia and try to identify eco-efficiency frontiers, associated with constrasting rotation sequences. We addressed the following question: Can higher yields and greater N-efficiency be expected in wheat-based cropping systems by diversifying rotation sequences?

2 Materials and Methods

Assessing the prospects for eco-efficiency on durum wheat production in Tunisia requires compiling and analyzing available data on crop performance and resource inputs as they are currently managed by farmers. Farm surveys were conducted on a sample of 576 farmers' fields which are representative of the diversity of farmers' practices in four grain-producing regions: 182 in Jendouba, 62 in Siliana, 198 in Kairouan and 134 in the Lebna catchment of the Cap Bon. Among these fields 310 were irrigated and 266 were rainfed. The resulting database contains information on wheat yields, N inputs, climatic parameters, previous crop in rotation sequences and other information about the crop management system.
The analysis of yield variability and N-efficiency is based on the concept of efficiency frontier (Keating *et al.,*2010; Carberry *et al.,* 2013). This approach involved analyzing durum wheat responses to N supply over a boundary curve which represents the maximum achievable yield when the input (here N) is the only limiting factor, using the following model (Fermont *et al.,* 2009):

$$Y = Ymax / (1 + K * Exp(-R * X))$$

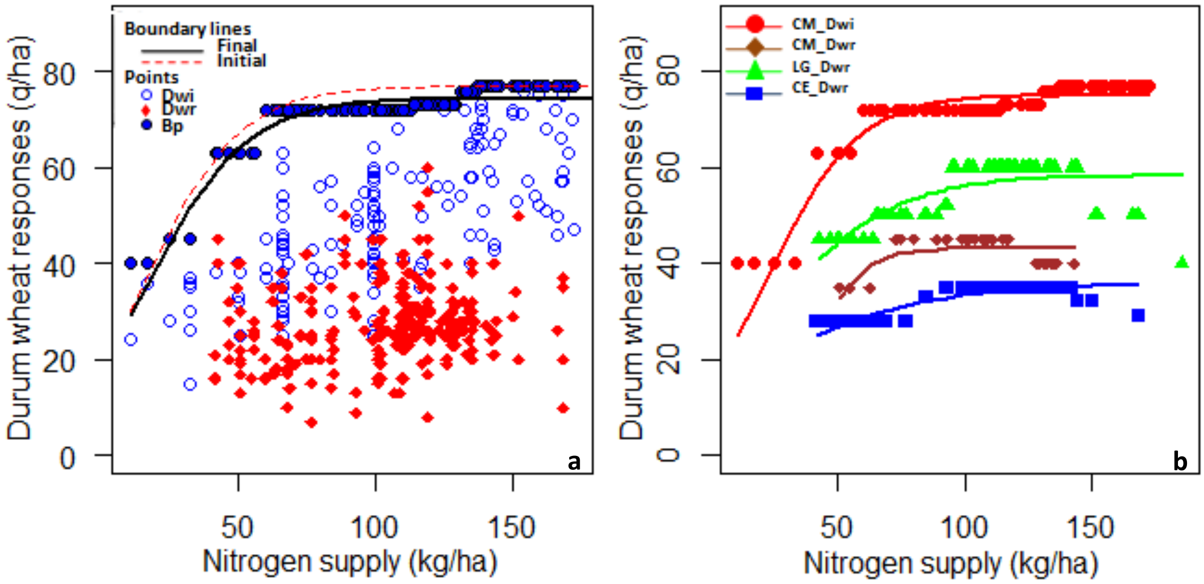
Where Ymax is the maximum level observed in the target variable (durum yield), X is the independent variable (nitrogen), and K and R, are two constants obtained by minimizing the root mean squared error (RMSE).

In order to sort the points that were used to define the boundary curves, we chose a window of fixed size, on the x-axis, and we calculated the maximum yield for each value of the independent variable (N). Then, we formed pairs of points, within the window, where each value of yield was replaced by maximum yield (X, Ymax). In this way, we created a new data set, to which a global boundary curve was first fitted for all the fields together. Then, distinct curves were fitted and tested according to rotation type. The different crop rotations included: (i) vegetable crops-wheat rotation (CM-Dw), (ii) legumes-wheat rotation (LG-Dw), and (iii) cereal (including wheat)-wheat rotation (CE-Dw).

3 Results and discussion

The performance of durum wheat grown in the four sites is benchmarked against a boundary curve that represents achievable yield (boundary points) when only nitrogen is limiting yield (Fig. 1a). The observed achievable yield (Ymax) was 75 q/ha. However, a large variability was observed in yield and yield gap. This variability was, in part, explained by water supply and its distribution. As indicated by the difference in boundary curve between irrigated and rainfed wheat (Fig. 1b). Other biotic and abiotic factors may also partly explain yield gap, such as poor soil quality, or lack of crop protection.
The effect of the preceding crop was a key factor in wheat yield and nitrogen efficiency relationship. Boundary curves of

wheat response to nitrogen supply were found significantly different according to rotation type (Fig. 1b). The highest Ymax (75 q/ha) was found for irrigated wheat following vegetables crops (CM_Dwi). In addition to water supply, the significantly higher performance and N-efficiency of this rotation compared to the other can be explained by fertlization and weeding practices on the vegetables, which altogether resulted in favorable growing conditions for wheat. By contrast, the lowest achievable yield (37q/ha) was found for rainfed wheat in cereal-wheat rotation (CE_Dwr), revealing the poor N-efficiency of rotation sequences based on cereals only. At intermediate positions were the rainfed wheat in rotation with vegetable crops (CM_Dwr, 44q/ha) and legumes (LG_Dwr, 58q/ha), illustrating the range of achievable durum wheat yields depending on the preceding crop. Apparently, legumes had higher fertilizing effects than did vegetable crop, probably due to greater soil N enrichment through legume N-fixing processes than N-credit from vegetables. Furthermore, the large gap between irrigated and rainfed wheat in wheat-vegetable crop rotations suggested important interactions between the effects of water and N supply on durum wheat performances.



Initial	Estimated	Std. Error	t value	Pr(>|t|)
Ymax= 77	74.444404	0.152712	487.48	<2e-16
K= 3	2.881828	0.210332	13.70	<2e-16
R= 0.06	0.056817	0.001786	31.81	<2e-16

Parameters	CM_Dwi	CM_Dwr	LG_Dwr	CE_Dwr
Ymax	75.120967	43.1738	58.36679	35.86087
K	3.805370	79.4774	2.67589	1.58634
R	0.058005	0.1077	0.04234	0.03087

Fig. 1. The relationship between nitrogen supply and durum wheat perfomances in irrigated (Dwi) and rainfed (Dwr) system compared to a boudary line representing maximum yields or boundary points (Bp)(a) and eco-efficiency frontier with each type of rotation: CM_Dwi: irrigated wheat after crop vegetable, CM_Dwr: rainfed wheat after crop vegetable, CE_Dwr: rainfed wheat after cereals, LG_Dwr: rainfed wheat after legumes (b)

4 Conclusions

In this study, grain yield responses of durum wheat to nitrogen supply, in a Mediterranean environment was used as a framework in the diagnosis of yield gap and nitrogen efficiency frontiers. In addition to the water supply and distribution, potential yields (Ymax) and yield gap can be explained by crop rotations. This analysis validate the hypothesis of higher eco-efficiency frontier determined by diversified crop rotations compared to cereal-based rotations and allow to identify strategies to reduce yield and N efficiency gaps.

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EXPLAINING YIELD VARIABILITY BETWEEN FARMERS AS A FIRST STEP TO REDUCE YIELD GAPS

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1 Introduction

Reducing yield gaps is one of the major pathways identified to meet the future food demand (Keating *et al.*, 2014). A prerequisite to design strategies to reduce the yield gap of crops is to understand its causes. The sustainability of most vegetable farms in south Uruguay is threatened by low family income and deteriorating soil quality. The main cause of low income is that most farms obtain 50% or less of the attainable crop yields in the region, with similar production resources and proper management (Dogliotti *et al.*, 2014). Low yields are the main cause of low labour productivity and resource use efficiency. There is a huge variability between farmers in crop yields, product quality and economic results. To explain the main causes of this variability and to identify strategies to reduce the distance between the average yield and the top yielding fields and farms, we started a project to study important vegetable crops in south Uruguay (onion, tomato, sweet potato and strawberry). In this paper we present the method developed to explain variability in physical and economic results, the main causes identified in the seasons studied on strawberry and onion, and discuss strategies to reduce the observed gaps.

2 Materials and Methods

We adapted and combined the methods of the Regional Agronomic Diagnosis (Dore *et al.*, 2008) and Yield Gap Analysis (Lobell *et al.*, 2009; Van Ittersum *et al.*, 2013). The region under study is 60 km around Montevideo, radiation and temperature was considered homogenous within this radius, rainfall was measured at each farm. Based on Census data, we built a typology of vegetable farms growing the selected crops using cluster analysis. Combining farm types and location, we selected a representative sample of 10% of the farms in strawberry (13) and 5% in onion (30). From each farm we selected one to three fields to be monitored and evaluated throughout the growing season. Bio-physical and economic data was gathered at the farm system and at the crop/field level. Growth and yield of the crop was evaluated in 4-6 plots per field. Variables were classified as growth-defining, growth-limiting, and growth-reducing, according to Van Ittersum & Rabbinge, (1997). Statistical analysis combined different tools: path analysis, boundary lines, and regression trees. We studied two seasons of strawberry crop (76 fields) and one season of onion crop (69 fields).

3 Results - Discussion

The strawberry average commercial yields were 18.6 ± 12.2 and 24.9 ± 8.1 Mg ha^{-1}, the top 10% average yields were 41.3 and 40.0 Mg ha^{-1} and the average yield gap was 55% and 38% in 2012 and 2013, respectively. Strawberries are planted end of summer and early autumn. To reduce costs, farmers use one third of the plants required to complete the target plant density. Planting is completed with the first two daughter plants of each plant.

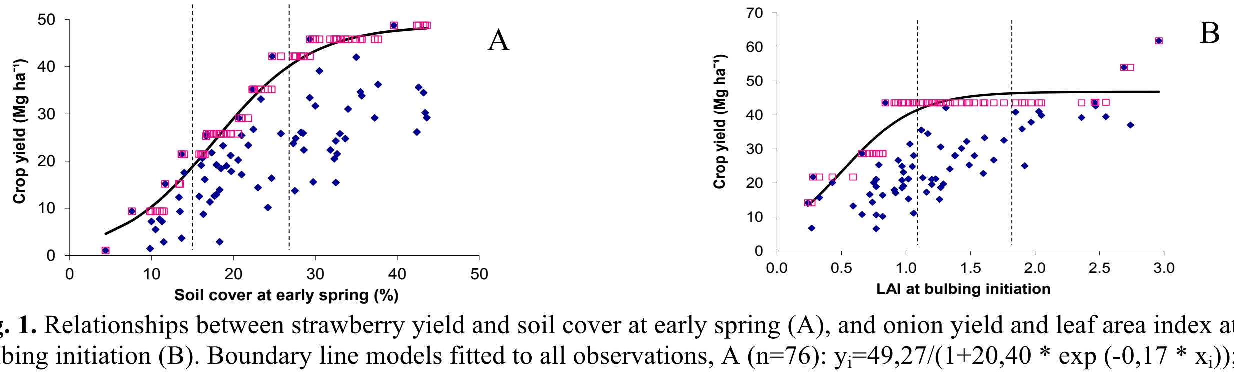

Fig. 1. Relationships between strawberry yield and soil cover at early spring (A), and onion yield and leaf area index at bulbing initiation (B). Boundary line models fitted to all observations, A (n=76): y_i=49,27/(1+20,40 * exp (-0,17 * x_i)); B (n=69): yi=46,82/(1+5,81 * exp (-3,5 * x_i)).

Strawberry yield was determined by soil cover at early spring (Fig. 1A), which was explained by the initial planting date, the date planting is completed, and the final plant density. We found that to yield over 30 Mg ha^{-1} strawberries should be planted before April 15th, the plant density should be over 40 thousand plants per ha and this number of plants should be completed before May 31th (Table 1). Using cluster analysis we divided the fields in three groups according to the soil cover at early spring to study the causes of yield gap within each group. We found that relative yield gap ((boundary line yield–observed yield)/boundary line yield) on the medium and high soil cover groups was mainly explained by N and K fertilization management and water balance. Most farmers applied more than enough N and K, but they applied them mostly at pre-planting. Farmers applying more N and K by fertigation since August had the best results. We couldn't identify causes of relative yield gap in the low cover group due to the reduced number of fields in this group.

Table 1. Strawberry soil cover, yield, relative yield gap and management variables associated to determinant factors for each soil cover group (Date 1st January = 1).

Group	N	Soil cover al early spring (%)	Crop yield (Mg ha^{-1})	Relative yield gap	Planting date	Complete crop density date	Plant densitiy (10^3 ha^{-1})
1 (low)	14	11 ± 3	8,7 ± 6,1	0,30 ± 0,30	117 ± 47	160 ± 34	32 ± 5
2 (medium)	32	20 ± 3	20,0 ± 8,1	0,29 ± 0,23	80 ± 17	144 ± 30	41 ± 7
3 (high)	30	34 ± 5	28,9 ± 8,5	0,37 ± 0,18	85 ± 19	125 ± 28	45 ± 6

Table 2. Onion Leaf Area Index at bulbing initiation, yield, relative yield gap, length of period from planting to bulbing initiation and plant density.

Group	N	Crop yield (Mg ha^{-1})	LAI at bulbing initiation	Relative yield gap	Leaf area per plant (cm^2)	Planting to Bulbing initiation (days)	Plant density (10^3 plants ha^{-1})
1 (low)	33	19,2 ± 7,6	0,78 ± 0,24	0,41± 0,23	448 ± 190	87 ± 16	216 ± 49
2 (medium)	23	26,4 ± 6,8	1,36 ± 0,18	0,40± 0,15	671 ± 165	84 ± 15	223 ± 40
3 (high)	13	41,4 ± 8,8	2,30 ± 0,37	0,15± 0,12	1045 ± 162	97 ± 8	237 ± 49

Onion crops in south Uruguay are mostly installed by transplanting in winter. The onion average commercial yield was 25.8 ± 11.1 Mg ha^{-1}, the top 10% average yield was 47.0 Mg ha^{-1}, and the average yield gap was 45% in 2014. Crop yield was determined by Leaf Area Index at bulbing initiation (Fig. 1B), which was explained by the initial plant density, the plant density at harvest and the length of the period from planting to bulbing initiation, which depends on the planting date (Table 2).

4 Conclusions

The average commercial yield of strawberry and onion in south Uruguay could be improved by more than 40% by adjusting timing of operations and crop management without significant increase in inputs and production costs. The first step to reduce yield gap would be to increase soil cover at early spring and LAI at bulbing initiation by adjusting planting dates and planting densities, which requires better planning of soil preparation and of plant nurseries. Second step to improve strawberry yield is to reduce relative yield gaps within the high soil cover group by adjusting crop fertilization management and irrigation. In the onion crop the relative yield gap within the group with high LAI at bulbing initiation was only 15%.

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On methodology of deciding nitrogen intensity: a case with dynamic typology in the small scale wheat-maize system in the North China Plain

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1 Introduction

In face of great challenges in increasing demand for increasing food grain productiion and resource-environmental issues, sustainable intensification has become the only way that Chinese agriculture must follow. There is a big yield gap in the wheat-maize cropping system in the North China Plain (Laing *et al.*, 2011) and at meanwhile the system has been criticized for applying too much nitrogen (N) (Chen *et al.*, 2013). This presentation tries to reveal the whole story behind the confusing phenomena and to propose a more relevant approach of deciding N intensity of the system.

2 Materials and Methods

Farm survey data that have partly published (Liang *et al.*, 2011; Carberry *et al.*, 2013) are further explored and analyzed. N efficiency frontier of the wheat-maize system built with APSIM was used as a bench mark in classifying N intensity. Analysis and typology is based on individual farm fields.

3 Results – Discussion

How attainable yield was achieved Yields of 9.1 t/ha for wheat and 10.5 t/ha for maize were obtained by careful land preparation, adequate soil moisture storage before wheat sowing, sowing timely at appropriate seed rate, timely irrigation, balanced fertilization (i.e. rate and ratio of nutrients; 234 kg N/ha on wheat and 236 kg N /ha on maize were applied in this case), effective disease and pest control, and harvest at mature (not too late for wheat and not too early for maize).

What happened to those fields with unsatisfactory yield Average farm yield was 6.5 t/ha for wheat and 7.3 t/ha for maize with corresponding N rates of 260 kg/ha on wheat and 112 kg/ha on maize, repedctively. Coefficient of Variation (CV) of wheat yield was 12%, of maize yield was 15% while CV for N rate on wheat was 49% and on maize was 125%, indicating a great variation of N rate among fields. Problems limiting the productivity of the system include unsatisfactory land preparation before wheat sowing, small maize population density, untimely sowing (too early of wheat and too late of maize), unbalanced nutrient application, untimely irrigation, untimely and improper pest and diseases control, etc.（Liang *et al.*, 2011）. As a result, only 11% of the surveyed fields obtained satisfactory yield (above 80% of the attainable yield) with rational N rate (within 80-120% yield corresponding N rate on the efficiency frontier), 1% of the fields obtained satisfactory yield with surplus N (higher than 120% yield corresponding N rate on the efficiency frontier), 46% of the fields obtained low yield (bellow 80% of the attainable yield) with inadequate N (bellow 80% yield corresponding N rate on the efficiency frontier), and 42% of the fields obtained low yield (bellow 80% of the attainable yield) with surplus N (above 120% yield corresponding N rate on the efficiency frontier).

Then, a subsequent question is: ***Would it be possible for the lower yielding fields to achieve attainable yield by eliminating the management problems?*** The answer is 'yes and no'. Most of the mis-implemented management practices could be improved by better extension service, etc, while timing of irrigation could only be better set till irrigation facilities being well developed. Current percentage of fields irrigated at water critical stages of the crops is: 42% of the wheat fields get irrigated at stem-elongation and 36% at heading-anthesis, while 30% of the maize fields irrigated at booting. This means that about two thirds of the fields would not be able to obtain attainable yield even if all the other management practices be perfectly implemented. And these timely and untimely irrigated fields shifts between crop seasons since the sequence of each irrigation is decided by drawing lots in most cases—This makes the situation complex, adding that the field size is very small (0.35 ha for wheat and 0.61 ha for maize in average) .
The most popular practice, being considered effective and efficient by most agronomists, is to apply all phosphorus and potassium and around half of the total N on wheat before sowing (basal application) `and top-dress another half N at stem elongation incorporated with irrigation; apply all the phosphorus and potassium and 30% N on maize at sowing and top-dress the left 70% N at booting incorporated with irrigation or rainfall. Thus the actual total N rate is decided by the amount of top-dressings which is also the basis for typology of N intensity. Hence all the fields fall into four

categories (table 1). A great potential of improving N efficiency, either by improving yield or by reducing N rate, exists in the last three categories by replacing the blanket recommendation for high yield with most possible yield targeted dosing.

Table 1 Typology for N intensity of the wheat-maize system in the Hebei Plain, China

Crop status, *wheat at stem elongation and maize at booting*	Timeliness of irrigation at critical stage	Typology	N intensity recommend
I Good	A timely	IA	Full
	B untimely	IB	Sub-full
II Not so good	A timely	IIA	Sub-full
	B untimely	IIB	Semi-full

Policy and support systems of the government should realize this fact and effort on improving agricultural infrastructure, especially irrigation facilities and effective-efficient machines to move more farm fields into type IA in the long run and on strategic operation of current facilities in the short term for more efficient use in the meanwhile.
This approach of sustainable intensification is essential for national food security.
Recommending N rate by soil testing is not practical because it is not possible to test soils in each field. Short term field trials are also not suitable to provide fertilization recommendations for their intrinsic feature of inadequate yield and especially of inadequated time period exhausting soil fertility. Well calibered simulations can serve this purpose with good satisfaction, as proved by Yield Prophet, commercial version of APSIM in Australia. However, before this kind of approach can be used to provide N recommendation, being limited by farm/field size and infrastructure, a role of thumb approach employing useful practical 'modern' technology as simulation may help.

4 Conclusions

Not all wheat-maize fields in the Hebei Plain are able to obtain attainable yield, and hence full N intensity, presently by improving management practices owing to inadequate irrigation facilities, thus it is not reasonable to adopt a blanket recommendation of N rate aiminig at high yield or at low environmental risk. N dosing should be based on mostly probable yield that is determined by crop population quality at stem elongation of wheat and booting of maize together with timeliness of irrigation at those critical stages. Better decision tools incorporating advanced modern technology and cutting edge scientific breakthroughs need to be developed, to serve bigger farms that are emerging by 'land transfer' policy.

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Trade-offs between greenhouse gas abatement and profitability of alternative management practices on Australian grain farms

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1 Introduction

Under proposed Emissions Reduction Fund policy, Australian farm owners can be paid for greenhouse gas (GHG) abatement if they bid the least cost delivery price through an auction process. Farm owners therefore need information about the effect of practices on soil carbon and nitrous oxide (N_2O) emissions, productivity and gross margins. However, practices that sequester carbon - thus reducing carbon dioxide (CO_2) emissions - may increase N_2O emissions. The potential trade-offs between these emissions pathways are not always obvious and may reduce the potential for Australian grains farms to mitigate GHG emissions. In addition, suitable mitigation practices may vary across regions, reduce whole farm profitability or fit poorly within farm management. To better understand all of these trade-offs, we estimated the net, whole-farm GHG mitigation balance and financial impact of various management practices applicable to Australian grains farms.

2 Materials and Methods

We established six representative farms in collaboration with farmer groups across Australia. The usual cropping systems and management employed by the farmers formed the baseline for analyses. In this paper, we present results for one of the case study farms. Baseline and alternative practices aimed at abating GHG emissions (Table 1) were simulated over 100 yr with the APSIM model (Holzworth *et al.,* 2014; www.apsim.info). The capacity of APSIM to represent baseline practices was assessed by modelling field experiments near the representative farms. Amounts of carbon sequestered and N_2O emitted were converted to carbon dioxide equivalents (CO_2e; IPCC, 2013) to evaluate the global warming potential (GWP) of different practices. We calculated the financial impacts of different practices before participating in emission reduction schemes through an analysis of the gross margins for each crop and management scenario on the farm. Gross margins were calculated at the paddock scale as income (yield x price) minus variable costs such as fertiliser. Economic data were sourced from the Department of Agriculture and Food Western Australia (DAFWA, 2012).

The case study farm was located at Dalwallinu (30.27°S, 116.66°E) in Western Australia. Average climatic conditions include annual (winter-dominant) rainfall of 310 mm yr^{-1} and minimum-maximum temperatures of 18-36°C (January) and 6-17°C (July). The farming system included several rotations of winter crops, but here only the results for one rotation (canola × wheat × wheat × barley) are presented. All crops were fertilised with ~65 kg N ha^{-1} $crop^{-1}$ in a split application. The most common soil types on the 6,000 ha case study farm were sands and sandy duplexes, so here results are described for a single representative soil (a deep sand; 0.7% carbon in 0.0-0.1 m).

Table 1. Baseline practices (Scenario 1) and alternative practices (Scenarios 2-8) modelled for the case study farm

Scenario number	Management practice description	Name
1	Stubble burnt, 65 kg N ha^{-1} fertiliser, bare summer fallow	Baseline
2	Stubble retained	NoBurn
3	Stubble burnt + 25% extra N fertiliser	Baseline+N
4	Stubble burnt - 25% less N fertiliser	Baseline-N
5	Stubble retained + 25% extra N fertiliser	NoBurn+N
6	Stubble retained - 25% less N fertiliser	NoBurn-N
7	Stubble retained + 5 t ha^{-1} manure applied every 5 yr	NoBurn+Manure
8	Stubble retained + opportunistic summer cowpea green manure crop	NoBurn+Cowpea

3 Results and Discussion

The median crop yield (Fig. 1a-c) was greater than the baseline for Scenarios 3 and 5 (+25% extra N fertiliser). Scenario 7 (NoBurn+Manure) also increased the median yield or the range of yields in the upper quartile for some crops. Median crop yield was lower than the baseline in Scenarios 4 and 6 (-25% less N fertiliser). The revenue generated from greater yields obtained when extra N fertiliser was applied (Scenarios 3 and 5) offset the additional costs associated with applying the fertiliser, and resulted in the greatest gross margins (Fig. 1d) of the scenarios. The savings in N fertiliser under Scenarios 4 and 6 did not outweigh the loss in revenue from the lower yields and resulted in the lowest gross margins for the scenarios. In Scenario 8, approximately 50% of cowpea crops reached harvest maturity due to low summer rainfall (data not shown) and so the nitrogen benefit from these legumes was limited. Therefore there was no yield benefit from this practice but there were increased costs from sowing the cowpea crop, which resulted in a decrease in the gross margin for this scenario compared to the baseline practice (Scenario 1).

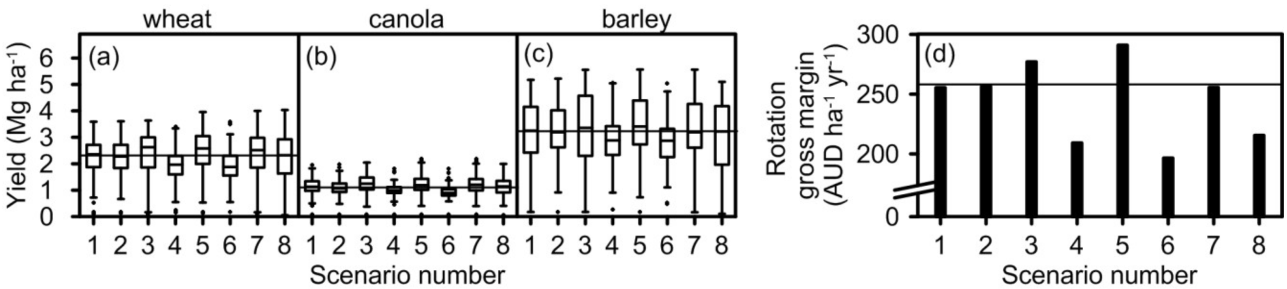

Fig. 1. (a-c) Crop yield and (d) partial gross margins from scenario practices (described in Table 1). Box plot whiskers in (a-c) represent 1.5 times the interquartile range of the lower and upper quartiles. The horizontal lines are aligned with (a-c) median baseline yields and (d) the baseline gross margin to assist with comparison of scenarios.

Annual changes in soil carbon ranged from gains (sequestration) of ~400 kg C ha^{-1} yr^{-1} to losses of ~150 kg C ha^{-1} yr^{-1} in different scenarios (data not shown). Annual emissions of N_2O-N typically ranged from 0.06 to 0.11 kg N_2O-N ha^{-1} yr^{-1} (data not shown), consistent with measured values for the region (Barton *et al*., 2013). The cumulative CO_2e emissions (from combined changes in soil carbon and emitted N_2O; Fig. 2) indicated that all scenarios with stubble retained (Scenarios 2, 5-8) provided GHG abatement for the duration of the 100 yr simulation period compared to the baseline. Scenarios in which stubble was retained and additional organic matter inputs were applied from manure or summer crops (Scenarios 7 and 8) delivered the greatest GHG abatement.

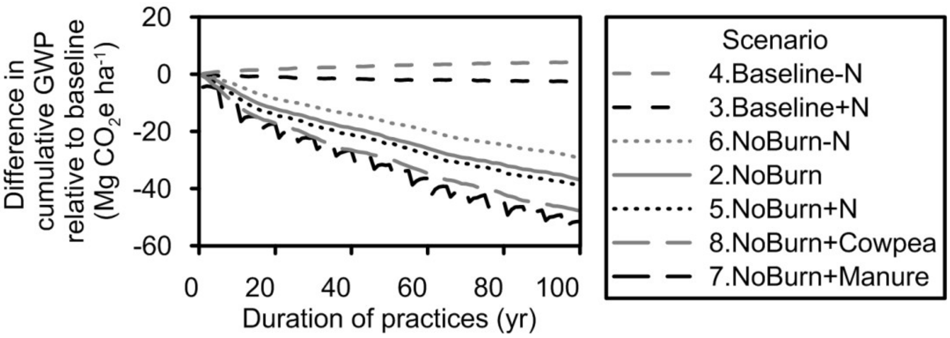

Fig. 2. Cumulative 100 yr GWP of emissions from practices relative to Scenario 1 baseline (described in Table 1)

4 Conclusions

Stubble retention at increased nitrogen fertiliser rates (Scenario 5) resulted in win-win outcomes for yield, GHG abatement and gross margins. Stubble retention alone (Scenario 2) or with added manure (Scenario 7) increased GHG abatement without reducing profitability. By comparison, reducing the amount of N fertiliser applied together with burning stubble (Scenario 4) resulted in lower yields and profitability while increasing GHG emissions. The greatest trade off between profitability and GHG abatement occurred when a cowpea crop was grown (Scenario 8), which provided some of the greatest abatement but lowered gross margins.

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Yield gap analysis and crop insurance

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1 Introduction

Yield gap analyses have been widely implemented over the last decades to evaluate the agronomic room for improvement of crop productivity (e.g. Affholder *et al.*, 2012; Lobell *et al.*, 2009; van Wart *et al.*, 2013). It has been proved to be a valuable concept for assessing and understanding the possibilities to meet food demand for an increasing population (van Ittersum *et al.*, 2013). Nevertheless, the use of this concept is not limited to the biophysical aspects of agronomy, but may be extrapolated to support research on socioeconomic aspects of agricultural production.
In this work, the use of yield gap analysis within a crop insurance context is explored: (i) by introducing the insurance parameter ―maximum insurable yield‖ in a yield gap analysis and comparing it the actual observed yields; and (ii) by evaluating the possible use of crop model simulated yields to calibrate insurance parameters.

2 Materials and Methods

The analysis uses four yield levels: (i) actual yields, (ii) expected yields, (iii) insurable yields, and (iv) simulated water-limited-yields. Data on actual yields (*Ya*), those achieved by farmers, were available from ESYRCE database (*Encuestasobre Superficies y Rendimientos de Cultivos*-Ministry of Agriculture, Food, and Environment. MAGRAMA). Expected yields (*Yexp*), those predicted previous to sowing, were estimated for each county from the detrended*Ya* series, using Stata v12. Data from all municipalities in Castilla y León (CyL) region (northern central Spain) with at least one insured farmer in 2011 or 2012 was made available by ENESA (*Spanish Agency of Agricultural Insurance)*. The zonal maximum insurable yield (*YinsZ*), for wheat grown under rainfed conditions for each municipality was obtained from the Spanish Official Gazette (BOE) No 217, 02.09.2013, at the Order AAA/1629/2013. Individual maximum insurable yields are adapted through a *bonus-malus* system based on the individual farmers' insurance history. Lastly, water limited yields (*Yw*) were simulated using the crop model CERES–Wheat (Godwin *et al.*, 1989). CERES-Wheat was calibrated and validated using published data from the trials conducted by the Agricultural Research Program of CyL between 2004 and 2010 for wheat (*Triticumaestivum*, L.) CV‗Marius'. The experimental sites are located across the grain production areas and are representative of the variability of its climate and soil. Crop development data such as emergence, anthesis and physiological maturity dates, and yield were available, as were sowing dates and plant density for all the sites. All yields are given per county.
Two yield gaps (*GapZ*, *Gap*W) were defined by the following yield differences:

$$G = {}_{ins} - {}_{ep} \qquad \text{[Eq 1]}$$

$$G = - {}_{ep} \qquad \text{[Eq 2]}$$

3 Discussion

The kernel density estimation of the zonal maximum insurable yield (*YinsZ*), the expected yield (*Yexp*), and the water limited yields (*Yw*) are presented in Fig. 1-A while the corresponding yield gaps, *GapZ* and *GapW,* are presented inFig. 1-B. The lowest yields were *YinsZ*, followed by *Yexp* and lastly, *Yw*, with means of 1.96, 2.77 and 3.78 Mg ha^{-1}, respectively. The largest variability was found for *Yw*, followed by *Yexp* and lastly *YinsZ* (Figure 5-A). *GapZ* had the mean of -0.85 Mg ha^{-1} and a low variability (percentiles 10 and 90, being -1.45 and -0.37 Mg ha^{-1}, respectively), while*GapW* had a mean of 1.01 Mg ha^{-1} and a high variability (percentiles 10 and 90, -0.36 and 2.13 Mg ha^{-1}, respectively).
Zonal maximum insurable yields (*YinsZ*) were 0.85 Mg ha^{-1} lower than the expected yields (*GapZ*) revealing that the parameter *YinsZ*is underestimated. This might explain why *bonus-malus* systems have been introduced to adapt individual maximum insurable yield based on the individual farmers' insurance history.
GapW was the highest yield gap found among the gaps included in this analysis (Fig. 1) and therefore, if used as expected yields for designing new insurance coverage, unbalances would be found as farmer´s yields would be overestimated. In that case, yield gaps should be estimated and considered before implementing them.
To evaluate the potential use of simulated yields to calibrate insurance parameters, first the uncertainty associated to the use of crop models must be considered. In Castañeda-Vera *et al.* (2015) it is suggested that winter wheat yields simulated with the crop models Aquacrop (Raes *et al.*, 2009; Steduto *et al.*, 2012), CERES-Wheat, CropSyst (Stöckle *et*

al., 2003) and WOFOST (Boogaard *et al.*, 2011; Supit *et al.*, 1994) are comparable when water is not limiting, but differences are larger when simulating under rainfed conditions and that could be due to the substantial differences they found in soil water simulations.

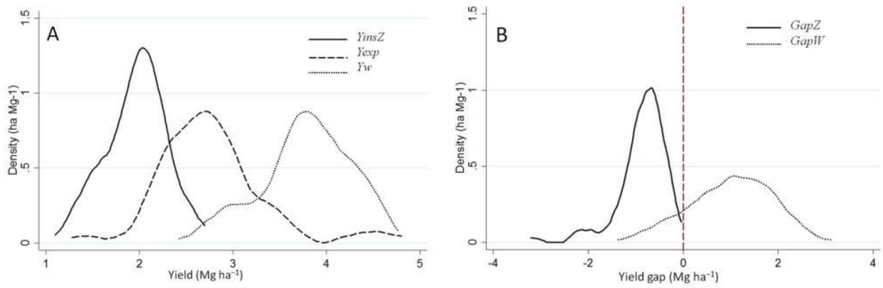

Fig. 1. Kernel density estimation of yields and yield gaps.

The mean simulated value of *Yw*at 3.78 Mg ha^{-1} (Fig. 1) diverges from that reported in Boogaard *et al.*, (2013), within an analysis for the whole of Europe using the crop model WOFOST. Those authors calculated *Yw* between 5 and 6 Mg ha^{-1}, and *GapW* between 3 and 4 Mg ha^{-1} in CyL region, so that *Yw* was more than 2 Mg ha^{-1}greater and *Yexp* about 1 Mg ha^{-1}smaller than reported here. These differences in the simulated *Yw* could be related to the accuracy in calibration and the scale of application. Deficiencies in the accuracy of the models to simulate soil water content or certain physiological processes subject the quality of models performance. Moreover, the orography and soil variability can hardly be included in the analysis as the high horizontal heterogeneity of the weather and soils or the differences in the cultivars used in different regions might result in significant errors when the scale of application is large. This is the case when calibrating models in a specific region to extrapolate results to a larger area and when available soil maps and weather data grids resolution is low.

4 Conclusions

The use of insurance historical data rather than using crop models is still preferred to evaluate and calibrate insurance parameters when available, otherwise farmer yields would be overestimated. Nevertheless, the use of crop models is useful to design new insurance packages when no historical data is available. In those cases, it is suggested that yield gaps be estimated and subtracted from simulated attainable yields.

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Modeling attainable yield and yield losses due to pests and diseases to compare performances of coffee farming systems

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1 Introduction

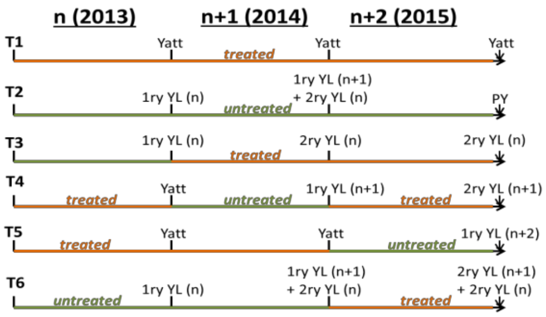
The regulation service of pests and diseases (P&D) can be assessed in terms of avoided crop losses (Avelino *et al.*, 2011). This approach is necessary to compare the performance of agroecosystems with different sets of P&D (injury profiles). For perennial crops, such as coffee, the assessment of yield losses is difficult due to the biennial production cycle, the complexity of agroecosystems where these crops are grown, and the existence of primary losses (in the current year) and secondary losses (losses in the following years due to the physiological damages caused by P&D) (Zadoks & Schein, 1979). Through this work, we contribute to: i) a better understanding of the impact of P&D on primary and secondary coffee yield losses; and ii) build a conceptual model to identify the main factors that determine coffee yield losses.

2 Materials and Methods

Trial: coffee at full sun exposure (5000 plants ha^{-1}) where six treatments with different sequences of fungicide applications are compared, with a duration of three years (Fig 1). In each of four replicates (40 m^2), six coffee plants were marked for measurements: fruiting nodes, fruits per node, dead branches, P&D incidences and severity, and yields.
Studied variables: standardized area under the disease progress curve (sAUDPC) and severity of P&D, dead branches, and yield losses. Depending on the treatment, at the end of each year we can obtain attainable yields (Yatt) and actual yields (Yac), whose differences represent primary or secondary losses (Fig 1). *Yield loss (%)* = ((*Yatt – Yac*)/*Yatt*)**100*
Statistical analysis: i) sAUDPC, severity, dead branches and yields were compared among treatments trough analyses of variance, with fruit load of the previous year and soil acidity as covariates (they characterize the production conditions of each plot), and LSD (Fisher) with $p<0.05$; ii) correlations (Spearman) between measured and studied variables of 2013 and 2014 to support the relationships presented in the conceptual model.

3 Results – Discussion

Diseases and yield losses. We observed significant effects of the treatments on several diseases in both years (Table 1). In the first year (2013), no difference of yield between treatments was found and therefore no yield loss was calculated. In the second year (2014), significant differences between treatments were observed for sAUDPCof coffee leaf rust and dead branches; and the yield of the treatments conducting to attainable yield (T1&T5) was different to others, making possible to calculate yield losses. The negative impacts of abandon fungicide application from one year to another (T4) can be worse than no fungicide application in two consecutive years (T2&T6), reflected by higher dead branches and similar yields.Both primary and secondary losses were high, showing a severe impact of diseases (Table 1). Although we applied fungicides, there was presence of diseases, which indicates that yield losses could be even higher.
Correlations and conceptual model. Several significant correlations were found between variables from one year to another and within the same year. The fruit load in 2013 influenced negatively the fruit load in 2014; higher yield components (fruits per node, fruiting nodes, fruit load) caused higher sAUDPC and severities of diseases in most cases; dead branches had positive correlations specially with severity of diseases, and dead branches of2013 influenced negatively the yield components in 2014 (Fig. 2). These findings indicate that physiological aspects and impacts of diseases lead to yield losses in a given year and in next years. Based on that, we present a conceptual model, showing how different factors can influence the components of attainable yield, and how this last one can be reduced to actual yield, due to primary and secondary yield losses of coffee (Fig. 3).



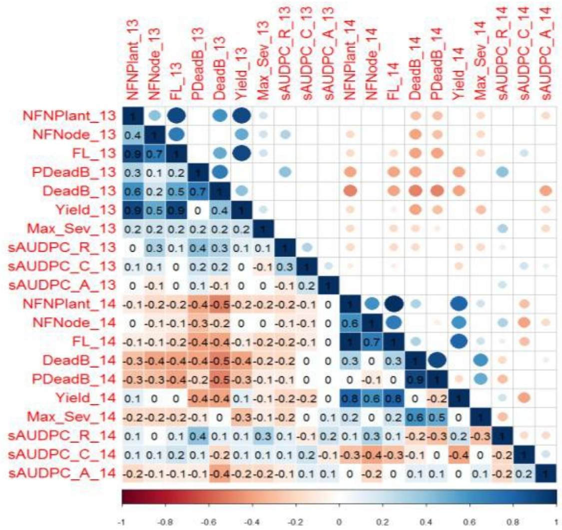
Yatt: attainable yield; YL: yield losses; PY: primitive yield

Fig. 1. Treatments for the assessment of yield losses.

Table 1. Effects of treatments on P&D and yield losses.

	Year 2013		Year 2014			
Variable	**T1&T4&T5**	**T2&T3&T6**	**T1&T5**	**T2&T6**	**T3**	**T4**
sAUDPC_R	24 a	34 b	34 a	41 b	40 ab	31a
sAUDPC_C	24 a	29 b	22 a	24 a	24 a	27 a
sAUDPC_A	6 a	5 a	8 a	4 b	6 ab	8 a
Max_Sev	3.1 a	3.2 a	3.5 a	3.4 a	3.2 a	3.6 a
DeadB	37 a	54 b	28 ab	29 ab	13 a	44 b
Yield	2077 a	2267 a	3397 a	1823 b	2125 b	1931 b
Estimated Primary Losses = ((3397-1931)/3397)*100 = 43%						
Estimated Secondary Losses = ((3397-2125)/3397)*100 = 37%						
Estimated Primary and Secondary Losses = ((3397-1823)/3397)*100 = 46%						

See interpretation of Fig. 2. for the meaning of variables and their units



Interpretation. Bellow the diagonal there are the Spearman coefficients; above the diagonal: the darker and bigger the circles, the stronger the correlation (symmetric matrix). Blue color indicates positive correlation; orange color indicates negative correlation. Cells with white color indicate that there is no significant correlation.

NFNPlant: Number of fruiting nodes per plant NFNode: Number of fruits per node

FL: Fruit load (=NFNPlant x NFNode) PDeadB: Percentage of dead branches

DeadB: Number of dead branches

Yield: Coffee yield (grams of coffee cherries per plant) Max_Sev: Maximum of severityof diseases in leaves (scale 0-6)

sAUDPC_R: standardized Area Under the Disease Progress Curve of coffee leaf rust (*Hemileiavastarix*) (% day^{-1})

sAUDPC_C: of cercospora(*Cercosporacoffeicola*) (% day^{-1}) sAUDPC_A: of anthracnoses (*Colletotrichum*spp.)(% day^{-1})

Numbers 13 and 14 represents the variables in 2013 and 2014, respectively

Note: we constructed the accumulated AreasUnder the Disease Progress Curve, but, since there were differences in the total time of incidence measurements between 2013 and 2014, we standardized them per day.

Fig. 2. Matrix of correlations (Spearman) among variables that determine yields.

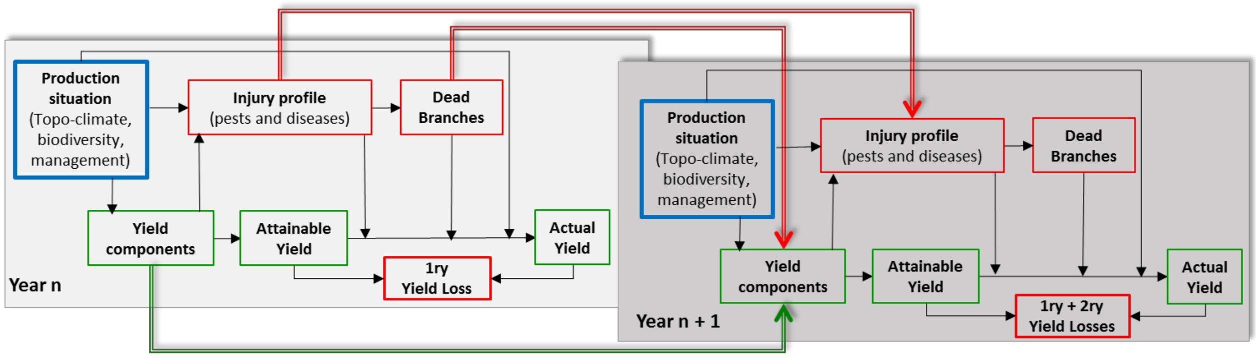


Fig. 3. Conceptual model to assess primary and secondary yield losses of coffee.

4 Conclusions

The negative impacts of diseases in coffee are not limited only to the year where they have developed. The high estimated secondary losses indicate that economic and technical measures to help coffee farmers to face phytosanitary issues (as coffee rust epidemic in 2012-13, Avelino *et al.*, 2015) need to be continued on several years.

The proposed conceptual model shows the main factors that should be taken into account to assess primary and secondary yield losses of coffee. Based on this model, statistical models could be developed (to be finalized in 2015) to estimate attainable yields and yield losses, in order to assess the performance of different coffee farming systems.

Acknowledgments. We thank the INRA Smatch Metaprogramme that funds this experiment through the DAMAGE action.

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T4. What's new with bioeconomic models for the analysis and design of agricultural systems?

Chair: Francois Affholder, CIRAD
Co-chair: Hatem Belhouchette, IAM.M

DAHBSIM, a Dynamic Agricultural Household Bio-Economic Model

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[4] CGIAR, IFPRI This model is being developed as part of the IFPRI BioSight project, coordinated by Siwa Msangi, in collaboration with CIHEAM-IAMM.

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1 Introduction

The development of bio-economic models responds to the need of tools able to represent in a consistent way different dimensions of Agricultural Systems, integrating different scale levels as well as impacts concerning agro-ecologic issues, socio-economic ones and indirect effects of other nature, such as global environmental impacts.
Most bio-economic models use outputs of bio-physical models (Flichman, 2011) to generate part of the parameters of the model. A small number of models including the bio-physical processes in the same code, usually apply empirical bio-physical relations, adapted only to the specific case that is studied. When bio-physical models are used to generate data to be introduced in the bio-economic model, it is not possible to fully simulate the dynamic interactions between the economic and the bio-physical dimensions of the whole model. In the majority of cases, the bio-economic models of this type are static, creating to some extent a lack of consistency.
On the other side, when only a simplified empirical approach is representing the bio-physical issues, the model cannot be easily adapted to a different context (Holden *et al.* 2004)
The development of DAHBSIM uses an accumulated experience in this type of models, and intends to introduce some specific improvements in relation with previous work in this field, essentially through its dynamic character and the possibility of application in different contexts, as it is developed in a generic way using a modular structure.
DAHBSIM is designed to capture some key features of developing countries rural areas. Some aspects of this work present a particular interest from a methodological perspective:
The fact that DAHBSIM is built in a modular and generic manner allows applying it in different contexts. The potential user will be able to use all or part of the modules. The architecture of the model may include new modules if it appears necessary to do so. The development of this model is done in the context of collaboration between IFPRI and CIHEAM-IAMM.

2 Materials and Methods

DAHBSIM is a model applying a Dynamic-recursive optimization approach: an inter-temporal optimization is performed, the results of the first period are observed and recursive equations (Summary biophysical model) are introduced before the second optimization, for taking into account the effect on resources of the production choices of the previous year. This procedure is repeated for all periods. There is a moving horizon then, the model takes into account future but reinitializes at each iteration the initial conditions, changed as a function of the previous choice. Inside each step, the inter-temporal optimization does not take into account the changes in the state variables (yield and externalities per activity) defined by the previous use of the soil. These changes are introduced in the following step, when state variables (water and nitrogen content of the soil) are reinitialized. Only the first year results of each iteration are considered at the end.
The model simulates farm household level decisions; market prices are defined exogenously.
Model features are coded in a generic and modular way to ease application to different farming systems and household types. The core modules comprise the common features of the model: (1) objective function; (2) cropping module; (3) biophysical module; (4) farm module and (5) household module.
Apart from these core modules, all other modules can be activated or deactivated depending on the application at hand. Presently, a livestock module is also available. Modules for perennial crops will also be developed. Thanks to its modularity, DAHBSIM can be easily extended and adapted to answer new policy questions.
The main outputs generated from DAHBSIM are land use, production activity levels, input use, farm income, time allocation decisions, household food and non-food consumption, and environmental externalities (as joint products). These outputs are translated into indicators to measure the impact of policies.
DAHBSIM can be applied to individual households (either real households or household types) or spatial regions. Results are provided at the household level or aggregated to higher spatial scales (department, region…).

The Dahbsim model has a modular structure.

• The biophysical module computes in its first part the water stress coefficient in year 1. And in its 2nd part it computes the water stress coefficient for the next years. A similar procedure is used concerning nitrogen.

• The crop module contains the equations describing the cropland allocation, the labor use, the rotation constraints, etc.

• The farm module contains the equations defining the resources constraints.

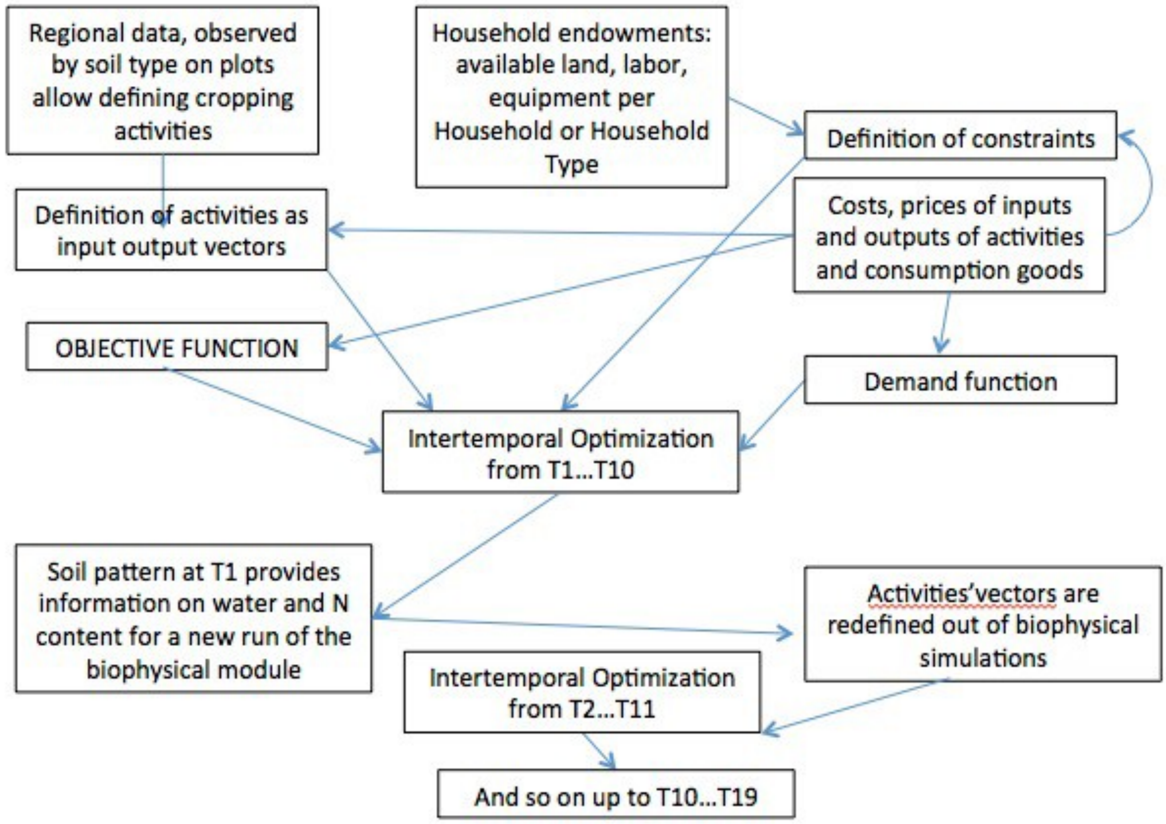
• The household module contains the equations defining household demand and time allocation

• A livestock module computes the feed requirements of different type of animals and has consistent feed-backs with the rest of the model, taking into account balances of feed consumption as well as manure for crop fertilization.

3 Results

Actually, there are not still results of any application; the results are the current development of the model. The following scheme shows the principal flows of the model, only considering cropping activities.

Simplified DAHBSIM scheme for cropping activities



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Is « bio-economic » farm modelling of any help for farming system design?

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1 Introduction

Many innovations at cropping system level impact the whole farm system by changing the flow of farm resources across farm activities. Using farm models has increasingly been proposed for assessing the feasibility of prototypes of cropping systems at farm level, and evaluating their impacts on household food production, farm income, and the environment. Such models are often called bio-economic model as a way to stress the mixing of knowledge about the biophysical and economic aspects of farming (Janssen & van Ittersum, 2007; Thornton & Herrero, 2001). *A priori*, one should not expect accurate predictions from these coupled bio-economic models, because of their complexity and the difficulty of measuring certain key input variables, such as labour availability for the different farm and off-farm activities, family income, and intra-farm consumption of agricultural products. This type of models can rather be used to explore 'what if' scenarios and to understand their outcomes including their inevitable uncertainty. In this paper, we review our experience with bio-economic farm models as virtual test benches for evaluating "cropping systems ideotypes" (CSI), i.e. idealized cropping systems proposed as alternatives to existing cropping systems, for increasing farm income and production or for reducing negative impacts of farming on the environment. Six published case studies are used (list of papers available at http://agents.cirad.fr/index.php/Krishna+NAUDIN/bio_economic_farm_modelling). The objective is to examine to what extent the models developed fulfilled their purpose of evaluating prototypes of cropping systems for farming systems design.

2. Materials and Methods

In 3 out of 6 case studies ('Madagascar', 'Brazil-CA', and 'Vietnam') the CSI were conservation agriculture options designed for low income family farms. In two other case studies, 'Senegal' and 'Brazil-Conv', the CSI were conventionally intensive cropping systems as an alternative to low yielding current practices. In the 6th case, 'France', CSI were options designed to reduce ground water pollution by lixiviated N. In all the case studies, we used farm models based on the 'Optimization Under Multiple Constraints (OUMC)' approach, in which an optimization procedure is used to find the set of crop, livestock and off-farm activities that best fits the objective of getting the highest farm income subject to constraints relative to seasonality of activities, the necessity to satisfy the family's basic needs (in food, clothes, health and education) throughout the time period covered by the simulation, as well as constraints relative to the farm's resources in land, labour force, equipments, and cash money. In each case study, a regional assessment of the diversity of farms was first established based on relatively large surveys. Table 1 shows the differences between cases regarding farm structure.

Table 1. Main characteristics of farms modelled in the case studies

Case studies	Predominant Farming system	Farm size (ha)	Number of family members	Number of workers	Total household income (€/capita/year)	Off-farm income (€/capita/year)
Brazil-Conv	Mixed crop livestock in transition toward intensive dairy farms	5-120	2-10	1.5-3.75	40-8000	0
Brazil-CA		16-51	2-4	2-3.8	800-6000	0-560
Vietnam	Mixed crop livestock systems in transition from subsistence to market oriented farms	0.7 – 4.7	5-12	2-7	20-400	0-200
Madagascar		2.5-3.5	5	6	5-800	0
Senegal		3.5-16	12-25	4-10	100-300	0
France	Mixed arable farms	100-120	3-5	0.25-1.1	25000	0

In 4 out the 6 studies, two typical farms were then selected within each of the farm category identified, and they were modelled thanks to a more detailed questionnaire applied to each individual farm. In the two other studies ('Senegal' and 'France'), each farm category was modelled using data of the survey averaged over the category. In all the case studies, model calibration was carried out to ensure that the model reproduced well the observed farm plans when using 'baseline simulations' in which the studied CSI were not incorporated into the list of options available to the simulated farm. Then, various scenarios were simulated in which CSI were included into the list of options, and changes in the economic environment of the farms were explored, such as changes in the prices of input or output, in the availability of credit or other financial tools, or introduction of subsidies of several kinds. Differences between studies in term of methodology were limited to the extent to which biophysical models were used to produce data relative to cropping systems and to minor differences in the optimization algorithm used. However, the level of complexity of the model varied greatly among cases, depending on the need to account for crop-livestock relationships, for the dynamics of farm performances over time, or for risks related to yield or price variability.

3 Results – Discussion

The main results are summarized in table 2. For several case studies, we found that even relatively uncertain model parameters or a highly simplified model structure allowed to draw robust conclusions on the feasibility of the locally studied CSI. The robustness of the conclusion was less dependent on the case study than on farm type within case studies. Typically, simulated farm plans were particularly robust for farms with strong labour constraints. In such case, the model prediction about rejection or adoption of CSI is not to be taken as an anticipation of what will occur in the real world. Rather, it provides insight on the economic relevance of the CS at farm level. When the model predicts rejection for farms with very low income, however, it is very likely that the technique will not be adopted by real farmers, who are not expected to make decisions putting at risk the daily subsistence of their family. When model outputs were less robust (i.e more sensitive to uncertainties on key inputs), they were still useful for qualitatively identifying the main factors at farm and field level determining the economic relevance of adopting the studied CSI. They also helped in identifying knowledge gaps that should be addressed for improving the reliability of quantitative assessment of the feasibility at farm level of studied CSI. Often, these gaps relate to the availability of data that quantify the agronomic performances of CSIs in the biophysical and socio-economic environment of the case study.

Table 2. Summary of results per case study.

	CSI tested	**Model complexity (*)**	**Data on CSI performances**	**Typical Result in terms of FSD**	**Typical gaps in knowledge identified**
Brazil-Conv	More intensive maize systems (cultivar, fertilizer, mechanization)	2/4 :S-R-LB	Ad hoc crop model calibrated and validated on site	Identification of soil constraints making dairy specialization too risky for certain farms under current economic environment	
Brazil-CA	Conservation agriculture	4/4 :D-R-LC	On-farm and on-site trials	CA ideotypes refined per farm types	Agronomic / environmental performances of CA
Vietnam	Conservation Agriculture	1/4 : S-NR-LB	On-farm and on-site trials	CA not appropriate for most farm types, subject to further studies for others	Long term Agronomic / environmental performances of CA
Madagascar	Conservation agriculture	3/4 : D-NR-LC	On farm surveys and trials	CA systems with fodder crop beneficial for dairy cow farmers. Fraction of biomass used for soil protection against erosion likely to decrease when price of milk increases.	Agronomic / environmental performances of CA
Senegal	More intensive cereal cropping systems (fertilization)	2/4 : S-R-LB	Ad hoc crop model calibrated and validated on site	Drought insurance may entail crop intensification but subsidies to insurance are less effective than subsidies to credit or than direct cash transfers to farmers for increasing the simulated farm income	Agronomic / environmental performances of crops under highly variable rainfall. Nutrient fluxes between livestock and crops.
France	Lower N lixiviation systems	1/4 : S-R-L0	Ad hoc crop model calibrated and validated on site	The cross-compliance restriction associated to nitrate directive needs to be high to incite farmers to adopt CSI	Suitability of bio-economic modelling for co-assessment and co-design of cropping systems.

(*) Model complexity is described using a 1 to 4 scale and a string chain accounting for Dynamic (D, 1) or Static (S, 0) approaches, plus the integration of Risk (R, 1) or not (NR, 0), plus the level of details of the relation between livestock and cropping systems (LC: detailed, 2; LB: basic, 1, L0: none, 0)

4 Conclusions

Bioeconomic farm models should not be seen as a way to predict adoption or rejection of innovative cropping systems by real farms, but rather as a way to better identify (i) gaps in knowledge about the agro-environmental performances of such innovative cropping systems that are critical for comparing them with current practice from the point of view of a farm, and (ii) the key factors determining the feasibility of such systems at that scale. In that sense, bioeconomic farm models are a very effective way to assemble available knowledge at field and farm scale for identifying the conditions at which strong changes in cropping systems may take place.

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Trade-offs in soil fertility management on arable farms

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1 Introduction

Crop production and soil fertility management implies a multitude of decisions and activities on crop choice, rotation design and nutrient supply. Within each of these management categories, many options are usually available to farmers. In practice, the choices to be made and the resulting outcomes are subject to a wide range of objectives and constraints. Objectives are economic as well as environmental, for instance sequestering carbon in agricultural soils or reducing nitrogen losses. Constraints originate from biophysical and institutional conditions that may restrict the possibilities for choosing crops or the use of specific cultivation and fertilization practices. Finding ways to maintain farm profitability while increasing carbon sequestration or reducing undesirable emissions is complicated by many interactions and feedbacks among agricultural practices (e.g. Powlson *et al*., 2011; Alluvione *et al*., 2010).

2 Materials and Methods

To explore farming options related to nutrient and soil fertility management, we developed the mixed integer linear programming model NutMatch. The novelty of the model is the coherent description of mutual interdependencies amongst a broad range of sustainability indicators related to soil fertility management in arable cropping, enabling the quantification of synergies and trade-offs between objectives. In NutMatch, farming systems are viewed as being composed of cropping and fertiliser activities. Cropping activities refer to the growing of crops at predefined nutrient (NPK) requirements. These requirements have to be covered by nutrients applied in fertiliser activities. Each activity is characterised by design criteria and quantified via so-called input-output coefficients derived from the literature and secondary data. Input-output coefficients are strongly linked to the goals pursued with nutrient management in crop rotations (e.g. food production, income generation, maintenance of soil fertility, minimising environmental impact) and describe inputs (e.g. organic fertilisers) and desired and undesired outputs (e.g. crop yields, nitrous oxide emission). Each activity not only contributes to any of the objective variables, but also claims limited 'resources'. In NutMatch, the sum of activities' claims is subject to a series of constraints, dictated by a priori set values. For example, phosphorus surplus at rotational level should be between -5 and +5 kg P_2O_5 kg per ha.

We applied NutMatch to two crop rotations, differing in crop areas and cultivation of green manure crops. ROT1 is a 'standard' 1:4 rotation with four crops: winter wheat, ware potato, silage maize and sugar beet. In ROT2+, the winter wheat area is doubled at the expense of silage maize, with fertilised green manure crops after both winter wheat crops. Winter wheat straw is left in the field in both rotations. In model optimizations, rotations can be combined with four fertiliser strategies differing in the use of organic fertilisers. In one strategy, nutrient supply to crops is based on mineral fertilisers only, in three others mineral fertilisers are combined with either cattle slurry, pig slurry or compost. The two rotations and four fertiliser strategies each contribute differently to desirable and undesirable objective variables, due to differences in financial returns, emissions and organic matter inputs into the soil via crop residues and organic fertilisers. In the case study presented here, for each combination of two rotation types and four fertiliser strategies, trade-off curves were calculated of newly built soil-C via additions of organic fertilisers and crop residues on the one hand (kg C ha^{-1} yr^{-1}), and nitrogen losses (NO_3-N, N_2O-N; kg ha^{-1} yr^{-1}) on the other. End points of each trade-off curve are defined by the maximum values of newly built soil-C and minimum values for nitrogen losses. Intermediate points are calculated by maximising newly built soil-C while gradually tightening the restriction on either NO_3-N leaching or N_2O-N emission.

3 Results – Discussion

Trade-off curves of newly built soil-C and nitrogen losses are shown in Fig. 1. Maximum newly built soil-C ranges from 325 to 880 kg C per ha per year. Compared to using mineral fertilisers only, the use of cattle slurry and especially compost results in large increases of newly built soil-C, while pig slurry hardly does so. Considerable differences in the contribution of organic fertilisers to soil C built-up are explained by differences in their organic matter contents. Per kg P applied in organic fertilisers, the supply of organic matter is relatively large when using cattle slurry or compost and low when using pig slurry. Compared to using mineral fertilisers only, the use of cattle slurry and compost in both rotations adds ca. 240 and 390 kg newly built soil-C per ha per year, while pig slurry adds only 26 kg C per ha per year.

In ROT2+, maize is substituted by winter wheat, and includes green manure crops after both winter wheat crops. In all fertiliser scenarios, these changes added ca. 160 kg C per ha per year (Fig. 1), but reduced financial return by ca. 340 euro per ha. The extra built-up of soil-C was mainly due to the increased winter wheat area (with straw left in the field), while the green manure crops only had a modest effect (data not shown).
Near-maximum values for newly built soil-C were attained when organic fertilisers were used at maximum allowable levels (as defined by maximum allowable phosphorus surplus at rotational level), and were hence associated with higher nitrogen loss. Relationships between newly built soil-C and nitrous oxide emission werefairly linear before plateauing, suggesting that there is a strong relationship between the build-up of soil-C and these losses. Nitrogen leaching loss, however, could be considerably reduced without dramatically affecting soil-C built up. When maximizing newly built soil-C while tightening the restriction on leaching loss, NutMatch maintains the supply of organic fertilisers as high as possible, while reducing mineral N supply to crops. This strategy initially only affected the return of carbon to the soil through crop residues, but left the more significant supply of carbon via organic fertilisers unaffected.

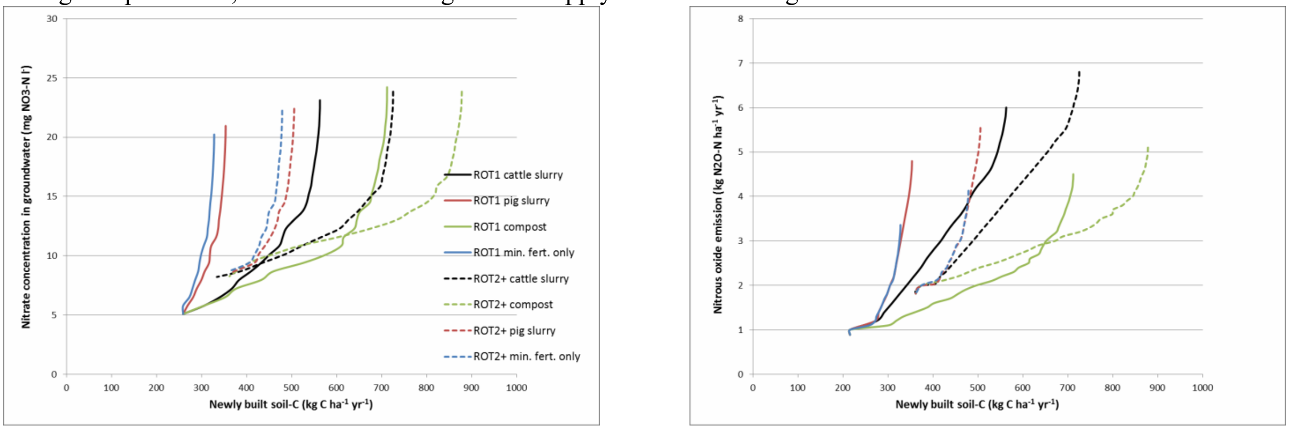

Fig. 1. Trade-off curves of newly-builtsoil-C and nitrate concentration in ground water (left) and nitrous oxide emission (right) in ROT1 and ROT2+ under four different fertiliser scenarios. End points of each curve correspond with maximum newly built soil-C and minimum N loss, respectively.

The aggregated effect of newly built soil-C and nitrous oxide emissions in terms of greenhouse gas (GHG) emissions in different rotations and fertilizer scenarios can be assessed by expressing both in CO_2-equivalents (1 kg newly built-up soil-C = 3.7 kg CO_2-eqs.; 1 kg N_2O-N = 487 kg CO_2-eqs.).For example, when maximizing newly built soil-C in ROT1 (i.e. right end points in right graph of Fig. 1), it can be calculated that additional soil-C built-up resulting from the use of cattle and pig slurry did not compensate for additional emissions of nitrous oxide, so that the net GHG emission effect of using these organic fertilisers is negative. Only the use of compost resulted in a net GHG emission benefit in the sense that additional soil-C built-up outweighed additional nitrous oxide emission. The net GHG emission effect of the introduction of (fertilised) green manures and increased winter wheat area in ROT2+ was positive. This positive effect was exclusively due to the increased winter wheat area.

4 Conclusions

Trade-off curves generated with NutMatch show that carbon sequestration conflicts with reducing nitrogen losses. From a greenhouse gas emission perspective (CO_2-equivalents), soil-C gained via the use of animal slurries is entirely offset by increased N_2O emissions. Using compost or adapting crop choice to increase crop residue return to soils resulted in a positive GHG emission effect, but was associated with lower farm profitability. Due to the many data used from a large variety of sources, our trade-off curves are uncertain. However, these trade-offs are very relevant and urgently require further study. Our analysis is partial, as we did not consider GHG emissions from mineral or organic fertilizer production. Our model-based explorations provide insight in options for soil carbon sequestration and their limitations vis-a-vis other objectives.

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A SPATIALLY-EXPLICIT MULTI-SCALE BIOECONOMIC MODEL TO DESIGN AND ASSESS AGRICULTURAL LANDSCAPES

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1 Introduction

Agricultural landscapes drive the provision of several ecosystem services. These landscapes are the partial results of farmer cropping system choices at the field and farm levels. Cropping system choice is driven by a range of parameters that act at the field, farm and regional scales such as biophysical parameters, farm structure and regional quotas. Bioeconomic models can assess *ex ante* the impacts of policies on landscapes resulting from the modification of farmer choices. They have scarcely been used for assessing new spatially-explicit agricultural landscapes with the integration of the field, farm and regional scales (Delmotte *et al*., 2013). To assess the effects of policies on the landscapes change and the regional sustainable development, we built a regional, spatially explicit, multi-scale bioeconomic model of farmer cropping system choices. The model is tested in Guadeloupe, a French archipelago in the Caribbean islands.

2 Materials and Methods

The Multi-scale model of the crOpping Systems Arrangement and Its Contribution to sustAinable development MOSAICA produces new agricultural landscapes at the regional scale by optimising the allocation of cropping systems regionally at the field scale. It accounts for the constraints and opportunities at the field level (e.g. soil types), the farm level (e.g. the availability of production factors), and the regional level (e.g. the policies implemented). The inputs of MOSAICA are i) the geographic database of fields, ii) the database of activities that describe the cropping systems that can be allocated to fields and iii) a farm typology.

The geographic database is composed of fields represented by polygons with relevant information for the cropping system allocation defined with geographical information systems, statistical data or farm surveys. The activities are cropping systems defined with technical coefficients and externalities derived from previously published papers, relevant documentation or expertise from local advisers. The farm typology is built with a classification tree that can help observe farming system changes across scenarios. For each farm type a risk aversion coefficient is allocated and used as the calibrating parameter of the model. The model optimizes the overall farmer's utilities, which includes the revenue and the risk aversion coefficient which is the calibrating parameter, similar for all the farms initially classified in the same type. The allocation of cropping systems is modelled through a set of equations that model the choice of cropping systems by farmers at different scales, namely the field, farm, sub-regional and regional scales. The prediction capacity of the model was assessed in Guadeloupe at field and regional scales by comparing the initial crop areas and the simulated ones and the initial and observed farm types at farm scale. The outputs of the model are the new agricultural landscape and the calculation of 19 sustainability indicators. These indicators assess the impact of agriculture on society and environment at a regional scale by accounting for cropping system externalities at plot scale and the location of these cropping systems throughout the region by using scale change methods.

As an illustration of its possible interest, we used the model to assess the consequences of three scenarios accounting for expected future modifications of subsidies. In the “area reallocation” scenario, the subsidies are reallocated to each crop with an amount of 1768€.ha^{-1}. The “workforce reallocation” is the reallocation of subsidies per unit of workforce with an amount of 15569€ per worker. The “decoupling” scenario is the decoupling of subsidies from production.

3 Results – Discussion

Results from the evaluation were good at all the scale tested (similarity of 91% at regional scale, 80% at farm scale and 75% at field scale) which means that the model can be used for scenario analysis. The scenario modified the repartition of cropping systems in landscapes in a spatially explicit way. The results are summarized in this abstract at the regional scale (Fig. 1).The general trends observed throughout the three scenarios demonstrate a sharp decrease in sugarcane and banana production over the island with their total disappearance in the "area reallocation" scenario and in the "decoupling" scenario only for banana farms. By contrast, the areas devoted to pasture and fallow fields increase and the area devoted to crop gardening and orchards increase more progressively, as well. The consequences of these new landscapes are assessed based on spatially explicit indicators at the regional scale (Table 1).

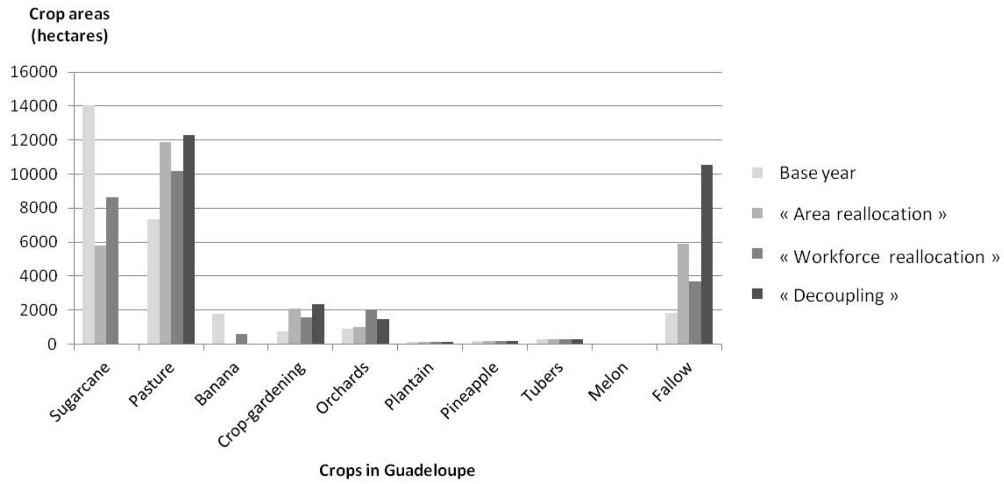

Fig. 1. Evolution of crop acreage from scenarios

Table 1. Spatially explicit assessment of agricultural landscapes from scenarios

Indicators	Base year	"Area reallocation"	"Workforce reallocation"	"Decoupling"
Agricultural added value (M€.y^{-1})	96	138	125	162
Total amount of subsidies (M€.yr^{-1})	75	60	62	72
Ratio of nutrients produced over needs	15%	20%	23%	23%
Potential electricity production with crops (MW.yr^{-1})	33	16	24	0
Total needs of workforce (persons)	3105	2566	2928	2772
Area of risk of contamination of food crops (ha)	1170	2013	1529	1843
Ratio of water bodies potentially polluted	35%	14%	27%	18%
Amount of water needed for irrigation (m3.yr^{-1})	17.7	14.7	19.6	15.1
CO2 emissions from farming (kT eq CO2.yr^{-1})	158	142	149	135
Diversity of crops across landscape (Simpson's Index)	3.0	3.1	3.4	2.7

In terms of economic sustainability, these three developed scenarios were relevant because they performed better than the base year in terms of economic sustainability especially the "area reallocation" scenario with the increase of the agricultural added value to 138M€.yr^{-1} and the decrease of subsidies to 60M€.yr^{-1}. For social sustainability, the scenarios performed better in terms of food self-sufficiency, especially scenario 3, with an increase of nearly 50% in food-self-sufficiency. In focusing on environmental sustainability, the pressure on biodiversity and water resources decreased over the three scenarios.
The modelling of farmers cropping system choices and the creation of agricultural landscapes resulting from the modification of a set of rules at different spatial scales is useful for the prototyping of landscapes. This multi-scale modelling is especially important for addressing sustainability issues, such as food security or biodiversity preservation that require multi-scale strategies for resolution. Our set of indicators can even assess the trade-offs in the provision of services by displaying the direction of change in the indicator value between the base year and the scenarios.

4 Conclusions

The bioeconomic model MOSAICA integrates the different scales involved in the decision-making process of farmers and policy makers, *id est* the plot, farm, sub-regional and regional scales. This integration of agricultural systems allows for the testing of the multi-scale policy and parameter changes that are involved in agricultural production and the assessment of these changes on the provision of ecosystem services with spatially explicit indicators.
Our model could be relevant for testing spatially targeted policies aimed at improving the contribution of agriculture to sustainable development.

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Linking modelling with optimization techniques to maximise farming system productivity - Preliminary assessment in an experimental field study

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1 Introduction

Majority of farmers in India practise subsistence farming. It is characterised by small and scattered land holdings, the whole family works on the farm, most of the work is done manually and most of the farm produce is consumed by the family. The types of farming systems practiced by the small holders in India vary across space and time. The interaction of biophysical, technological, institutional and socio-economic conditions leading to temporal and spatial variability among the farming systems. However, the enterprises of the farming system depends largely location specific and farmer centric nature. The farming system for Nutrition (FSN) model protocol demonstrate the feasibility of a wide-ranging and sustainable nutiriton-sensitive agricultural intervension (Das *et al.*, 2014). It tries to capture the extent of productivity and profitability enhancement in the farming system contributing to enhanced spending by the household towards balanced diet. In an another approach used a whole farm model - APSFarm in a participatory modeling approach to examine the sensitivity of four contrasting case study farms to a likely climate change scenario (Rodriguez et al, 2014). A review on farm household modeling showed that there are enough techniques for integrated assessments of farm systems in relation to climate change, adaptation and mitigation, but they have not yet been combined in a way that is meaningful to farm level decision makers (van Wijk *et al.*, 2012). However, there is a need to include the resource availability of the farmer, and their capability to sustain under risky weather, particularly unseasonal weather aberrations. It is very complex to model the entire farming system in a single tool. If you succeed in linking modeling with optimization techniques, then it will be highly useful for the small holder farming community to select the farming enterprises based on their resource availability and agro-climatologically suitability. With this aspect in mind, we have initiated a study to link modeling with optimization techniques to maximise farming system productivity along with the food habit/nutritional security of the small farmers. The methodological framework for the region was developed and monitored one year data from the field experiment which consists of different enterprises crop sequences (rice, wheat, maize etc), livestock and fish pond.

2 Materials and Methods

The study area is located in Meerut (29°4' N, 77° 46' E, 237 m), part of the Upper Gangetic agro-climatic region of the Indo Gangetic Plains (IGP), India (Fig. 1). The climate is semi-arid subtropical, with dry hot summers and cold winters. Meteorological data were collected from the agro-meteorological observatory located at the Project Directorate of Farming Systems Research, Modipuram, near to the experimental site, during the period 1992–2010. Data collected include daily maximum and minimum temperatures, rainfall, and sunshine hours. The solar radiation was estimated based on sunshine hours, by using the Angstrom equation (Angstrom, 1924; Medugu and Yakubu, 2011).

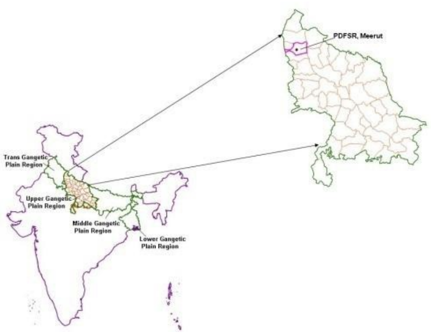

Fig. 1. The Indo-Gangetic Plains in India, indicating agro-climatic zones and the location of the study site in Meerut District, Uttar Pradesh, India.

Fig. 2. Typical farming system followed in the Meerut district of northwest India.

The climate data for the period 1980–1991 were created using the bias-corrected AgMERRA (Ruane *et al.*, 2014) satellite-derived data. The soil of the experimental site is a sandy loam (18% clay, 19.5% silt, and 62.5% sand) of Gangetic alluvial origin. It is very deep (>2 m), well drained, flat (about 1% slope), and representative of an extensive soil series, i.e., the Sobhapur series of northwest India. Rice–wheat and sugarcane–wheat are the predominant cropping systems in the area with livestock being an integrated part of the farming system of sample households. However, in this present study we have considered only the rice-wheat farms of each households. Livestock holding is generally proportional to land holding but majority of the farmers, even with tiny land holdings, keep at least one milch animal (indigenous or crossbred cow and/or buffalo). The study site has excellent irrigation facilities with almost 99% cultivable area being irrigated. The typical farming system followed in this region is depicted in Fig.2. The methodological framework used for the study is given in Fig 3.

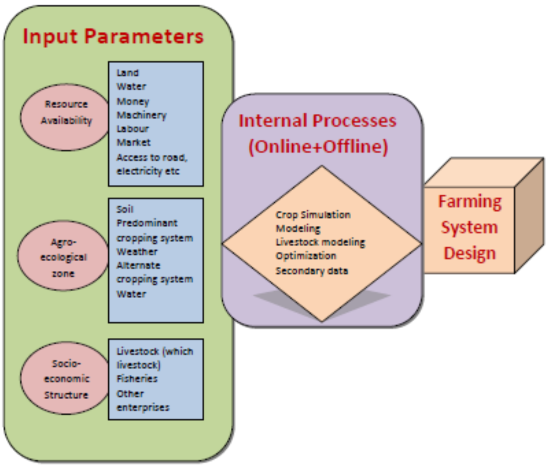

Fig. 3. Methodological framework of FSDST (Farming System Design Support Tool)

We have used APSIM7.5 to build the simulation set up of major crops. Since we have grown the other crops under controlled environment, we have used the yield obtained as the potential yield.

3 Results - Discussion

Based on the experiments conducted at the same study site during a period of six year (2004-2010), with a farmer having 1.5 hectare irrigated land, besides fulfilling all the requirement of 7 members household food and fodder demand (animals) inclusive cost of production, could create an additional average annual saving, which will be helpful to meet the farmer for health, education and social customs and thereby improved the livelihoods (Singh *et al.*, 2011). During the year 2013-14, we have completed the recording of crop phenology, crop growth, yield and yield attributes for two crop seasons - kharif and rabi for all important crop enterprises. The potential yields of rice, wheat, maize and sugarcane were simulated through APSIM7.5. Some enterprises, crop calibrations are not available and hence we have used maximum yield of other experiments as the potential yield. As far as livestock component is concerned, we have used the secondary data for estimating the household potential yield. The fish yield for one year was also monitored and taken this as the potential yield because it is located in the research farm and followed all the recommended management practices. To compare the productivity of all farming system enterprises, converted the productivity into one major crop ie., rice equivalent yield. LINGO14.0 was used for optimization of farming system enterprises.

4 Conclusions

The initial results indicated that linking of modeling with optimization tool provide an integrated approach to pinpoint the environmentally location specific enterprises of farming system based farmer centric resources. More research and fine tuning of methodology is needed for developing an integrated FSDST (Farming System Decision Support Tool).

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Characterization of farming systems in drylands of South Asia for assessing resource constraints and technologies

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1 Introduction

Millions of smallholder farmers in South Asia derive their livelihoods from dryland agricultural systems. These agricultural production systems are characterized by low productivity, low farm incomes and natural resource degradation. There is a growing emphasis on sustainable intensification of these systems for improving farmer livelihoods. The CGIAR research program on Dryland Systems has adopted a systems approach to enhance agricultural productivity through technological interventions in South Asia. It is important to identify options that are manageable within the context of the farmer's resource base and the household's objectives that could improve farm household well-being. This study focuses on the development of representative farming systems for subsequent development of bio-economic farm model. Representative farming systems are developed using objective approach. We adopted an objective approach to determine the number of representative farming systems by using Model-based clustering method based on finite mixtures (Fraley & Raftery, 2002).

2 Materials and Methods

Farm level data is captured using, crop simulation modeling and on farm trials. The typology of representative farms is created through multivariate analysis of 780 observations from pooled cross section data from 2009 to 2012, obtained from Village Dynamics in South Asia (VDSA) farm household survey conducted by International Crop Research Institute for Semiarid Tropics (ICRISAT, 2014). Multivariate outliers are eliminated based on Mahalanobis' distance to enable robust estimation (Todoro et al., 2011). Then forty two socio economic and bio physical variables are identified (key variables are listed in the Table 1), then we applied principal component analysis to create latent variables. The typology of representative systems is created through cluster analysis on latent variables. We adopted an objective approach to determine the number of clusters by using Model-based clustering method based on finite mixtures (Fraley & Raftery, 2002). In this method, number of clusters is determined statistically contrary to conventional methods such as hierarchical or kmeans method, which depends on subjective judgment.

3 Results - Discussion

Optimal number of clusters is identified based on Bayesian Information Criterion (BIC). In this case, the best model according to BIC is a variable -covariance model (MClust VVV) with 5 components or clusters (Fig. 1).

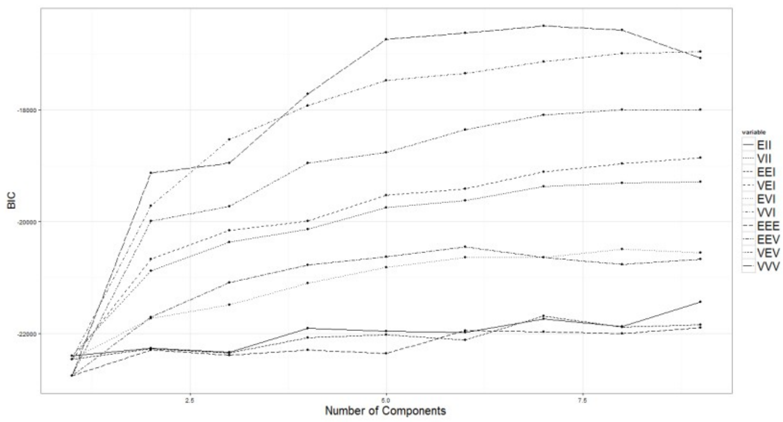

Fig. 1. BIC values across the clusters under different covariance structure

Table 1. Descriptive statics of farm clusters

Farming Systems					
Variables	**Type1**	**Type 2**	**Type 3**	**Type4**	**Type 5**
Adult mean education (years)	2.6	6.0	3.5	7.2	5.4
Farm size (ha)	1.8	5.6	0.0	1.8	2.5
Irrigated area (ha)	0.0	1.9	0.0	0.2	1.2
Good_soil_area	0.6	2.1	0.0	1.1	1.1
Drought tolerant crop area (ha)	0.8	1.8	0.0	0.6	0.8
Value of crop produce marketed (USS)	157	1645		1467	244
value of livestock product marketed (USS)		39351		1	0223
Cash crop area (ha)	0.1	1.3	0.0	0.2	0.7
Tropical Livestock Units (TLU)	0.5	1.0	0.1	0.0	0.8
Fertiliser use (kg/ha)		44165		062	232
Purchased feed (US$)		14115		0	064
Crop gross margin (US$)	119	2315		0270	848
Livestock gross margin (US$)	212	826	38	17	504
Nonfarm Income (US$)	504	1165	991	1695	812
Off farm income (US$)	701	167	482	193	341
Farm Machinery (US$)		83966	43	171	362
Value of durable goods (US$)	887	3641	1006	2001	1617
Building assets (US$)	1628	3739	1802	3031	1838
Family.hours.sum	201	844		0228	533
Hired.working.hours.sum	108	1007		0237	579

Table 1 reveals the existence of wider heterogenity in farm types. It ranges from land less households to irrigated-livestock cropping systems. The drivers for the heterogenity are varying access to irrigation, livestock units, non-farm employment and land size The farm types are validated through informal interviews, key informant interviews and focus group discussions. We found potential interactions among different farm types such as landless farmers provide labour as well as linking with markets for trading livestock and restock inputs with farm based systems.

4 Conclusions

Synergies and tradeoffs on range of scenarios on technological interventions and resource constraints will be assessed, relating to changes in current enterprise mixes, potential for intensification and environmental impact. Indicators generated from the model are useful for effective farming system design and up scaling to larger areas, when linked to the typology.

Acknowledgements : Authors are greatfull to National Agricultural Research system Partners

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Identifying sustainable farms under diverse agro-ecological conditions and livelihood strategies in southern Africa: An interdisciplinary simulation-based approach

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1 Introduction

Agricultural systems face the challenge to feed a growing population while at the same time reducing their environmental impact in a changing world subjected to shocks, such as extreme weather and economic volatility (Godfray *et al.*, 2010). In this global context, southern Africa appears as a particularly sensible region due to the fact that more than 60 % of the livelihoods rely on rain-fed agriculture and have low adaptation capacity (Zinyengere *et al.*, 2014). The diversity of biophysical and socio-economic situations in this region requires prudence in the promotion of "good practices", and a good understanding of local farming systems complexity and their current level of inefficiency. In order to identify the most efficient farms (i.e. minimizing their inputs and simultaneously maximizing their outputs), we implemented the Data Envelopment Analysis (DEA, Charnes *et al.* (1978)) method, which is the most commonly used non-parametric frontier efficiency approach. Using results from farm household surveys conducted in Zambia and Malawi, we modelled the efficiency frontier based on observed best practices in 2012 and identified potential progress margin of efficiency. Even if those results are themselves significant outcomes as efficiency analysis in southern Africa are very rare (Chiona *et al.*, 2014), the originality of this research is the combination of DEA with APSIM (Agricultural Production Systems Simulator) crop model to assess the evolution of this multi-dimensional efficiency frontier. The crop growth model APSIM was used to simulate the performance of a wide range of maize-based cropping systems under different agro-ecological conditions and future climatic scenario, for several types of farming systems identified on structural data basis (cattle, adult equivalent, income, etc.). With this approach we aim to identify cropping systems and farms in southern Africa that are most efficient under future climate.

2 Materials and Methods

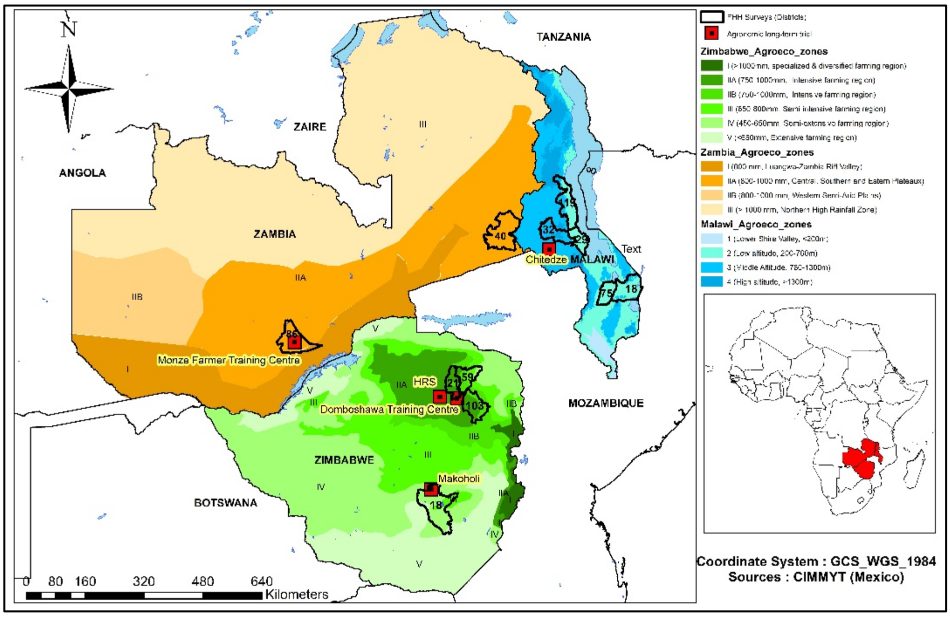

Fig.1. Data overview in the study region: From field scale (long-term agronomic trials) to farm scale (farm household surveys)

Figure 1 shows the location of the long-term agronomic trials used for APSIM calibration and the number of farm households investigated in each district where trial data were available. At the field scale, APSIM (v. 7.6) was calibrated using long-term trial data and future climate was generated with 17 General circulation models (GCM) for two extreme emission scenarios (RCP 2.6, RCP 8.5) (Rusinamhodzi *et al.*, 2015). At the farm scale, farming typology has been implemented with a classic Principal Component Analysis - Ascendant Hierarchical Classification in R 3.0.0. Compared to data displayed in Figure 1, the final typology includes only half of the data available as some survey was incomplete and/or data inconsistent. The efficiency frontier analysis was implemented in GAMS 23.4. The chosen model assumed variable return to scale, i.e. marginal cost differs for each level of inputs and outputs, which implies that each farm can only be compared with farms of similar size. Undesirable outputs are included in the model using the weak disposability assumption (Färe *et al.*, 1989), i.e. to connect undesirable production to the desirable output, while the first one is minimized and the later maximized.

3 Discussion

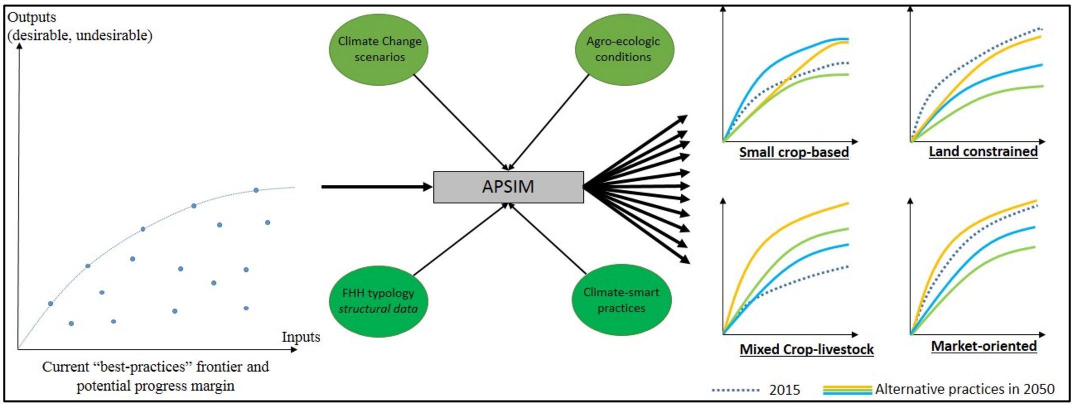

Fig.2. Combining efficiency frontier analysis with APSIM for ex-ante assessment of climate-smart practices

Figure 2 represents the modelling framework implemented to identify future climate smart practices in southern Africa. In this simulation-based optimization modelling approach, APSIM allows simulating the levels of inputs and outputs for several combinations of climate change scenarios, agronomic practices and agro-ecological conditions, for each types of farming system identified. DEA, represents the optimization model which allows assessing on a multidimensional plan the most appropriate climate-smart practices, for every level of inputs, outputs, and undesirable outputs. Compared to classical approach where farm and crop models are combined in a complex integrated framework, our model represents a "loose coupling approach" as promoted by Van Wijk *et al.* (2012) in their review of farm household modelling in climate change context.

4 Conclusions

The diversity of agro-ecologic and socio-economic situations in southern Africa must be tackled with a site and farm-specific calibration of crop models and ad-hoc farm models taking into account farm constraints and farmers' objectives. Frontier efficiency analysis appears as very promising approach compared to other optimization model (e.g. multi objective optimization, multicriteria decision making, etc.) as it allows identifying a whole set of efficient solutions (instead of few Pareto ones) and an interdisciplinary interpretation including microeconomic theory (marginal cost, allocative inefficiency).

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Dynamic Crop Production Responses to Realizations of Weather and Production with Application in Jordan

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1 Introduction

Farming decisions across the globe are defined by the uncertainty of output quantities and prices, and this axiom holds true in the semi-arid areas of Jordan, where farmers must adapt throughout the calendar year to manage the variability of production due to the magnitude and timing of the onset of rains. In order to understand and model the response farming practiced by Jordanian farmers, a dynamic and stochastic modelling approach is required.
Agricultural production decisions are shaped by the stochastic interactions of crop growth, weather, and financial outcomes. Incorporation of the biological responses with economic incentives, while intuitive, presents many challenges in modelling. Optimizing agents respond to current biological developments, with only distributional knowledge of future outcomes (as opposed to perfect foresight). The selection and timing of production decisions are important for determining outcomes both in the short-run (e.g. yields, revenues, etc.), as well as in the long-run (e.g. soil moisture and soil organic matter). Producers choose which crops to plant, how much and when to apply inputs, and when and what to harvest. These choices influence the profitability of production each year within a stochastic environment, and when incorporated in a single year model can easily be optimized. However, agricultural production decisions also influence future profitability through their effect on soil properties, such as soil moisture or organic carbon, which are important for both the long term sustainability of the household, and avoiding environmental degradation. Optimization models analyzing intra-seasonal stochastic production and dynamic inter-seasonal resource management present a modeling challenge due to the often encountered curse of dimensionality, where model size increases rapidly exponentially with the number of time periods and stochastic events.
The agricultural systems model presented here overcomes these issues by addressing this problem with a combined Dynamic Programming (DP) model and a portfolio model. The model developed here values the production trade-offs of short- and long-run outcomes, within a stochastic choice model. This methodology allows for the dynamic testing and valuation of various production technologies, including conservation agriculture and crop varieties.

2 Materials and Methods

The approach is illustrated with a model of representative agricultural households in Jordan, specifically within the Karak Governorate. Model data is obtained from crop and weather simulators and household surveys. As the data required for a dynamic bio-economic model are intensive and unavailable through historical records, the Agricultural Production Systems Simulator (APSIM) is calibrated at the local level to approximate crop yields given various weather and managerial choices (Keating et al. 2003). To generate a rich distribution of outcomes conditional on production choices and weather conditions, necessary for the stochastic model, a simulated distribution of weather years using LARS-WG 5.5 (Semenov 2010) was generated to serve as inputs to APSIM.
Data were collected at the household level by the International Center for Agricultural Development in the Dry Areas (ICARDA) to define farm household typologies for testing the sensitivity of results and households to differences in various endowments. Households are small-holder farms in the semi-arid region of Central-Western Jordan, typically relegated to barley and wheat production with no access to irrigation for field crops.
A two-part dynamic stochastic model was created to efficiently model conditional production decisions and short- and long-run economic incentives for the farming system. While a single Discrete Stochastic Program (DSP) might be preferred, dependence of transition probabilities for soil attributes (i.e. moisture and organic carbon) across years on managerial choices is not consistent with the DSP approach. For this reason, the soil attribute management problem is addressed in part one of the modeling system using a stochastic DP model over a ten year horizon using discrete choices of crop/conditional management strategies to derive the long-run value of soil attributes. The DP models an optimizing agent maximizing time-discounted returns within and across years given stochastic outcomes and conditional production choices. The resulting dynamic solution, provides estimates of the long-term marginal value of carry-over soil attributes.
Part two of the dynamic stochastic model is based on a single year portfolio model. The choices available can be thought of as investment assets which are defined by set crop/conditional management strategies that fully specify the

management practices for the crop given weather outcomes. The distribution of returns to these assets is evaluated for each of the simulated weather years and reflects both the value of crop products (grain and fodder) and a term for valuing the ending stocks of soil attributes derived from the DP model of part one. Choices in the portfolio model are continuous allowing for diversification across crops and input levels to allow for less computationally restrictive risk management strategies. While the portfolio model may seem static at first blush, the incorporation of management choices that depend upon weather outcomes (e.g. timing of planting conditioned on rainfall, weather conditions that trigger fertilizer applications, etc.) make this model effectively dynamic as well as stochastic. The incorporation of a valuation of soil attributes as it affects future production possibilities can be intuitively analogous to the co-state variable in a dynamic Hamiltonian or the expected future returns in a Bellman's equation, where decisions are optimized for a single period given the conditionally optimized future periods.

Combining these two dynamic models builds upon the strengths of each to produce an efficient and tractable system for modeling inter- and intra-seasonal choices. The stochastic process in both models is driven by the combined weather and crop simulation models to provide a large enough sample to generate rich distributions of the returns to crops and conditional managerial strategies. The stochastic portfolio model can be considered similar to a DSP, however, the model defines choices through thresholds and ranges in each time period, as opposed to simplified discrete states. The threshold and range modelling approach does not require state specific assumptive transitional functions, thus maintaining the observed biological process of crop production. The combined DP and portfolio approach capture the short- and long-run benefits and costs of agricultural production in such a way that allows the imposition of constraints in a household modeling framework, such as limits on labor and liquidity, consumption requirements, etc. These household specific features with the combined approach allow for testable hypotheses to the effects of household endowments on choices and outcomes.

3 Results – Discussion

The results of the model will show both the importance of dynamic intra-seasonal management responses, as well as the impact of long-run soil valuations on production choices. Optimizing agents balance the trade-offs of short-run income and financial constraints/preferences with the incentives to manage soil quality. With the incorporation of the valuation of soil parameters, optimizing agents, both risk-neutral and risk-averse, will adopt crop rotations and diversified land allocations. The impact of taking a myopic view that does not place a value on soil attributes is also assessed.

The model is also used to assess the long-term benefits of innovations such as zero-tillage for increasing the sustainability of the farming system by better management of soil attributes, showing the importance of incorporating the financial incentives with the biological trade-offs. As planting strategies influence current year outcomes, they also directly influence the distributions of the end-of-year soil attributes, which determines future production potential. The results illustrate the dynamic trade-off, through the valuation and incorporation of soil attributes, of zero- versus conventional tillage.

4 Conclusions

We develop a two-part dynamic stochastic model that integrates the stochastic biological process with the financial and economic incentives of crop production. Land use and input decisions are based on short- and long-term trade-offs of current and future returns which includes the impact of weather-related risks. By analyzing the long-run horizon through a dynamic programming model that ignores short-run constraints on household resources, we derive a dynamic valuation of soil attributes. This valuation is then used in a short-term dynamic, stochastic model of the household that focuses on issues of crop mix and the diversification of conditional management strategies for the purpose of measuring the sustainability of the household and their resource management strategies. This hybrid approach results in a tractable model which can be used to optimize production behavior over both the short- and long-run.

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Strategic and tactical Urban Farm design, a conception and sizing problem

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1 Introduction

During the last decades, urban agriculture have been brought up to date in developed countries. Adapting existing peri-urban farms and creating new urban farms with robust and sustainable business models are major issues to enable this new development. Indeed, urban farm systems are more constrained than rural ones by infrastructures and practices restrictions and higher costs (investments, logistics). But urban farms can easily integrate multi-functionality, combining production, leisure activities, environmental or logistic services (Mougeot, 2000 ; Ogier *et al.,* 2013).
Many works have been made on Sustainable Food Supply Chain and Agri-Food Supply chain since the 2000s. Ahumada and Villalobos (2009) developed production-delivery tactical models to maximize the producer income. Other works concern the storage of perishable products (Costa, 2011) but they often focus on an industrial fresh products buyer point of view (Tan & Çömden, 2012), with a few variety of products. Multiproduct market gardening has been less studied than specialized systems like dairy or grain systems.
We develop a strategic and tactical model to integrate and optimize both fruit and vegetable production and logistics in urban sites selection and multifunctional farming system design (goods and services production).

2 Materials and Methods

We use mix integer linear programing to establish a model for fresh fruit and vegetable production. We aim at maximizing the annual farm result, answering a fixed daily demand. Our main variables are the area a_i to grow using management practices i, the beginning date of each plot cultivation d_i and the workers to hire to produce mo_d. We introduce other variables to consider the perishability of the products in different ways. As Ahumada and Villalobos (2009), we use a storage cold room loss function and cold room limited capacity. But we also allow a standing storage on the plot, associated to another loss function: the crops can be harvested some days after the ideal harvest time. The selling price is lowered according to storage time, both on the plot and in the cold room. We force the unsold products left on the plots (losses) to be harvested before a management practice dependent deadline, to limit diseases and insects proliferation.
Considering short time perishability (a few days) make us work on a tow-day step. It enables a good combination of different crop management practices on the farm to have the best labor affectation. Perishability, considered at a tactical level, has major consequences on the strategic farming system sizing. Climate is not taken into account as we do not need operational outputs, but management practices beginning can only vary in a small time period, to guarantee realistic solutions. Treasury and water consumption can be used as constraints according to the contexts.
This deterministic problem integrates lot sizing problems. Dependences between areas, harvest and delivery dates of several products, growing tasks and labor make this problem highly combinatorial and hard to solve on big data sets.

3 Results - Discussion

Following results are obtained using Cplex 12.6 on Intel Core i7-4600U 2.10GHz processor and 8.0 Go of RAM. Given a certain demand, the model affects areas to the plots cultivated with different management practices, which are represented by a production curve (x kg.m^{-2} reaching maturity on day d), a set of cultivation tasks and some parameters such as the range of areas in which the management practices are defined. With our data set, the best profitability is obtained combining 5 management practices, *(i4, i5)* for product 1, *(i6, i8, i9)* for product 2 (Fig. 1). 90% of the available area is used.

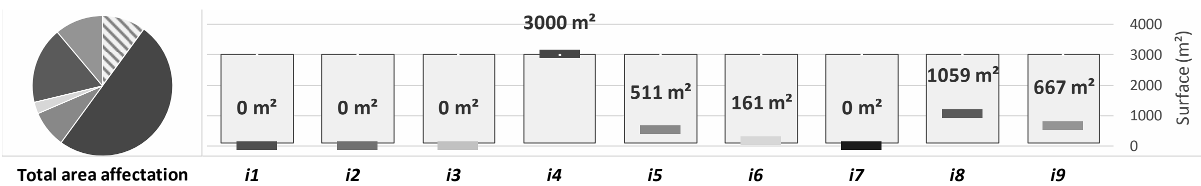

Fig. 1. Plot areas obtained by the model

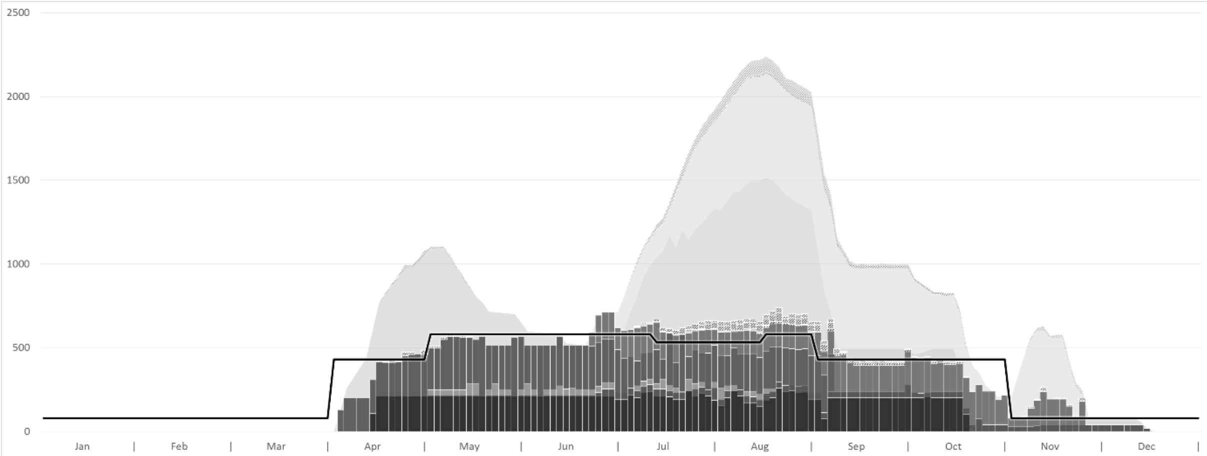

Fig. 2. Demand (line), quantities harvested each day (dark bars) and on-plot available quantities (light areas)

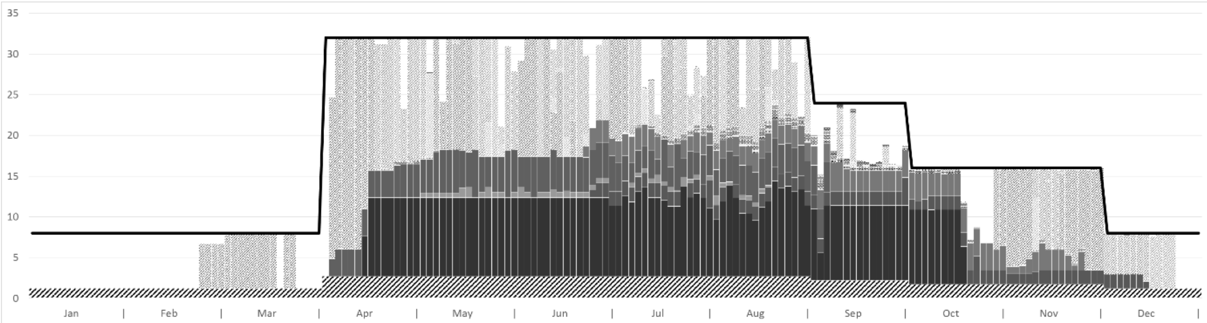

Fig. 3. Labor to hire (line) to harvest (dark bars) and cultivate (light bars), including idle time (stripes)

To answer the demand, 1 permanent farmer and 3 seasonal workers are needed (Fig. 3). Operations planning takes into account the daily demand (quantities and prices) of two clients to affect the workers to the harvest or to malleable cultivation tasks, such as weeding or trimming. Fig. 2 shows two major phases in April and August when too much products are available on the farm compared to the demand and products are stored several days in cold room (not depicted here). On this test data set, the model enable to deliver 81% of product 1 demand and 88% of product 2 demand, with 9% of losses over the year, to reach an result of 281 k€.
According to the data set parameters, the optimal solution is reach in 2 to 50 minutes, as no work has been not to improve the resolution process yet. Realistic farm designs have been obtained with real data set, producing different varieties of strawberries, tomatoes and lettuce to deliver 2 to 4 clients.

4 Conclusions

Using mix integer linear programming, we manage to model the tactical combination of different fruit and vegetable productions and its impact on the strategic sizing of urban farms. The model gives good results on real data set and are currently compared with field experimentation.
Besides the resolution process improvement, next steps will consist to integrate logistics (supply and delivery) in the model to select the best farm locations in a city, and services to get relevant tactical and strategic models of multifunctional urban farms. Variability and robustness will also be integrated.

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A household model to assess consumption-production-resources nexus in West Africa: The rice based farming systems in Sierra Leone

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1 Introduction

In West Africa, several programmes have been established in order to boost rice production and consumption in those countries. However, these actions are often carried out at a national level without real consideration for the highly contrasting needs of agricultural households across a territory. This also implies the use of more specific approaches and methods that can quantify agricultural production while taking into account the diversity of cropping systems and of household food needs (Herrero *et al.*, 2014). The aim of this paper is to present a non-linear optimization model that highlighting the production strategies of rice farming households with non-separability between production, consumption, and available resources. The model is applied for rice production in the north of Sierra-Leona, which is known for its significant rice production, but also for its low and variable yields and consumption levels, which are among the lowest in the world. It also defines and assesses political alternatives encouraging agricultural production, and therefore the improvement of food consumption.

2 Materials and Methods

The methodology is composed from 3 steps:
- Selection of representative rice farming household: Based on clustering analysis, only four rice farming households were selected and studied by taking into account structural, resources, production and consumption criteria (table 1, for more details see Chenoune *et al.*, 2014).

Table 1. Farm types by considering structural, production and consumption criteria. The intensification level is determined based on seeds and labour amounts and the denomination of lowland or upland is expressed based on the percentage of each ecosystem by farm type (for more details see Chenoune *et al.*, 2014).

	Class 1: high rice consumption household				Class 2: low rice consumption household			
	$\text{upland}_{\text{intensive}}$		$\text{lowland}_{\text{intensive}}$		$\text{upland}_{\text{extensive}}$		$\text{lowland}_{\text{extensive}}$	
	Mean	Std.deviation	Mean	Std.deviation	Mean	Std.deviation	Mean	Std.deviation
Total farm area (ha)	3.7	0.87	1.92	0.65	3.14	0.63	0.94	0.35
Rice seed density (t/ha)	0.05	0.03	0.09	0.03	0.02	0.01	0.02	0.02
Rice production (t/farm)	1.18	0.3	0.8	0.28	0.3	0.19	0.2	0.12
Rice total labour (d/ha)	145	39	121	67	99	30	59	30
Size of family (member)	10.2	5	5.6	1	8.3	4	6.8	4
Rice consumption (t/capita/year)	0.075	0.013	0.094	0.012	0.057	0.008	0.054	0.005
Total calorie /cap/day (kcal)	1338	180	1739	850	900	169	843	695

- The farm household model specification: The household model developed in this study is a static annual model with a utility based on the full income approach, which includes both consumption and farm income (Strauss, 1984). The Utility function is described as following:

$$Max\ U = \left(\sum_{pr} R_{pr}^{v} + \sum_{pr} A_{pr} P_{pr}^{a} - \sum_{mo,pe} Q_{mo,pe} P_{mo}^{l} - \sum_{c,s,t,j} C_{c,s,t,j} X_{c,s,t,j} \right) - \emptyset \partial$$

Where U is the value of the utility function, P is the matrix of agricultural revenue by products (pr) sold and price v; A is the matrix of the amounts of products consumed (self-consumption), Pa are the shadow prices of agricultural products kept for self-consumption, Q is, for each activity, the total labour cost expressed by gender (mo) and period (pe), i.e. sowing, weeding and harvesting, Pl are the daily labour prices expressed by gender, C are the total input costs (other

than labour) expressed by crop (c), ecosystem type (s), intensification level (t) and fallow duration (j), Ø risk aversion coefficient and standard deviation of farm income by considering market price and yield variability in the study area.
- Scenario specifications: Table 2 summarizes the 4 tested scenarios targeting to promote the rice production and consumption in the Bombali District.

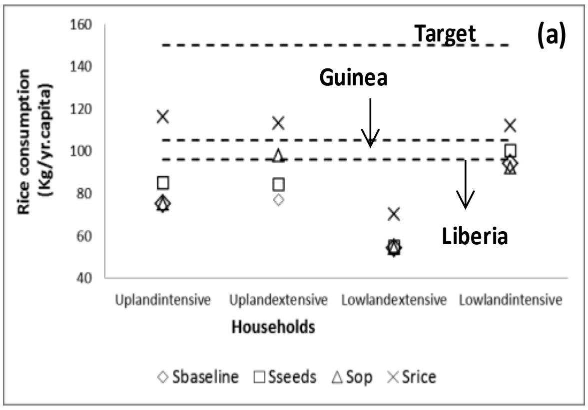
Table 2. Scenarios definition.

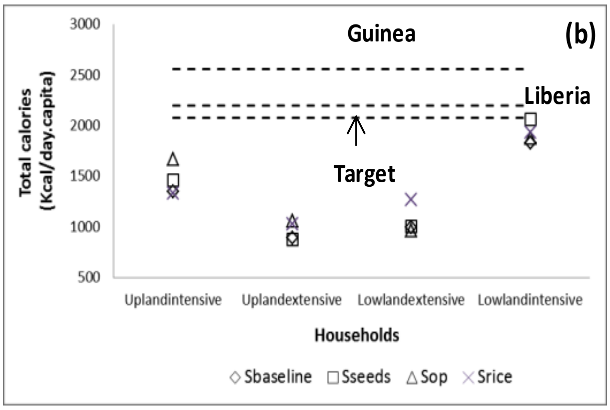
Scenario definition
$S_{baseline}$: Baseline scenario. This scenario represents the current situation and should be serving as a reference to evaluate the impacts of below incentive scenarios in terms of rice production and consumption.
S_{seeds} scenario: Subsidizing the purchase of rice seeds. It seeks to assess the impact of a gradual covering of rice seed purchase cost per hectare, varying its value from 0% to 100%, with a 20% pitch
S_{op} scenario: Subsidizing the plantation of oil palm scenario as a cash crop. Several levels of subsidization are applied to cover the cost of oil palm plantation per hectare gradually, varying from 0% to 100% (with a 20% pitch)
S_{rice} scenario: Subsidizing rice plantation in lowland ecosystems. Several levels of subsidization are tested, in relation to the gradual covering (from 0 to 100% with a 20% pitch) of the cost per hectare of lowland ecosystem conversion to rice production

3 Results and discussion

The scenario for the subsidization of rice plantation in lowland ecosystems seems to be the most relevant in the current context of Sierra Leone (Fig. 1). In fact, only this scenario has induced a significant rise in rice consumption to reach the same level as that of the two bordering countries : Guinea and Liberia, but far away from the consumption planning hoped for by the National Sustainable Agriculture Development Plan 2010-2030 (fig. 1). In terms of calories, the $Lowland_{intensive}$ households alone are at the FAO's recommended minimum level but far from Guinea which shows an average number of calorie intakes of 2500 capita/day (fig. 1). The other households, especially extensive ones, show very low caloric intakes. Similarly, regardless of the type of household, the scenarios have only had a slight effect on the number of calories consumed per day and per capita. This study also highlights the fact that lowland-based households with low intensification means ($Lowland_{extensive}$) and rice consumed per capita barely respond to the scenarios.

Fig. 1. Variation of rice consumption (a) and total calorie (b) for the 4 farm types, Guinea (average national values), Liberia (average national values) and the targets set by the Sierra Leone Government for the National Agricultural Strategy (2010-2030) and the FAO organization.





4 Conclusion

The scenario that contemplated subsidizing rice plantation in lowland ecosystems has been identified as the most efficient, which is relatively coherent with the numerous initiatives that contemplated this type of investment (SLIEPA, 2012). Nevertheless, this scenario has also generated a rice-cash crop specialization (data not shown) which could raise questions as to the resilience of such systems. Besides, the effects of these scenarios remain below the expectations of public authorities. The structure of the current model based on the notion of activity would make it possible without any major changes to test other scenarios strongly contemplated by several initiatives such as the introduction of irrigation, of fertilization, and intensification of others food crops.

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T5. Design Climate Smart Agricultural Systems: methods, scales, results and challenges

Chair: Olaf Christen, Agronomy and Organic Farming University of Halle
Co-chair: Jacques-Eric Bergez, INRA

Farm4Prophet - Managing whole farm business risk in Australia

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1 Introduction

Australia's rain-fed mixed farming region (49M ha) has a highly variable climate, which results in a level of financial risk three to ten times higher than that experienced by its major competitors (OECD-FAO, 2011). Australian farmers receive minimal Government support and businesses thrive or fail depending on their ability to manage risk. There are currently few tools which enable farmers and other stakeholders to quantify the risks resulting from a strategic change in management. Farm4Prophet is a new whole-farm business management tool developed by the BCG (Birchip Cropping Group) in association with leading farmers, CSIRO and farm business consultants. Long term pasture and crop production modelling, using APSIM (Holzworth *et al.,* 2014), is integrated with long-term, whole farm financial projections. This enables users to assess production and financial performance and run scenario analysis to predict impacts on profitability from changes in farm management practices.

2 Method

Farm4Prophet uses the SMA (Sequential Multi-variable Analysis) methodology developed by Hutchings and Nordblom (2011), which prepares risk profiles for individual farms derived from multiple iterations of long-term, whole-farm financial simulations. Farm4Prophet is an extension of this concept. It is being developed as a web-based product with three functional components:

1. APSIM is used to prepare crop and pasture production simulations for a period of up to 50 years, based on long-term climate and soil data for any individual farm and enterprise combination.
2. A development of the Farmplan Budget Planner software enables farm specific financial measures to be calculated (eg. Cashflow, Profit&Loss, Balance sheets).
3. A Monte-Carlo routine, randomly selects sequences of production data for a chosen period from the 50 year APSIM production data for each commodity. The routine is then used to build cumulative probability functions (CDFs) based on the cash margins (closing minus opening financial balance) for each iteration.

This process allows the user to test the long-term effects on cashflow of various management scenarios. Cashflow was chosen as the benchmark, for two reasons. First, cashflow is the only common indicator which contains all costs. Secondly, the change in the net cash balance drives the change in the farm debt, which often constrains both the ability and the desire to invest in growth (Bamberry *et al.*, 1997).

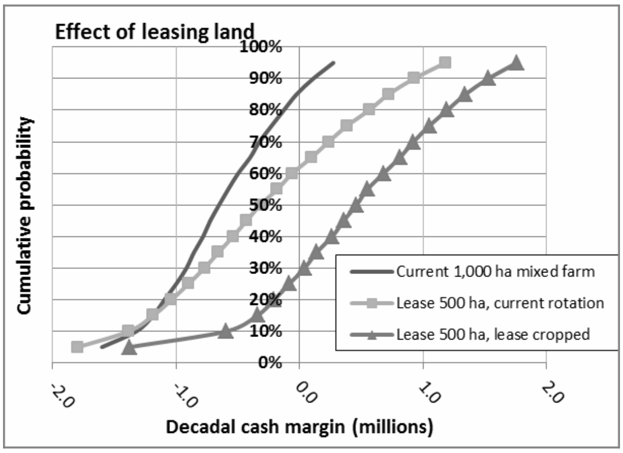
3 Results

A prototype model has been used as proof of concept and a range of outputs have been prepared and verified on a farm near Wagga Wagga in the Southwest Slopes region of New South Wales in Australia (Lat -34.817, Long 147.198, Alt 247m). This owner-operated, 1,000 ha farm is typical for the region. The farming system is based on 5 years of annual crops – canola /wheat /barley /canola /wheat under-sown with lucerne/clover pasture, followed by four years pasture, grazed by a self-replacing flock of Merino sheep for prime lamb production. The farm has a current financial equity of 80%. Under the existing management system with current prices the farm is currently not viable, having an 85% probability of operating at a loss (Fig. 1).

Farm4Prophet was used to test alternative management scenarios on profitability, such as leasing an additional 500 ha of adjoining farmland, where the farming practice on the leased land was either (i) maintained with the current rotation and grazing practices; or (ii) the additional land was continuously cropped (no grazing). In each case the model adjusts the variable costs, the variable components of fixed costs (labour, fuel, maintenance and rental) and the capital costs (additional sheep and machinery) for the increasing scale.

Scenario (i): the additional 500ha maintained in the current farming system reduces the risk of loss to 62%, which is a considerable improvement, but still unlikely to be viable.

Scenario (ii): the additional 500ha of cropping only increased the percentage cropped from 60% to 73%. All cost components were adjusted for this change, which reduced the risk of loss to less than 30%, indicating that this is likely to be a viable strategy.



4 Conclusion

Farm4Prophet sample analysis contains all the complex interactions between farm enterprises at the production, commodity prices, costs and management levels. This complexity is increased by the inclusion of time in the analysis, each iteration is run for a range of historical climate, prices and costs, and includes between-year, as well as within-year interactions. Factors such as nitrogen balance, supplementary feed requirements, and financial and management constraints are modelled, costed and included and compounded over the period.

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Specification of nitrogen use in regional climate impact assessment studies

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1 Introduction

Understanding how crop yields will be impacted by climate change is facilitated by the use of process based crop models. However there is little systematic knowledge across environments about how management (e.g. nitrogen use) interacts with climate change effects to impact crop yields. Specification of management is difficult in large area impact assessment studies due to a lack of data and the need to make assumptions regarding future management. This study investigated whether it is required to include nitrogen limitation in regional climate change impact assessments for Europe.

2 Materials and Methods

Water limited and nitrogen-water limited relative yield changes between 2004 and 2050 for SRES scenarios A1B1, B1 and B2 were simulated with SIMPLACE<Lintul5, DRUNIR> (Gaiser *et al.*, 2013) for spring-sown grain maize, silage maize, potato and sugar beet, as well as for winter-sown barley, oilseed rape and wheat across the EU27. Historical yields and nitrogen inputs for NUTSII administrative regions were from the CAPRI database (Fig. 1a). Future nitrogen fertilizer rates were calculated from the fertilization in 2004 multiplied by a factor of how water-limited yields are expected to change to 2050. Climate and soil data were at the level of the simulation units defined by the spatial intersection of eleven environmental zones (Metzger *et al.*, 2005) and NUTSII boundaries (Fig. 1b). Simulations in the baseline period (1982–2006) sometimes had a significant trend due to the use of historical nitrogen inputs and were regressed to obtain yields in 2004. Yields in 2050 are the average yield in the respective scenario period (2041-2064).

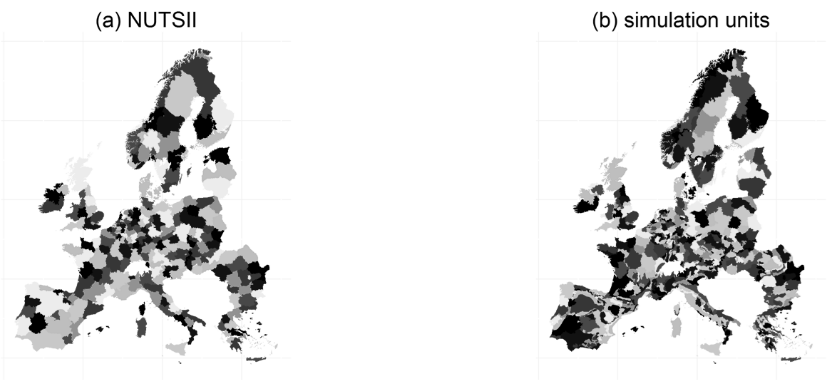

Fig. 1. Observed yields and nitrogen fertilizer rates are from the CAPRI database at the level of (a) NUTSII (n=240). The (b) model simulation units (n=534) are the spatial intersection of the NUTSII zones with environmental zones (Webber *et al.*, in review)

3 Results - Discussion

Water-limited and nitrogen-water limited relative yields changes to 2050 are largely similar for spring sown crops but differ for winter sown crops, being more negative when nitrogen limitation is considered (Fig. 2). For the winter crops, particularly in Southern Europe, water stress also results in lower nitrogen rates. The longer growing conditions in the autumn, without accelerated development, lead to more autumn nitrogen use with the result of increased nitrogen stress in the spring. Other options to specify future nitrogen rates (e.g. using farm systems models and including more information on the timing of nitrogen fertilizer) are explored (results not shown).

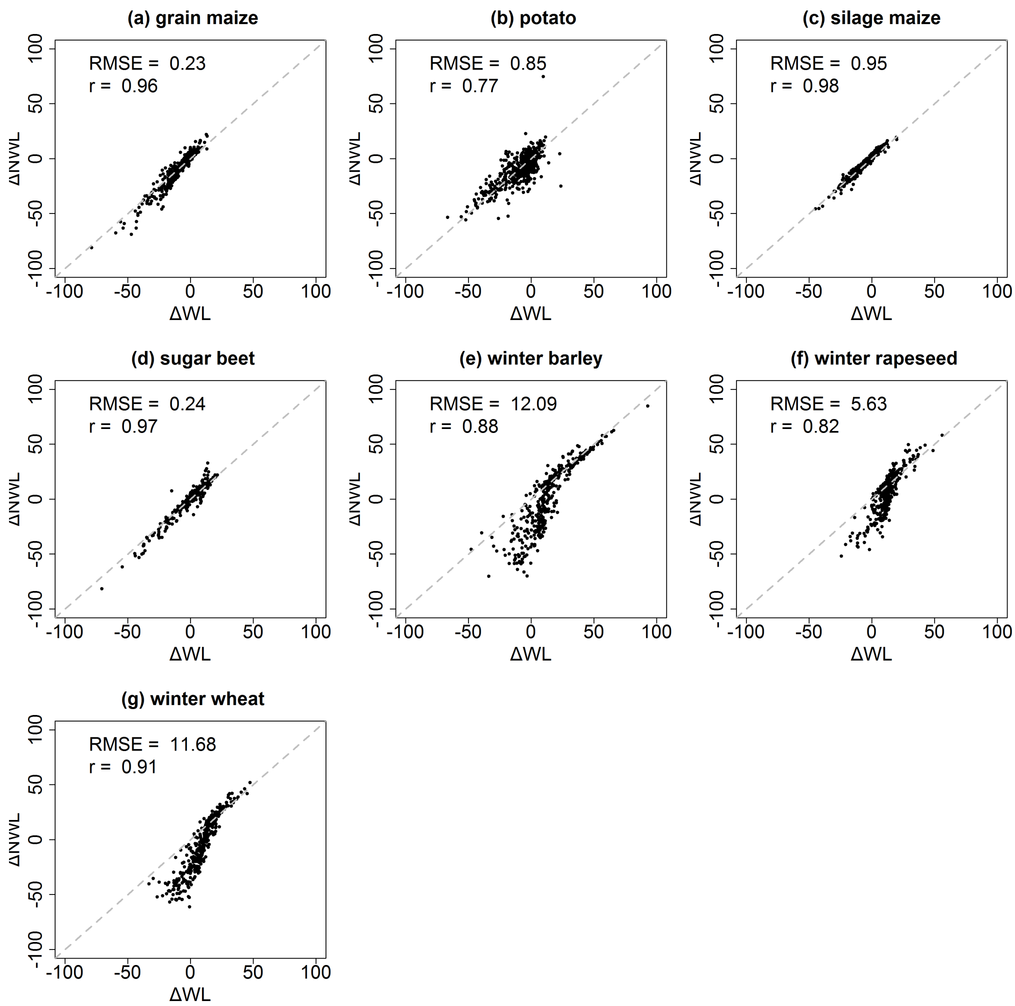

Fig. 2. Agreement between relative yield changes between 2004 and 2050 for water limited (Δ_{WL}) and nitrogen-water limited (Δ_{NWL}) simulations for the A1B1 scenario across Europe (Webber *et al.*, in review).

4 Conclusions

Relative yield changes due to climate change between 2004 and 2050 do not depend on nitrogen limitation for the spring-sown crops simulated in this study. However, for the winter-sown crops, simulated impacts were more negative when nitrogen limitation was considered. These results suggest that additional model complexity (parameterization, input data and assumptions about future use) is not needed for regional scale assessment of climate change impacts for spring-sown crops, but is required for winter-sown crops. Options on how to specify future nitrogen use are presented and the challenges of each explored.

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Re-designing smallholder farming futures for reduced vulnerability to climate change in semi-arid southern Africa

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1 Introduction

Climate change will impact the productivity of maize-based crop-livestock systems and the food security of smallholders depending on them in semi-arid southern Africa. Earlier results from testing climate change adaptation options showed that incremental improvements in fertilizer application rates, use of adapted maize cultivars or introduction of forage production are insufficient for substantial improvement of smallholder livelihoods (Masikati *et al.*, 2015). In this paper we therefore explored effects of more transformative system re-design on households' vulnerability to climate change, farm net returns and poverty rates. We tested the hypothesis that packages tailored to specific farm situations are more effective than blanket recommendations.

2 Materials and Methods

The study was carried out in the Nkayi district of semi-arid Zimbabwe, characterized by average annual rainfall of 650 mm with high interannual variability. Climate change projections agree on an increase in temperature of 2 to 3.5 °C, whereas future rainfall conditions are less certain. Apart from low and erratic rainfall, the poor soil fertility status and limited agricultural input use result in low productivity of the predominantly maize-cattle based systems, with average maize yields below 0.7 t ha^{-1}, high mortality rates up to 15%, and low milk yields. According to national statistics 76% of all rural households in Zimbabwe are poor and more than 22% are extremely poor (ZimVAC, 2013). Food self-sufficiency varies from 3 to 10 months depending on the annual rainfall, leaving rural households extremely vulnerable to the adverse effects of climate change. Heterogeneity in the farming community is high and three farm types are distinghuised, (1) extremely poor households with no cattle, cultivating 1.3 ha on average, (2) poor households with 0 to 8 cattle, cultivating 1.8 ha, (3) better-off households with more than 8 cattle, cultivating 2.5 ha.

We followed the AgMIP Regional Integrated Assessment procedure (Antle *et al.*, 2015) using (i) a multi-modeling framework of climate, crop, livestock and economic simulation models, and (ii) representative agricultural pathways (RAPs) generated with stakeholders to define plausible future socio-economic conditions. System re-design for the three farm types (Table 1) followed the assumption that improved access to inputs, knowledge and markets encourages smallholders to intensify agricultural production, making full use of the cultivated land areas, diversifying production of crops (grain and forage legumes), enhancing mineral and organic fertilizer use and improving livestock management and marketing. Three transformative packages were designed and effects evaluated accros the entire farm population. Based on this, a set of tailored packages per farm type was developed to maximize net returns.

Table 1. Transformative packages (Tr) as compared to the current situation for three farm types in Nkayi

	0 cattle		0 – 8 cattle		> 8 cattle	
	Current	Tr 1	Current	Tr 2	Current	Tr 3
Maize (% of cropland)	75	25	70	25	70	20
Sorghum (% of cropland)	11	12.5	11	8	16	5
Groundnuts (% of cropland)	10	37.5	10	33	10	25
Common beans (% of cropland)		25				
Mucuna (% of cropland)				33		25
Banagrass (% of cropland)						25
Cereal fertilizer use (kg N / ha)	3	20	3	20	3	20
Offtake rate (%), cattle/small ruminants	0 / 17	0 / 50	4 / 12	10 / 50	7 / 10	20 / 50
Milk production (l/day/cow)	n.a.	n.a.	0.8	1.5	1.3	2

3 Results - Discussion

Stakeholders RAPs projected an optimistic future mid-term (2050s) scenario (called RAP1) towards positive economic development, Zimbabwe stepping out of the crisis and massive investments in market-oriented agriculture. Among key drivers they estimated productivity growth rates for maize (40%) and other crops (35%), cattle (30%) and other ruminants (25%). Producer price growth was expected to be limited to 5-20% for the various agricultural commodities. A step further, following improved availability of inputs and markets, farmers would be motivated to increase their cultivated land by 60%; poor farmers would at least double flocks of small ruminants (called RAP 2). Within that socio-economic context a dry climate change scenario would expose about 60% of the farming households to greater vulnerability. The very poor will loose up to 9% of their net returns, others will loose a smaller proportion.

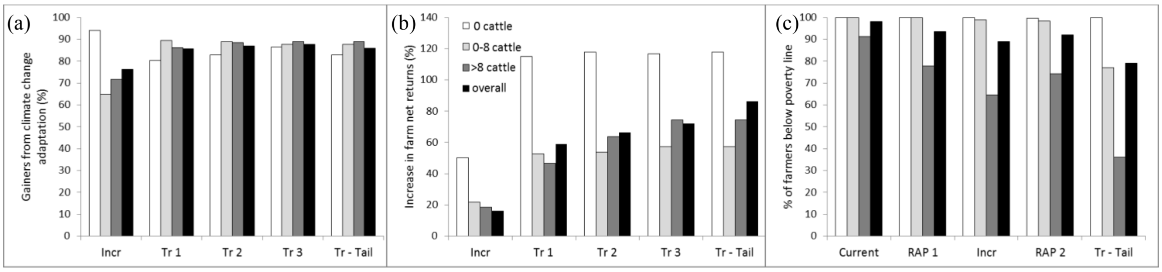

Fig. 1. Effects of incremental (Incr) and transformative (Tr) adaptations and RAPs on the percentage gainers from adapting (a), increase in net returns (b) and farmers below the poverty line (c) (packages 1, 2 and 3 are explained in Table 1 ; Tailored package (Tail) is a combination based on highest net returns).

The adaptation packages are likely to reduce vulnerability to climate change for most of the very poor farms. The incremental change will possibly benefit almost all very poor and more than 60% of the less poor (Figure 1a). It will increase their net returns by 50% as compared to < 20% for the less poor (Figure 1b). The magnitude of the benefits will however be small, less than 100 and 500 US$/farm for the very poor and less poor respectively. In comparison, drastic diversification of crop production along with greater participation in livestock markets will lift more than 85% of all farm types to a better economic situation (Figure 1a). The drastic adaptation packages will more than double the net returns of the very poor, and increase those of the poor and better off by 50 to 75% (Figure 1b). In absolute terms those with large cattle herds will benefit more, with on average 1300 US$ higher net returns, as compared to 500 US$ for the very poor, but they also face higher risk. Tailoring the technology packages to farm types increases the net returns for the entire community by 86%, as compared to 72% if technology packages are applied across the entire population as a blanket. Poverty levels might however remain high, even after drastic economic changes and tailored investments, (Figure 1c). Most substantial change in poverty rates will be for those with large cattle herds. The drastic adaptation package will reduce the proportion of these farms below the poverty line to around 35%, as compared to 65% under incremental change. It will reduce poverty levels among those with small cattle herds to 75%. Households without livestock, about 43% of the farm population, will have very little chances to move out of poverty.

4 Conclusions

This research illustrates that tailored systems diversification and market orientation can substantially increase farm production, food security and net returns from agriculture. Greater impact on poverty however requires further steps on multiple component innovations, better synchronizing of technologies, markets, policies, on-and off-farm investmens, triggering transformative system change (Geels and Schott, 2007). Incorporating the influence of socio-economic development and institutional and policy improvements defined in the RAPs enabled the comparison with purely climate change effects and is a first step to inform adaptation strategies at farm and larger scales. This approach should be taken further with policy and decision makers, to adjust socio-economic and institutional conditions that would make investments in farming more attractive while considering risk, essential to reduce vulnerability to climate change and enable sustainable futures for smallholders in semi-arid southern Africa.

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Resilience of adaptation strategies for small-holder farmers in Cambodian lowland rice ecosystems in response to future climate uncertainty.

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1 Introduction

Food security in the face of population growth, urban migration, loss of agricultural land and climate change is a major challenge for Cambodian small holder farmers reliant on rainfed rice-based agriculture. However, by 2050 climate change is predicted to reduce the national rainfed rice cultivation area by 20%. Replacing a traditional low input transplanted rice crop with a 'response farming' approach (Dalgliesh *et al.*, 2015 this edition) has potential to not only mitigate effects of current seasonal variability but enable farmers to transition their farming practices in response to future climate uncertainty. This approach is based on utilising improved, shorter duration varieties, more efficient establishment methods and better agronomic management responsive to timing, intensity and longevity of the monsoon. Well-tested biophysical models have been successfully employed in investigating impacts of projected climate change on food production at global (Rosenzweig and Parry, 1994), regional and country (Ruane *et al.,* 2013) scales and are a cost effective method for evaluating possible adaptation strategies available to farmers in managing current and future climatic risk. The APSIM-Oryza model (Gaydon *et al.*, 2012) has been calibrated and validated for transplanted and direct seeded rice for current climatic conditions (Poulton *et al.* 2015). This analysis investigates the risk from projected climate change at the IPCCs 2060 time horizon, on rainfed and irrigated rice production in Southern Cambodia.

2 Materials and Methods

Baseline climate was generated from local observations (1997-2011) and downscaled GCM data using a 'Linear Mixed- Effect State-Space' model applied to produce effective point scale projections suitable for use in bio-physical modelling (Kokic *et al.*, 2011). APSIM-Oryza was parameterised for a short duration rainfed rice crop and run for incremental changes to CO_2 (380 – 830 ppmv), ambient temperature (28.06 – 34.06 °C), rainfall (-20% – +20%) and in combination of all three climatic factors to evaluate model response for a given set of input parameters. A multi-factor sensitivity analysis was then applied to assess potential variation from current baseline yields for IPCC projected scenarios of 0.7 –2.7 °C change in ambient air temperature and a 31.0 – 64.0% increase in atmospheric CO_2 to 2060 for the Cambodian region. Three scenarios compared traditional transplant (MSTR) with a 'response' farming approach using a modern rice variety grown under rainfed (SSDR) and irrigated (SDDI) conditions for a combination of temperature and CO_2 within the ranges previously described and ±15% change in annual rainfall. Results are presented as a series of probability of exceedence graphs that highlight both the probability of experiencing a failed crop (< 0.4 t ha^{-1}) as defined by -100% change on the x axis and as the difference in rice yield from the baseline yield (defined as 0% on the x axis) as a percentage change (%). Climate scenarios projected to 2020, 2040 and 2060 are presented (Fig.1).

3 Results and Discussion

Model response to elevated CO_2 of 680 ppm for current temperature and rainfall is consistent with the accepted physiological effects of CO_2 on C3 crops, simulating a 17.5% yield increase above baseline levels. Sensibility testing of the model to incremental changes to CO_2 and temperature, results in a yield response comparable with Li *et al.* (2014), for 13 rice models, reporting a 7% to 11% (APSIM 6.11%) increase per 100 $\mu mol\ mol^{-1}$ for the 380-480 ppm CO_2 range and 3% to 5% (APSIM 4.13%) for the 630-730 ppm range and a reduction in yield of 2% to 11% (APSIM 4%) per degree C increase above the baseline temperature. Simulated long-term mean yields of 3.65 t ha^{-1} (MSTR), 4.64 t ha^{-1} (SSDR) and 5.16 t ha^{-1} (SDDI) for 380 ppm CO_2 and 1997-2011 temperature and rainfall are the basis for directly comparing the resilience of the selected management scenarios for projected increases in temperature and CO_2 (2020–2060) and changes in annual rainfall of -15% (a), 0% (b), +15% (c). Baseline yields are comparable with on-farm yields observed by Dalgliesh *et al.*, (2015 this edition) in 3 years of experimentation. For the 15% decline in annual rainfall example, for 2020 (Fig. 1 MSTR (a)), the probability of a crop failure occurs in 39% of years and increases to 42% by 2060. Years exceeding baseline yields declined from 24% (2020) to 15% (2060). In comparison, for a 15% increase in annual rainfall in 2020 (Fig. 1 SSDR (c)), the probability of crop failure occurs in only 9% of years. For this scenario baseline yields are exceeded in 55% of years but decline to 42% by 2060. While crop failure remained relatively static within each rainfall scenario, yields fell in response to the combination of higher temperature and CO_2, particularly with declining rainfall. A 15% increase in rainfall and elevated CO_2 partially offset the effect of increased temperature on crop development whereas a reduction in rainfall of 15% results in a 40% yield penalty.

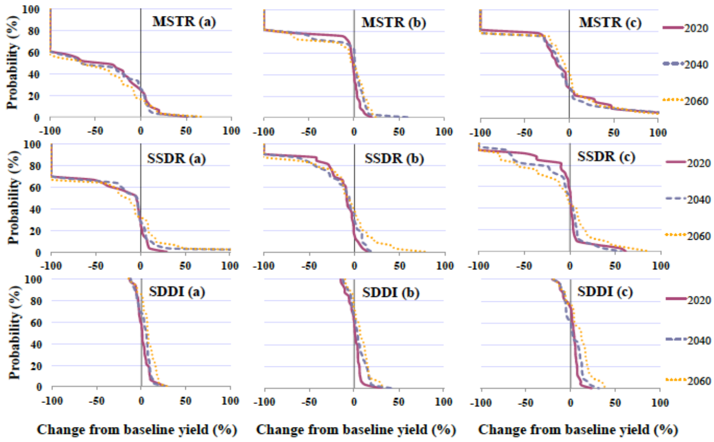

Fig. 1. Probability of exceeding baseline yields (0% on X axis) for current ambient air temperature and 380 ppm CO_2, for a rainfed transplanted single medium variety (MSTR), rainfed single direct-seeded short variety (SSDR) and irrigated double cropped direct-seed short variety (SDDI) in response to projected increase in temperature and CO_2 and for a changes in annual rainfall of (a) -15%, (b) 0%, (c) +15% for 2020, 2040, 2060.

Access to irrigation mitigates the effect of climate extremes, reducing risk of crop failure and improving yields for all rainfall scenarios in 60% to 85% of years (Fig. 1. SDDI a-c). Except for the wetter climate scenario (+15%) where additional rainfall offsets the irrigation required to maintain current yields until 2040, a significant investment in irrigation infrastructure or improved water use efficiency will be required to maintain existing rainfed yields in response to increasing temperature by 2060. In comparison, use of supplementary irrigation early in the season has been shown to support successful early crop establishment and development during the critical growing period and delivers the opportunity for a second crop and therefore higher on-farm returns. For a 15.7% increase in CO_2 by 2030, early established modern rice varieties and improved N fertiliser management can double production compared with traditional systems utilising low input late maturing local varieties.

4 Conclusions

The response of APSIM-Oryza to elevated temperature and CO_2 is consistent with measured physiological CO_2 effects on C3 crop yields and is comparable with results from similar crop modelling studies. For Cambodian small-holder farmers, traditional rainfed rice production beyond 2030 is at risk from increased variability in the distribution and timing of rainfall. The long-term resilience of a 'response farming' approach in managing seasonal variability is demonstrated by a reduction in crop failures when compared with traditional transplanted practice. Adoption of direct seeding of higher yielding, quicker maturing rice varieties; access to mechanical harvesting; improved nitrogen management; and use of supplementary irrigation at sowing and/or better utilisation of available water, all support early crop establishment and deliver farmers additional strategies for maintaining and potentially increasing rice production in response to future climate uncertainty.

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Assessing impacts of changes in farm management and farm structural change on sustainable development in a rural area in the Netherlands

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1 Introduction

Changes in climate, technology, policy and prices affect agricultural and rural development. Policy makers and stakeholders involved in landscape planning require impact assessments that integrate economic, social, and environmental dimensions of land use dynamics. Therefor, there is a need for integrated assessments considering multiple drivers of change and multiple impacts. The aim of this paper is to show such an application by performing an integrated assessment of impacts of climate change in concert with socio-economic change on sustainable development of the Baakse Beek catchment in the east of the Netherlands.

2 Materials and Methods

A bio-economic farm model (FSSIM; Kanellopoulos *et al.*, 2014), an agent-based land-use change model (RULEX; Bakker *et al.*, 2014) and a regional emission model (INITIATOR; Kros *et al.*, 2014) have been used to simulate economic, social and environmental indicators at both farm and landscape level. While the bio-economic farm model can assess detailed farm management and resulting agricultural outputs, the spatially explicit agent-based land-use model allows to assess farm structural changes and interactions with nature. The regional emission model allows to assess environmental impacts in a spatially explicit way.
Climate change affects crop yields, which were simulated with the crop models WOFOST and LINGRA and the semi-quantitative participatory method Agro Climate Calender (Schaap *et al.* 2013). Impacts of technology change on crop and milk yields were based on historical analysis, extrapolation and agronomic knowledge. The market model CAPRI was used to assess changes in product prices. All these changes were provided as input to FSSIM to simulate changes in farm plans and management. The resulting gross margins were used as one of the inputs in RULEX to simulate land use change. Changes in crop areas, crop yields and animal numbers as simulated with FSSIM were used as input in INITIATOR to simulate environmental emissions.
Impacts were assessed for 12 indicators (Table 1) for the year 2050 and for four scenarios: Global Economy (GE) and Regional Communities (RC) with changes in climate, technology, policies & prices (further denoted as full GE and RC scenario), and considering climate change alone (GE CC, RC CC).

Table 1. Selected indicators in the economic, social and environmental dimensions.

Dimension	Indicator	Unit	Current	Sign of impact
Economic	dairy farm income	euro/farm/year	98000	+
	arable farm income	euro/farm/year	40854	+
	dairy output/input	euro/euro	1.90	+
	milk production	ton/year	333491	+
Social	farm size	ha	22.5	-
	number of farmers	#	1349	+
	nature area	ha	1731	+
	landscape diversity	Shannon-Weaver index (-)	0.78	+
Environmental	global warming	kg CO2eq/ha/year	13510	-
	terrestrial eutrophication	NH3 emission/ha/year (in kg N)	65	-
	aquatic eutrophication P	kg P/ha/year run off	1.9	-
	aquatic eutrophication N	NO3 leaching/ha/year (in kg N)	15.5	-

3 Results – Discussion

Results show that in the Baakse Beek area, climate change alone will have mainly negative economic impacts in the more extreme ‘global economy’ climate change scenario (GE CC), while impacts are slightly positive in the moderate climate change scenario ‘regional communities’ (RC CC) (Fig. 1). Conversely, changes in technology, prices and policy are projected to have a positive economic impact in the full GE scenario, more than offsetting the negative climate impacts. Important is however that their social and environmental impacts are largely negative. In the full RC scenario, the average dairy farm income in particular is negatively affected. Social impacts are similarly negative, while environmental impacts are less severe compared to the GE scenario.

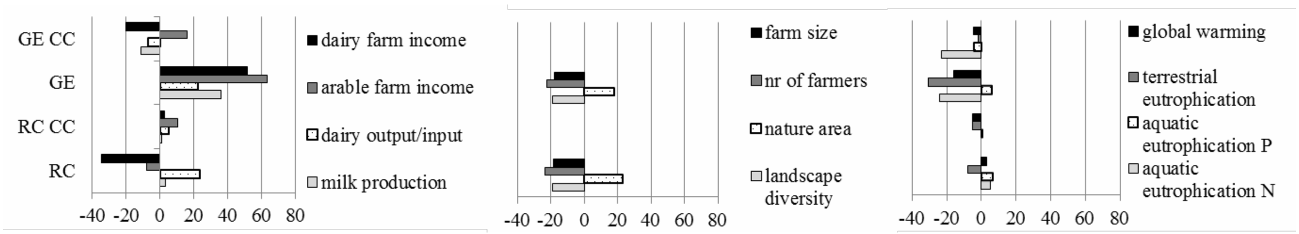
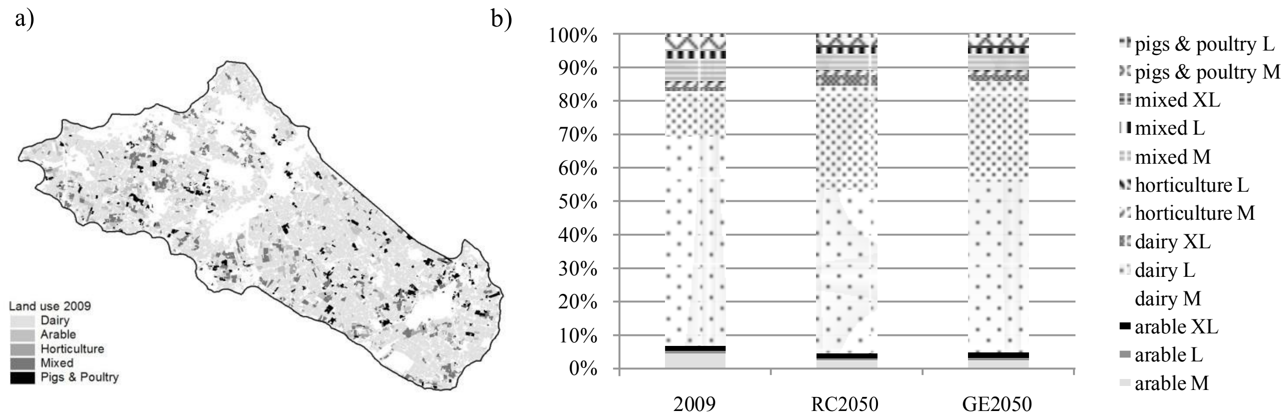


Fig. 1. Impact of the scenarios on 12 indicators in the Baakse Beek, in % change compared to the current values (average/total). Note that an increase is considered positive for sustainable development; signs of the values have been changed depending on perceived impact.

Focusing specifically on farm structural change, we observe that dairy farms further increase in number (Fig. 2). The number of medium sized farms (M) decreases, and the number of large (L) and very large farms (XL) increases.
Although land use change patterns are similar in both scenarios, it is interesting to observe that in RC the increase in very large farms is larger than in GE. This may be due to the lower income increase, causing more medium farms willing to sell their land to larger farms. In GE more farms may want to buy land, but because of competition this is not possible.

Fig. 2. Current land use (a) and projected farm structural change (b) based on land use type and size category, in the full GE and RC scenarios.



4 Conclusions

Our results suggest that integrated assessments at farm and landscape level can be used to guide decision-makers in spatial planning policies and climate change adaptation. As there will always be trade-offs between economic, social and environmental impacts, stakeholders need to interact and decide upon most important directions for policies and measures.

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POTENTIAL IMPACTS OF CLIMATE CHANGE ON LEGUME-BASED CROPPING SYSTEMS

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1 Introduction

In organic farming systems (OFS) legume-grass swards (LGS) are systemically relevant, first, because of the symbiotic N_2-fixiation, and second, because it is the basis of the forage production. LGS shows a high susceptibility to climate change, due to the high water demand. Therefore LGS may become the major weakness in legume-based cropping systems. Particularly, dry regions with low precipitation and sandy soils are under threat of decreasing forage production and thus lower N supply through symbiotic N_2-fixiation. In Germany, in particular, the federal state of Brandenburg, which presently already has low precipitation and where pre-summer droughts are common, the production of LGS is endangered. These effects are particularly relevant for the large-scale organic farms on sandy soils, which are prevalent in Brandenburg and covers approximately 10% of total agricultural area (Reyer *et al.*, 2012). As such, a modelling approach was developed in order to assess the potential impacts of climate change on organic farming in Brandenburg. With it the yield performance of LGS was modelled for two study regions (Uckermark and Spreewald). In both study regions 30% of the total agricultural area is organic but they differ in their site characteristics. In the Spreewald region (SP) the average annual temperature is 9.5 °C and average annual precipitation is 551 mm whereas in the Uckermark region (UM) the average annual temperature and average annual precipitation is 8.5 °C and 517 mm respectively. The climatic water balance (CWB) is approximately the same (SP: -143 mm; UM: -147 mm). The sandy soils in SP are only suitable for red clover grass (RCG) whereas in UM lime rich sandy loams allows for the cultivation of alfalfa clover grass, which needs pH values above 6.0. In contrast, red clover alfalfa is characterised by a higher drought tolerance (Bloch, 2015). For both regions the following hypotheses were examined:

1. Caused by a warmer climate the growing period will be extended. This can be used in more productive way for the cultivation of LGS. Until the end of the 21st century the average annual yields of LGS will increase.
2. Caused by a warmer and dryer climate the uncertainty of the single cut yields will increase.

2 Materials and Methods

Using the yield model for legume-grass swards (Bloch *et al.* 2015) applying historical and projected weather data generated by the regional climate model STARS, single cut dry matter yields were calculated for LGS based on alfalfa (Model A) and red clover (Model B) for the periods 1972–2008 (Past) and 2062–2092 (Future). The calculation is based on the assumptions of the emission scenario RCP 8.5 in which the average annual temperature will increase from 2011 to 2100 by approx. 4 °C. In order to account for the uncertainties in the precipitation development, a wet and a dry scenario were used for the yield assessment (CWB at Wet: SP: -298 mm, UM: -250 mm; CWB at Dry: SP: -361 mm, UM: -377 mm). The dry matter yield calculation for a maximum of four single cuts in this model are based on regression analyses of cumulated actual Evapotranspiration values as described by Bachinger and Reining (2009). The beginning of the growing period and the cutting dates, indicated by the Julian Day Number (JDN), was predicted by using cumulative temperature sums and threshold values for the yield of the third (2 t DM ha^{-1}) and fourth cut (1 t DM ha^{-1}). Based on single cut yield data of the extreme drought year, 2003 an algorithm for drought impact assessment was developed. This is algorithm based on the assumption that in contrast to alfalfa LGS (Model A) pure red clover grass stands (Model B) will dry up when, between the second and third cut, 50 modelled drought days (MDD) will occur. For the model calibration long-term data on single cut yields and LGS cutting dates were used from the ZALF experimental station. For the model validation phenological data from the German Weather Service (DWD) and cutting dates from organic farms located in the study regions were used. For more details see Bloch *et al.* (2015).

3 Results – Discussion

The results show, that by the end of the 21st century the growing season will begin up to three weeks earlier. The growing period for a productive LGS growth will thus be considerably extended (Fig. 1). In spite of the extended growing season, the LGS annual yields for the period of 2062 to 2092 will remain almost unchanged in both regions, assuming a wet scenario (Table 1). The dry (Dry) scenario in contrast will show declining annual yields in both regions up to 20%. Hypothesis 1 can therefore not be confirmed. The reduction of the annual crop yields is a result of the explicit change of the single cutting dates and yields (Fig. 1). Based on an earlier cutting date for the first cut (up to four weeks earlier than in the period of 1972–2008) and at, this point, lower global radiation, the yields for the first cut will be reduced by up to 0.5 TM tha^{-1}. Contrary to this, the yields for the second cut can be higher, if there is sufficient soil water from the winter precipitation (up to 1 DM t ha^{-1} at the Uckermark location in scenario Wet). Despite the change in the yield level, the yield stability will slightly increase for the first and second cut. The third cut, in contrast, will be in all locations, particularly under the Dry scenario, highly affected by dry periods and thus distinctly unstable. Pure RCG (Tab. 1; model B), cultivated on sandy soils in the Spreewald region, are especially vulnerable due to their lower dry tolerance. During the 2062–2092 period there is the threat that pure RCG would dry out every second year. The third cuts impacted by drought stress are characterized in Fig. 2 by i) significantly delayed cutting dates; and ii) only achieving the minimum threshold yield as predefined by the model (see oval symbol). The dry periods during summer also influence the total amount of possible fourth cuts and their yields, showing increased yield fluctuations. Hypothesis II can thus be confirmed for the third and fourth cut.

Table 1. Annual dry matter yields (dt ha^{-1}) of alfalfa (model A) and red clover grass (model B) in the regions of Spreewald and Uckermark modelled for the time periods 1978–2008 and 2062–2092 (scenarios Wet and Dry).

			Annual yield (t TM ha^{-1})		
Study region	Model		1978–2008	2062–2092 (*Wet*)	2062–2092 (*Dry*)
Spreewald	A	$\tilde{x}$	8,8	8,9	8,4
		σ	*1,7*	*1,7*	*1,3*
	B	$\tilde{x}$	8,7	7,3	6,0
		σ	*2,2*	*2,5*	*1,9*
Uckermark	A	$\tilde{x}$	10,3	10,4	8,5
		σ	*2,0*	*1,5*	*1,6*
	B	$\tilde{x}$	10,1	10,2	7,0
		σ	*2,1*	*2,3*	*2,4*

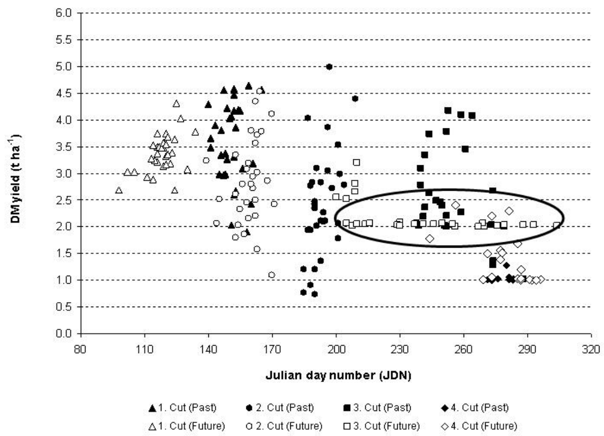

Fig. 1. Single cut yields and cutting dates modelled for the time periods 1972–2008 (Past) and 2062–2092 (Future). Region: Spreewald; scenario Dry.

4 Conclusion

The yield stability and the cultivation of legume-grass swards will become more uncertain in both regions. This could result in a higher risk for the nitrogen supply and fodder production for organic farming in Brandenburg. To adjust to the climate-change, it is recommended to develop drought resistant legume-grass swards for the Brandenburg region.

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Climate change adaptation in Australian wheat farm systems upscaled from farm to national scale

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1 Introduction

Wheat production is known to be sensitive to variations in both temperature and rainfall (Lobell *et al.*, 2011). Changes in climate are expected to have varying impacts in different regions of the globe although negative impacts are expected to be more common than positive ones (Porter *et al.*, 2014). A reduction in Australian wheat production can potentially affect global food security (FAO, 1996), its global availability (Ingram, 2011), and the global food market (Lobell *et al.*, 2011) as Australia is the fourth largest wheat exporter in the world (Connor *et al.*, 2011). Changes in climate over the past century interact with advances in agricultural technology and farming systems (Lobell *et al.*, 2011). As, greater changes in climate are predicted in the near future compared to the changes of the late 20th century (Parry *et al.*, 2007) continued technology and farming systems adaptations will be needed. Previous evaluations of climate change impacts on Australian wheat yield and gross margin change have been applied to a limited number of sites and have not included effective methods to scale up the analyses to a national level to provide industry and policy makers with a clearer insight for high level planning. In this paper we evaluated the impact of climate change and the effectiveness of adaptations for projected climate scenarios in 2030 relative to a historical baseline of 1980-1999, in order to estimate the value of adaptation in terms of production and financial returns. We did biophysical modelling of unit scale results and used farm survey data and a survey estimation method to upscale results to a cross-regional/ national level.

2 Materials and Methods

APSIM version 7.5 was used to simulate biophysical processes. We applied additional functions to account for frost and heat stress further to APSIM's current formulation. Soil parameters were selected from the APSoil data base. Initial soil Nitrogen (N) of each location was estimated from a long term historical run under continuous sowing without resetting soil N. Models were setup for continuous sowing while soil nitrogen was reset at the end of each year. The baseline sowing window and reference cultivars were selected based on local conditions (literature) and producer's workshops. Sowing was simulated when 3-day total rainfall exceeded 10 mm and plant available soil water (PASW) exceeded a threshold. Since many Australian farmers are already applying financially optimized N fertiliser (Carberry *et al.*, 2013), we modelled a financially optimized N fertilizer policy. Here we assessed 3 incremental adaptation options included varying the input nitrogen fertiliser, the sowing dates and the choice of crop variety maturity type. These options provide opportunities to enhance the system's efficiencies toward the enhanced frontier (Keating *et al.*, 2010) by increasing water use efficiency. We identified the financially optimal combination of the above options at each location under historical and projected climate to determine the management resulting in the best financial output averaged over time. A factorial simulation experiment was conducted in which the factors were climate (2 scenario × 2 sensitivity × 6 GCMs), location (30), and adaptation options (11 sowing offsets × 4 levels fertilizer × 3 cultivars). A multipurpose model based survey estimation methodology (Bardsley and Chambers, 1984; referred to as the BC methodology) was used to upscale the simulation results to a national scale. This is the same methodology as used by the Australian Bureau of Agricultural and Resource Economics and Sciences to produce estimates from its national broadacre farm survey (ABARES, 2003). Simulation results for the 30 case study sites are expressed on a per-hectare wheat area harvested basis. In the BC method a weight is computed for each case study unit. To achieve this, units are categorized into a typology, in this case the ABARES (Australian Bureau of Agricultural and Resource Economics and Sciences) farm survey regions (Fig. 1a), from which covariates can be calculated for upscaling. These covariates are the mean wheat yield and wheat price averaged over the base time period 1980-1999 and estimated from ABARES's farm survey. All financial values were deflated by the consumer price index (CPI) and expressed in 2007 AUD. Corresponding national estimates of these quantities were obtained for the farm survey from ABARES's Agsurf website. All estimates produced from APSIM-derived variables need to be bias-corrected to compensate for modelling assumptions that differ from reality. Bias correction factors were computed for ABARES regions and applied equally to all locations within each region. The adapted yield (AY) and adapted gross margin (AG) are upper limits for fully enhanced systems with all adaptation strategies (in this study) at the enhanced frontier (EF). For historical climate, lower limits are the historical yield (HY) and historical gross margin (HG) under current practice. For future climate we defined lower limits as current practice yield (CPY) and current practice gross margin (CPG). AY and AG are fully adapted (enhanced) systems on the EF. These modelled values may not be achievable due to biophysical, management, social, or economic constraints. Here, all projections in 2030 have been associated with the effect of elevated atmospheric CO_2 unless otherwise indicated.

3 Results – Discussion

Enhancing system efficiency of the baseline period could increase yields across sites up to 79% with a median of 15% compared to HY. In the baseline, gross margin increased by optimal adaptations (AG) across sites in range between 1% and 216% with a median of 20% compared to HG. By applying current practice in 2030, relative yield compared to the baseline varied between -37% and +19% with a median of -1%. Adaptations could offset the impact of climate change on yield across sites up to +76% with a median of +15% compared to the baseline. This offset by adaptation in terms of gross margin was up to 208%. By applying adaptation options to the baseline, yield (tonnes/ha) and gross margin (AUD$/ha) changed by +17% and +33%, respectively, at the EF. Under projected climate for 2030 (averaging over scenarios, sensitivities, and GCMs) and without enhancing current efficiency of the farm systems, yield and gross margin over the entire Wheatbelt were projected to decline by 1% compared to the baseline, i.e. a 0.15 million tonne decline in production. With current cost and prices this will result in AUD$32M p.a. lower gross margin compared to the baseline. Yield and gross margin per unit area of the Wheatbelt increased by applying the adaptation options in both the baseline and 2030 climate while inter-annual variability (1980-1999) increased. Given the consistency of our modelling results for CO_2 effect with experiments (Ainsworth and Long, 2005; Amthor, 2001; Asseng *et al.*, 2013a) we expect that the Wheatbelt should realise the benefits of elevated atmospheric CO_2 (Fig 4) projected here. At the national scale, the simulated fertilisation effects of the elevated atmospheric CO_2 on yield are predicted to be large enough to not only offset the negative impacts of changes in rainfall and temperature but also to increase yields without enhancing current efficiency (Fig 1b). The upscaling methodology in here is a tried and well tested methodology, it is an approach that can be used when the sample of case study sites is unbalanced relative to the whole population. The upscaling weights approximately calibrate the estimates to totals of the benchmark variables in the base period at the national level. Accurate estimation of the potential value of adaptation relies on a strong linear relationship between the benchmark variables and income, as well as the bias correction. It is not possible to predict changes in the bias so it was necessary to assume that this component remains fixed in relative terms in the projection period and at the EF.

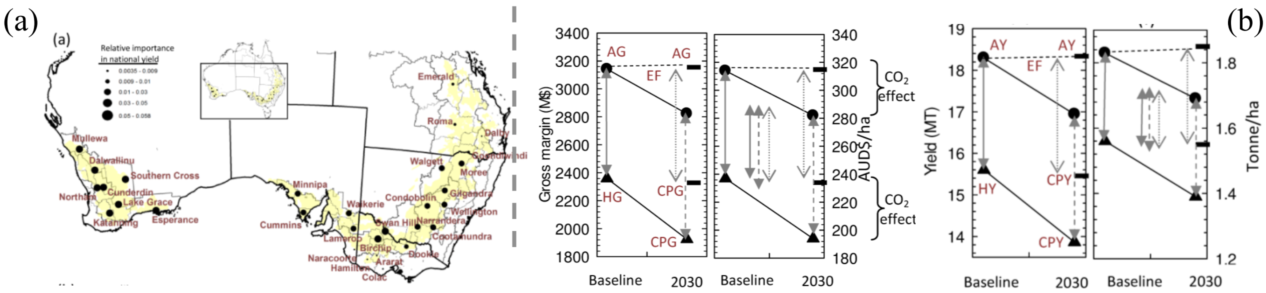

Fig. 1. (a) Location map (b) upscaled gross margin and yield, with and without effect of elevated CO_2.

4 Conclusions

Over the Australian Wheatbelt as a whole, the projected yield and the gross margin at 2030 did not change substantially compared to the baseline with current practices. At the national scale, there might be a greater opportunity to increase yield over current levels by applying currently available management options, due to a boost from the moderate elevated atmospheric CO_2 effect on enhanced water use efficiency in 2030. It should be noted, however, that at more than half of sites a decline was projected in production and gross margin.

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Climate change impact on Western Australian mixed farm systems

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1 Introduction

Primary enterprises are expected to contend with more frequent climate crises, environmental degradation and even climate-related regulatory change (IPCC, 2014). These stressors occur against an existing backdrop of conventional drivers including economic, biophysical, institutional, cultural and political pressures (Marshall *et al.*, 2012). Australia's primary industries have historically operated in a highly variable climate and this has posed significant challenges to production, requiring sound and responsive risk management practices. Climate change, brings with it a number of new challenges not yet accounted for by Australian primary producers, and so understanding the scale of these impacts is of importance in undertsanding the changing nature of agricultural risk in the near future. Western Australia with about 4 million ha of wheat production is a major contributor to the Australian agrifood sector and economy. Like cereal production, pastures in WA play a major role in agricultural enterprises and contribute over $3 billion annually through animal production, improvements to crop rotations and conserved fodder (The Department of Agriculture and Food, 2014). Farming profitably in the Western Australia in recent years has been a challenge due in part to declines in annual rainfall as well as exposure to both heat and cold teperature extremes (McConnell & O'Hare, 2013), although lower production might be still profitable. Climate drives the productivity, profitability and environmental health of these systems as they often have to respond to low and variable rainfall. Here we identify the likely effect of climate change in 2030 on mixed farm systems of the Western Australia across a climate transect in terms of production, profit, and environmental impacts for projected climate scenarios in 2030 relative to the baseline of 1980-1999. This work will give insight for designing strategies to respond to changes in climate such as optimized shift towards more intensive livestock systems, dual-purpose cropping, etc.

2 Materials and Methods

Four (4) representative mixed farm systems were identified across a climate gradient of 369 to 241 mm of growing season rainfall (Apr-Oct). The rationale for using a transect approach was to capture the range of possible future impacts across a range of soil and climate regimes (Fig. 1a). These sites represent complex agro-ecosystems with different soil, farm, livestock management and input intensity regimes. Representative farming systems were developed across this transect through facilitated workshops with stakeholders, and modelled by linking the APSIM soil water, soil nutrient cycling, crop and surface residue simulation models (Holzworth *et al.*, 2014) to the GRAZPLAN pasture and ruminant simulation models (Moore *et al.*, 1997) via an AusFarm interface. Future climate conditions we established by using two greenhouse gas emission scenarios of A1FI and A2 in conjunction with six different global climate models (GCM): ECHAM 5, GFDL 2.1, HADCM3, HADGEM1, MIROC-H, and MRI-GCM232. This range of emission and climate models allowed us to sample across a wide range of possible future climate conditions at 2030 and compare against mean conditions for the period 1980 to 1999. A gross margin (GM) calculation was carried out for each financial year of each modelled farming system (ABARES, 2014). Atmospheric CO_2 concentrations of 449 ppm for 2030 under the A1FI and 444 ppm under A2 were assumed, and for the baseline, we used monthly observed atmospheric CO_2 concentration. C-N flow was made possible by coupling organic matter cycling amongst plants, soils, and animals. In addition to expert knowledge, simulated crop yields were validated through producer's workshops and with regional database of Co-operative Bulk Handling (unpublished) as the best proxy yield data available.

3 Results – Discussion

Averaged over 20 years and for all climate models, projected yields declined for most of the crops × sites combinations in a range between 1.6% (Canola) to 18.2% (Lupin). Wheat yield increased only at Katanning by 6.7% while barley increased by 4.2% in Katanning and 13.7% at Cunderdin when compared to the baseline (Fig. 1b). Simulated crop gross margins were also shown to decline between 4.5% and 21.4%, except for Katanning, where GMs were simulated to increase by 8.9%. Crop gross margins were highly variable over time with greatest variability at Merredin and smallest at Katanning (Fig. 1a). Changes in simulated livestock production were much more modest than for crop production with stock sale weights increasing by up to 1.7% (Fig. 1a). Wool production declined by 3.3% and 2.7% in Cunderdin and Merredin, while increased by 1.7% in Katanning. Changes in crop/livestock production and financial outputs of sites and years were non-linearly related to the changes in growing season (Apr-Oct) rainfall and temperature projected for 2030 (Fig. 1c). Relative changes in crop gross margins declined progressively with a warming in maximum and minimum temperatures and declines in rainfall greater than 11% (Fig. 1c). Some improvements in crop GM's were simulated for modest declines in rainfall (i.e. 1 to 10% declines) which is most likely related to reductions in water-logging and oxygen deficits in root systems on shallow duplex soils common in this area (Fig. 1c). Livestock production/profit tended to be less responsive to changes in climate (Fig. 1b).

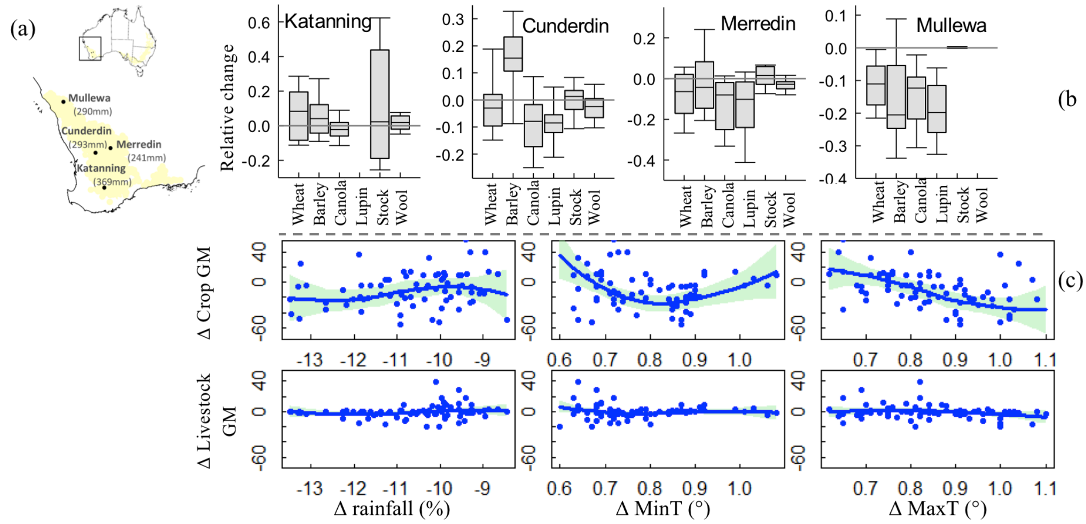

Fig. 1. (a) Location map, (b) Relative changes of production in 2030 compared to the baseline, (c) Relative change of crop and livestock production & gross margin (GM) in 2030 (averaged over all GCMs, sensitivities, and scenarios) compared to the baseline related to the changes in the local climate (Apr-Oct) at each simulated year - the fitted lines are non-parametric regressions; the shaded areas are the 95% confidence intervals.

The fertilization effect from elevated atmospheric CO_2 is one component of the climate change impacts in water-limited environments i.e. the great majority of Australian agriculture (Tubiello *et al.*, 2007). Here the positive effect of the elevated atmospheric CO_2 on crop yield and crop annual net primary productivity (ANPP) declined with climate gradient toward the drier eastern farming areas (Table 1) while the modelled pasture ANPP had less decline (Table 1). Changes in climate generally had less impact on livestock and pasture production (with current stocking rate) in comparison with cropping systems. A main characteristic of the climate change adaptation strategies in dryland mixed-farming system management would see shifts in enterprise mix options, and include shifts toward & away from livestock enterprises depending on how the climate drives the financial optimization of the whole farm system. Overall the livestock gross margin is more likely to be sustained in 2030 in comparison with those of crops (Fig. 1c).

Table 1. Relative changes in ANPP with (+CO_2) and without (-CO_2) fertilisation effect of elevated atmospheric CO_2

	Cunderdin		**Katanning**		**Merredin**		**Mullewa**	
ANPP	+CO_2	-CO_2	+CO_2	-CO_2	+CO_2	-CO_2	+CO_2	-CO_2
Total	-2.8%	-3.6%	+2.3%	-1.2%	-8.5%	-9.2%	-12.9%	-12.8%
Pasture	-2.3%	-16.6%	+2.7%	-4.8%	-8.6%	-16.4%	-	-
Crop	-7.1	-2.4%	+4.5%	+1.4%	-6.6%	-8.7%	-12.9%	-12.8%

4 Conclusions

The current production and profitability of whole mixed farm systems in Western Australia appears to be unsustainable around the drier margins in 2030. The cropping component of mixed-farm systems is more sensitive to climate change than the livestock component, and an increase in the proportion of livestock in the farming system in these regions may enhance current and future resilience to climate change.

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Will breeding efforts be counteracted by uncertain water supply due to prospective climate change?

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1 Introduction

Extreme yield drops in Europe in 2003 (loss of ~13 billion Euros) were partly associated with declines in precipitation of approx. 300 mm (Tubiello *et al.*, 2007). Regional climate models (Meinke *et al.*, 2013) show strong tendencies for decreasing rainfall in summer i.e. growing period for the North German Plain (-11%). Continuously increasing yields of the most field crops (Laidig *et al.*, 2014) together with the knowledge of decreasing summer rainfall guided us to the question if crop yield will increase in future like it increased over the last 60 years, or if insufficient rainfall may cause a plateau or decrease in crop yield development?

2 Materials and Methods

In the present study Diepholz in the western part of the North German Plain was investigated. Diepholz has a long term mean temperature of 9.6°C and 719 mm of precipitation. In Diepholz, 2003 was the year with the lowest precipitation (523 mm) during the observation period (1981–2010). Regionalised observed weather data (STARS (Orlowsky *et al.*, 2007), 1950 to 2010) and regionalized projected climate data (RCP 8.5, ECHAM6, MPI Hamburg, Germany, STARS, 2011 to 2070) was provided by the PIK on the basis of daily values. We analyzed two time slots with 20 years each. The first represents the status quo from 1981 to 2010 (slot1) and the second the future from 2051 to 2070 (slot2). Typical plant available soil water in the study region is 120 mm (pseudogleyic luvisol, mostly sand with small loam content and 60 cm rooting depth) and soil water storage is full in spring. Begin and end of crop transpiration during the growing period in the harvest year was determined on the basis of phenological data as provided by the German Weather Service (DWD). While transpiration in summer crops begins with the plant emergence (Roth *et al.*, 2005) (silage maize 10.5.; potato 5.5.), winter wheat starts significant transpiration in the harvest year when mean daily temperature exceed 3° C in the phase of tillering (21.2. in the Diepholz region) (Roth *et al.*, 2005). End of transpiration was assumed to match with the harvesting event (silage maize = 6.10.; potato = 19.7.; winter wheat = 6.8.). All future management dates were fixed on to the dates determined for the status quo. Yield data of silage maize, potato and winter wheat (nuts1; each for 1951 to 2010; n=60) was provided by the statistical office of Lower Saxony. For each crop we fitted a linear model to the yield (Rijk *et al.*, 2013; Laidig *et al.*, 2014). The slope of this function than, represented the annual yield increase of the past and served as the yield increase of the future. Water use efficiency of winter wheat was set to 349 l kg^{-1} while potato has 217 l kg^{-1} and silage maize has 191 l kg^{-1} (Roth *et al.*, 2005).

3 Results

Mean annual precipitation does not change over time (709 and 708 in slot1 and slot2 respectively) but in previous studies we found a significant shift towards increased winter rainfall and consequently decreasing precipitation during summer (Svoboda *et al.*, 2014). Rainfall during the growing period (begin of significant transpiration) in slot1 amounted in 318 mm for silage maize (10.5. to 6.10.), 160 mm for potato (5.5. to 19.7.) and 316 mm for winter wheat (21.2. to 6.8.). When summing up precipitation within the slot2 growing period we have 255 mm for silage maize (-63 mm), 139 mm for potato (-21) and for winter wheat 284 (-32) mm. Thus we have a decreased rainfall of 10 to 20 percent relative to the respective crop within the growing period due to the shift towards more winter precipitation. Taking this in mind, we calculated the yield in both time slots and, consequently, the water demand of the crops based on mean yield and water use efficiency. In slot1 winter wheat has a mean water demand of 249 mm (yield 7,13 t DM ha^{-1}). For silage maize in slot1 we calculated a water demand of 262 mm (yield 12,06 t DM ha^{-1}) and for potato 172 mm (yield 9,00 t DM ha^{-1}). For the slot2 we found an increased water demand due to increased yield of 426 (+71) mm for winter wheat (yield 12,20 t DM ha^{-1}), 304 (+42) mm (yield 15,92 t DM ha^{-1}) for silage maize and 272 (+100) mm (yield 14,24 t DM ha^{-1}) for potato. Thus we calculated an increased water demand of 16 to 71 percent related to the respective crop.

Table 1. slot1: Yield, relating water demand and possible water deficit of important crops (silage maize: SMA; potato: POT; winter wheat: WWE) today (slot1: 1991 – 2010) and in the future (slot2: 2051 – 2070).

time slot	crop	plant available soil water [mm]	growing period [date]	precipitation during vegetation period [mm]	total available water [mm]	yield [t DM ha^{-1}]	water demand [mm]	water deficit [mm]
slot1	SMA	120	10.5.-6.10.	318	438	12	262	176
	POT	120	5.5.-19.7.	160	280	9	172	108
	WWE	120	21.2.-6.8.	316	436	7	249	187
slot2	SMA	120	10.5.-6.10.	255	375	16	304	71
	POT	120	5.5.-19.7.	139	259	14	272	-13
	WWE	120	21.2.-6.8.	284	404	12	426	-22

Together with the plant available soil water at the beginning of the growing period (120 mm) we have a crop dependent water supply from 280 to 438 mm. During the slot1 there is sufficient water, as characterized by a positive water deficit, for all three crops but a small deficit becomes visible in the second slot. While for silage maize an oversupply of 71 mm is left, we could expect a water deficit of -13 for potato and of -22 mm for winter wheat (Table 1). Thus we could detect only little water deficit within the future time slot for potato and winter wheat while for silage maize no deficit becomes visible. For winter wheat the deficit becomes zero eight years earlier (2044 – 2063) with a yield of 11,6 t DM ha^{-1} and for potato nine years earlier (2043 – 2062) with a yield of 13,5 t DM ha^{-1}.

4 Conclusions

In conclusion, we cannot expect any drought-related reductions in yield increase of silage maize. For potato as well as for winter wheat a plateau in yield increase is reached. For these crops management procedures has to be adjusted if yield gap should maintain on the present level. The intensification of irrigation is in this region a sustainable option, since the total precipitation is sufficient. Next steps will be identifying the count and length of drought periods in future scenarios. Drought periody may cause strong yield depression within the growing period due to drought stress. Calculating water demand of catch or intercrops, often grown before summer, may guide to increased water deficit and, consequently, makes adaption strategies more necessary.

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The contributions of recent climate change trends to maize phenology and yield in Northeast China

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1 Introduction

Northeast China (NEC) is one of the major agricultural production areas in China, but it is also the most susceptible to climate variability. The total maize sown area accounts for 29% of the nation's totals and the production of maize in NEC accounted for more than 30% of the nation's totals (NBSC, 2008-2010). In the past five decades, NEC experienced a warming trend in surface average temperature equal to 0.38^{o}C per decade (Liu *et al.*, 2012). Therefore, it is important to investigate the contribution of climate change to maize yield to improve our understanding of how we can ensure increased yields in the future. It is difficult to separate the effects of different climatic variables to changes in crop production. Therefore, simulation models have been used extensively to estimate the impacts of climatic variables on crop productivity. The Agricultural Production Systems Simulator (APSIM) has proven to be an effective tool to investigate the potential impacts of climate variability on crop productivity (Asseng *et al.*, 2004; Liu *et al.*, 2010). Therefore we used the APSIM-Maize model to separate the impacts of changes in solar radiation (SR), maximum (T_{max}) and minimum temperature (T_{min}) on maize phenology and yields in NEC during the period from 1961 to 2010.

2 Materials and Methods

The study area is located in NEC, comprised of Heilongjiang (north), Jilin (center), and Liaoning (south) Provinces. In this study, 55 sites in NEC were selected from the weather stations operated by the National Meteorological Networks of China Meteorological Administration (CMA). Climate data includes daily mean, maximum, and minimum temperatures, daily sunshine hours, and daily precipitation from 1981 to 2007 at each station. Sunshine duration was converted into daily solar radiation using the Ångström formula (Black *et al.*, 1954; Jones, 1992).

APSIM-maize has been calibrated and used in NEC for simulating the growth and yield of maize (Liu *et al.*, 2012 & 2013). Rely on these previous studies, APSIM-Maize was run with historical climate data (1961-2010) to quantify the impacts of changes in SR, T_{max}, and T_{min} on the duration of growing period and yields of maize in NEC. We designed three simulations to examine these effects, names as $Run_{\_SR}$, $Run_{\_Tmax}$, and $Run_{\_Tmin}$. Each simulation used the observed 50-year time series of one selected climatic variable, with the remaining variables held constant at 1961 values. Simulations assumed that water applications and nutrient inputs were taken as non-limiting in order to eliminate the effect of water and nutrient stresses on simulated maize yield, and other management details are kept constant throughout the simulated years 1961-2010.

3 Results – Discussion

In NEC, when the same hybrid was specified in APSIM for all years, a simulated increase of T_{max} shortened the length of vegetative periods (LVP) and reproductive periods (LRP) at the rate of 0.1-0.9, and 0.1-1.2 days per decade depending on the locations, respectively. Moreover, the warming trend of T_{min} also shortened the LVP and LRP but with a larger magnitude (0.2-2.0, and 0.1-2.3 days per decade). The simulation suggests that this negative impact was higher in the high latitude. The regional LVP and LRP with varying T_{max} shortened at the rate of 0.26 and 0.50 days per decade, moreover, the regional LVP and LRP with varying T_{min} shortened at the rate of 0.97 and 0.92 days per decade ($p < 0.01$) from 1961 to 2010 (Fig. 1).

Our results indicate that one climate variable at a time, whilst holding the other variables constant at 1961 values, changes in SR, T_{max}, and T_{min} would have led to a negative impact on maize yield, decrease it by 212.1, 72.4, and 72.2 kg ha^{-1} per decade (Fig. 2), caused a decrease in yield by 9.9%, 3.4%, and 3.4% during the past five decades, respectively (Table 1).

4 Conclusions

In this study, APSIM-Maize model was used to separate the impacts of changes in SR, T_{max}, and T_{min} on maize phenology and yields in NEC during the period from 1961 to 2010. Our results indicate that the warming trend significantly shortened the LVP and LRP, and climate trends (SR, T_{max}, and T_{min}) would have led to a negative impact on maize yield in NEC if there was no adaptation was taken.

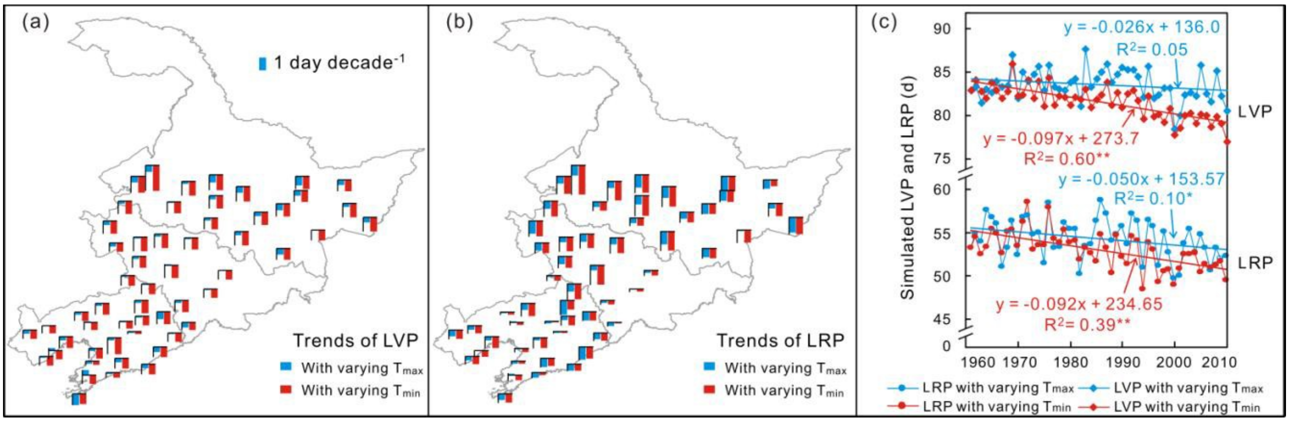

Fig. 1. The relationships between changes in T_{max} and T_{min} and the length of vegetative (LVP, a) and reproductive period (LRP, b) of maize in each location and (c) entire NEC.

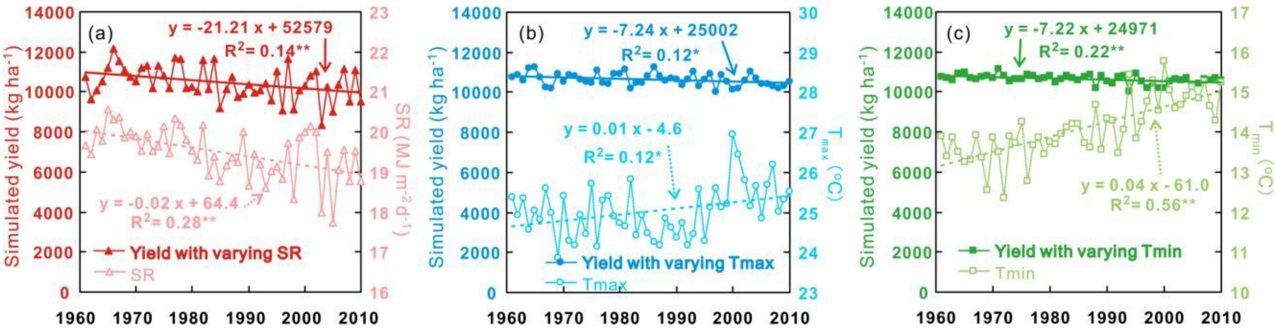

Fig. 2. Simulated regional maize yield in 1961–2010, with varying (a) SR, (b) T_{max}, and (c) T_{min}, and annual changes of associated climatic variables. Other climate variables are kept at 1961 values.

Table 1. Simulated changes in maize yield (%) under different climatic drivers (SR, T_{max}, and T_{min}) for different

Region	Yield in 1961 (kg ha^{-1})	Yield changes with varying climate variables in 50-year		
		SR	Tmax	Tmin
Heilongjiang	8830	-5.8%	-4.4%	-1.4%
Jilin	10764	-13.1%	-3.2%	-8.4%
Liaoning	13007	-9.8%	-2.7%	-0.2%
Entire region	10727	-9.9%	-3.4%	-3.4%

Acknowledgements. This work was supported by National Natural Science Foundation of China (31471408 & 41401049).

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Running NUANCES-FARMSIM to predict greenhouse gas emissions in mixed smallholder crop-livestock systems under different scenarios in Western Kenya

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1 Introduction

African smallholder farming systems are complex, dynamic systems with many interacting biophysical subcomponents (Van Wijk *et al.*, 2009) that strongly influence livelihoods and the farm greenhouse gas (GHG) balance. A modelling tool, NUANCES-FARMSIM, brings together the different production components of African smallholder farm systems, however until now, the model has not included a component to analyze climate impacts. In this communication we test FARMSIM's outputs to predict GHG emissions under different scenarios.

2 Materials and Methods

We ran FARMSIM for a representative case study farm of the highlands of Western Kenya. Each of the components of the model (livestock, crop, soil and manure management) have already been tested (Rufino *et al.*, 2007; Tittonell *et al.*, 2008). We followed IPCC guidelines (IPCC 2006) to calculate emissions for four scenarios related to Kenyan policies and plans of agriculture intensification and climate change action (Table 1). We ran the model several times to average the interferences of stochastic values in the model outputs (e.g. sex of the new calves).

Table 1: Inputs, parameters and scenarios for FARMSIM

	CT[1]	FERT	FEED	FERT+FEED
Cropping sub-system(*0,8 ha of maize; 0,4 ha Napier grass*)				
NPK fertiliser to maize (kg ha^{-1})[2]	0 0 0	72 34 84	0 0 0	72 34 84
Livestock sub-system(*Frisian cows (1 lactating cow, 1 calf); Calving interval=2 years (Deterministic)*)				
Supplementation with concentrates: In all stages (kg month-1 per head)	0	0	60	60

[1] Scenarios: CT=Control; FERT=Fertilizer Rise; FEED=Feeding improved through concentrates; FERT+FEED: Fertilizer rise and improved feeding
[2] Fertilizers are added every 6 months (2 seasons, the annual added amount is twice the amount indicated in the table)

3 Discussion

Farm components and total farm GHG emissions (Fig. 1 & Fig. 2)
The fertilizer rise scenario (FERT) showed a 22% increase in total farm emissions from the control (CT), due to an increment of N-inputs in soils. With the rate of fertilizer applied (144 Kg N ha^{-1} $year^{-1}$), the N_2O emissions of soils are almost doubled (97% increase). Improving the livestock feeding by adding supplementation in the form of concentrates (FEED, 60 Kg $month^{-1}$ $head^{-1}$) resulted in a 24% increase in total farm emissions, mainly because it also led to an increment of the dry matter intake of the cow (concentrates supplement the diet, they do not replace napier grass). We observed an increase in GHG emissions from the manure management system, due to an increase in the nitrogen content of cow excreta, which in turn results in manure with higher nitrogen content and a slight increase in soil emissions. Finally, the scenario which combines fertilizer rise and improved feeding (FERT+FEED), resulted in an increment of 52% of the farm emissions.
Maize production and milk production (Fig 3 & Fig 4.)
Adding fertilizer (FERT) increased the production of maize by 6% on average (287 Kg ha^{-1} $year^{-1}$). Improving the feeding (FEED) resulted in a 160% increase in milk production (869 L $year^{-1}$). Fertilizer in the maize fields did not have a significant effect on milk production –in spite of the maize stover flow to the cows–, whilst improving the feeding resulted in a slight increment in maize production by 0,13%. The combination of both treatments (FERT+FEED) brought an increase both in maize and milk production. Note that the CT and FERT scenarios do not produce milk in the 4th year, while the scenarios with supplements (FEED and FEED+FERT) do produce milk.
GHG emissions per product (Table 2).
Emissions per unit of output are reduced as the production increases in the case of the feeding improved scenario (FEED), but not for the fertilizer rise (FERT) or the combination of fertilizer rise and feeding improved (FERT+FEED).

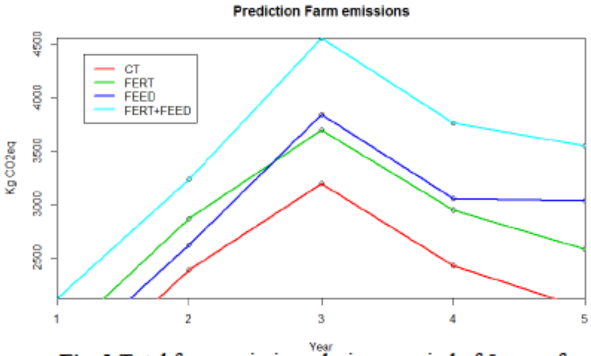

Fig. 1 Total farm emissions during a period of 5 years for the 4 scenarios(CT, FERT, FEED, FERT+FEED)

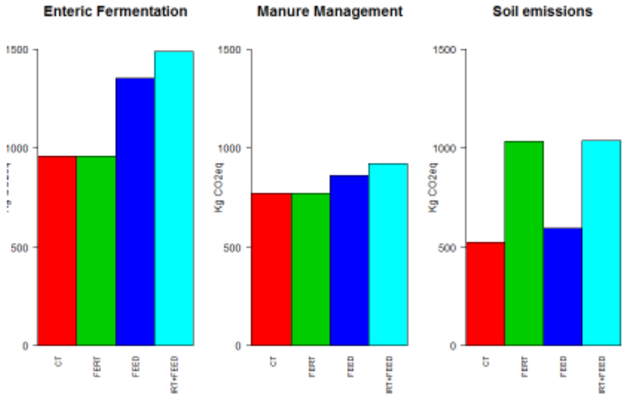

Fig. 2 Contribution of the 4 scenarios to the farm components emitting GHG: Enteric fermentation; manure management and soils

Fig. 3Maize productionfor a period of 5 years

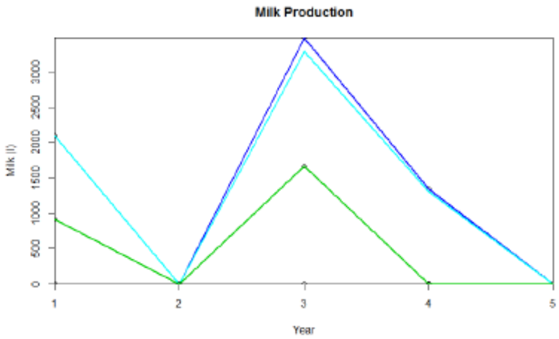

Fig. 4Milk production for a period of 5 years

Table 2. Emissions per product

	Kg CO2eq l-1 of milk				Kg CO2 eqkg -1 of maize			
Year	CT	FERT	FEED	FERT+FEED	CT	FERT	FEED	FERT+FEED
1	0,70	0,70	0,38	0,42	0,007	0,13	0,01	0,14
2	0	0	0	0	0,10	0,18	0,10	0,17
3	0,73	0,73	0,48	0,56	0,26	0,38	0,28	0,38
4	0	0	1,09	1,24	0,10	0,18	0,11	0,18
5	0	0	0	0	0,10	0,23	0,17	0,23
Average	0,72	0,72	0,65	0,74	0,11	0,22	0,13	0,22

4 Conclusions

FARMSIM can be used to predict GHG emissions and analyze trade-offs and synergies at farm scale. It provides the necessary outputs to study the interaction between the farm components and climate impacts. By calibration, a sub-model will be developed and loosely coupled to the relevant input and output parameters of the NUANCES-FARMSIM model, to examine productivity and climate system trade-offs to identify not only optimal farm management innovations but also constraints to their implementation.

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T6. Designing sustainables agricultural systems with legumes

Chair: Marie-Hélène Jeuffroy, INRA
Co-chair: Snapp Sieglinde, Michigan State University

Greener food production in Africa: intensification through multipurpose legumes

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1 Introduction

The Green Revolution did not reach all parts of the world evenly. Many problems faced by farmers in sub-Saharan Africa are old and familiar, but preclude the large-scale approaches that drastically improved agricultural production in a few key crops in Asia. The unique climate and soil challenges of sub-Saharan Africa are now compounded by climate change and socio-economic instability. 'Sustainable intensification' is the research and development effort to find solutions that raise yields and incomes – and provide social and economic benefits – in a rapidly changing environment. Agrobiodiversity, soil health and multifuncationality are some key components of sustainable intensification. This talk will explore how multipurpose legumes that produce food, fodder and fuel while building soil resources are key to catalyzing SI in a maize-dominated farming system. Not all types of legume species are effective, nor are they all adoptable.

2 Materials and Methods

We initiated on-farm experimentation with over a thousand farmers to try out a basket of legume crop options grown with intensified planting arrangements, in sequence with maize and other staple crops. Four sites were chosen in central Malawi to represent an agricultural potential gradient from semi-arid, low production zone to a sub-humid high production zone. The mother and baby trial design and innovation platforms were used at these sites to foster participatory action research and extension. Food legumes such as modern varieties of common bean and groundnut were popular with farmers, but produced a modest number of benefits (cash and food). A 'doubled up legume' system that combined the complementary growth patterns of a food legume with a multipurpose legume (pigeon pea) was also popular and produced a wide range of benefits (cash, food, fuel, fodder, and soil fertility).

3 Results - Discussion

Farmer interest was evaluated by monitoring the number and size of field plots where farmers expanded production of new legume varieties. Use of inputs and spacing intensity provided further insights into farmer interest in sustainable intensification. Female farmers showed high interest in food, multipurpose and doubled up legume systems (Fig. 1).

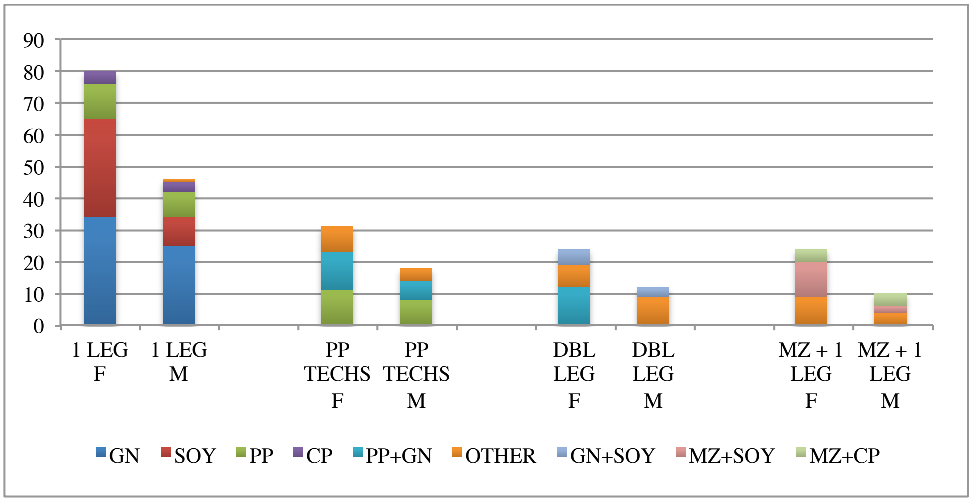

Fig. 1. Count data on number of technologies farmers have expanded on their farms in central Malawi. F= Female farmers, M= Male farmers. Improved varieties of GN = Groundnut (peanut), SOY = Soybean, PP = Pigeonpea, CP=Cowpea, PP+GN = doubled up legume (intercropped legumes), MZ = maize

Crop model simulations were used to evaluate the performance of intercrop, rotational and sole crop variations of legume and maize systems. Soil moisture and nutrient dynamics associated with various maize-pigeonpea systems were explored for a range of climate scenarios. The simulations highlighted the buffering effects of intercrops for food security, particularly in terms of building soil fertility while ensuring maize yield every year when compared to a maize-pigeonpea rotation or the low yields of a sole-cropped maize system (Fig. 2). Soil types with higher initial fertility (soil type 1) supported higher maize yields from a sole-maize crop systems, but over time the pigeonpea diversified cropping systems built soil fertility and performed as well.

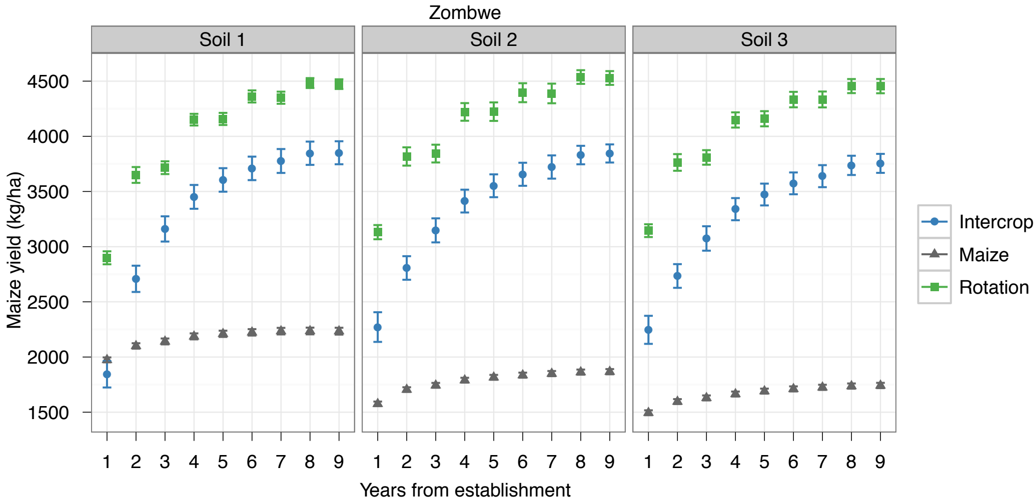

Fig. 2. Simulated maize yields using APSIM model, showing improvement in maize grain yield over time in maize-pigeonpea intercrop, maize grown after a pigeonpea rotation and continuous maize (fertilized at 20 kg N/ha). Error bars are standard errors of the mean generated through weather field variation. M. Ollenburger, 2012.

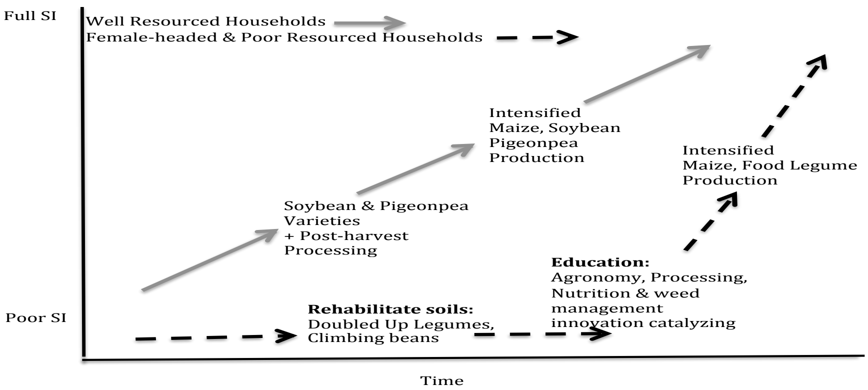

Fig. 3. Trajectories of sustainable intensification based on household type.

4 Conclusions

The combination of on-farm experimentation and crop simulation modelling has provided novel insights into the performance of multipurpose legume crops for a range of farmer socio-economic groups and environmental conditions. Female farmers in our central Malawi case study sites were particularly interested in food legumes, and in pigeonpea combinations such as doubled up legumes (pigeonpea grown as an intercrop with groundnut, and rotated with maize). Initially under higher soil fertility modelling results indicated that a maize-pigeonpea intercrop could reduced maize yields compared to sole crops, yet over time the intercrop produced two to three times as much maize yield and – importantly – produced a maize crop every year. On the other hand, the maize rotated system with multipurpose pigeonpea produced the highest yields and was the most stable cropping systems. This lead us to recommend that better off farmers use rotations with improved soybean and pigeonpea varieties, whereas doubled up legumes with pigeonpea are appropriate for female headed households and those with poor soils.

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A comparison of past and current cropping systems with designed innovative cropping systems including legume crops, in three french regions.

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1 Introduction

Since 20 years, French agriculture is facing a considerable decrease in legume areas, while numerous studies showed their contribution to a sustainable management of territories and resources (Voisin *et al.*, 2014). Due to their numerous ecosystemic services, mostly due to their capacity for biological nitrogen fixation, legume crops, when introduced in cropping systems (CSs), may be able to cope with a diversity of challenges imposed to agriculture (e.g., climate change, resource scarcity). Our aim was to design innovative CSs including legumes and to compare their performances to those of past and current CSs, in three French regions (Bourgogne, Midi-Pyrénées and Pays de la Loire).

2 Materials and Methods

The first phase of our work aimed at rebuilding the main current CSs of the 3 regions. This was done with a database from the French Ministry of Agriculture, describing crop management and previous crops (5 previous years) of 7 crops in 2011: wheat, oilseed rape, corn, pea, sunflower, triticale and barley. First, we described patterns of crop successions. Next, thanks to multifactorial analysis (Multiple Correspondence Analysis and Factorial Analysis of Multiple Correspondences), we described each crop management and rebuilt main current cropping systems by combining crop successions and crop management.

In the second phase, we organized in each region a workshop with people concerned with local agricultural issues and constraints, including agricultural advisors, farmers and researchers (around 15 people per workshop), involved in conventional and/or organic farming. The goal was to design innovative CSs which included legumes as much as possible, as major sole crop, intercrop, living mulch of another cash crop, or as sole or mixed catch crop. It was recommended to design these systems in a hypothetical socio-economic context favourable to legumes (business opportunities, competitive sales prices compared to those of cereals…), in order to propose more innovative CSs.

The workshops were organized in 3 steps. During the first step, we shared knowledge with stakeholders about i) major past and current CSs in each region, ii) agricultural objectives and constraints for territories (*e.g.* nitrate vulnerable area, alfalfa dehydration project…) and for farmers (*e.g.* forage's quality requirements, lack of available legume cultivars…) and iii) ecosystem services/disservices provided by legumes. During the second step, we asked stakeholders to write around 5 sub-objectives and one solution per sub-objective, linked with the general objective of the workshop. This step aimed at ensuring a time for personal thoughts and expression. At the end of the second step, we summarized and organized collectively all the ideas and identified additional sub-objectives and constraints to design the CSs. The last step was a collective discussion: based on previous steps, stakeholders designed a batch of innovative CSs with legumes.

In the third phase, past and current CSs and innovative CSs will be assessed and compared on environmental, economic and social criteria with multicriteria assessment tools.

3 Results – Discussion

Only the results of Pays de la Loire's workshop will be presented in this paper. During the first phase, we showed that CSs in Pays de la Loire are varied: in fact, we highlighted more than 190 crop successions. Most of them are suitable for mix farming systems (crop and livestock): one third of CSs with at least 1 year of grassland and 40 % with at least 1 year of maize, mainly used for forage in this region. CSs including annual legumes represented less than 10 % of sample studied, with pea as the main annual legume species.

During the second step of the design workshop, numerous ideas (34 proposals) about reintroduction of legumes in CSs have been raised by stakeholders. For instance, *i)* sow a forage legume into grain legumes before harvest to control weeds at the end of crop cycle and before the sowing of the following crop; *ii)* intercrop wheat with pea to produce high protein content wheat with low nitrogen (N) fertilization. Six additional sub-objectives were identified from step 2 and used to guide step 3: i) reduce risk of N leaching, ii) optimize N fertilization, iii) optimize weeds control, iv) improve soil structure, v) secure forage production for breeders and vi) optimize quality of forage. Three innovative CSs including legumes were designed during the workshop: two are adapted for mix farming systems (main systems in Pays de la Loire) and one for cereals production systems. For each system designed, stakeholders described crop succession (including cover crops), crop management of each crop (soil tillage, quantity of N fertilizer…) as well as yield objectives. CS adapted for cereals production systems is described in figure 1. Compared to the common current CS managed in cereals production systems (winter oilseed rape-winter wheat-winter wheat), stakeholders hopped that the innovative CS will allow a reduction of N fertilization (thanks to numerous legumes in the rotation), a reduction of risk of nitrate leaching (thanks to cover crops in winter), a control of weeds (thanks to cover crops and introduction of new plant's family in the rotation) and an improvement of soil structure (thanks to the diversification of crops and their root system).

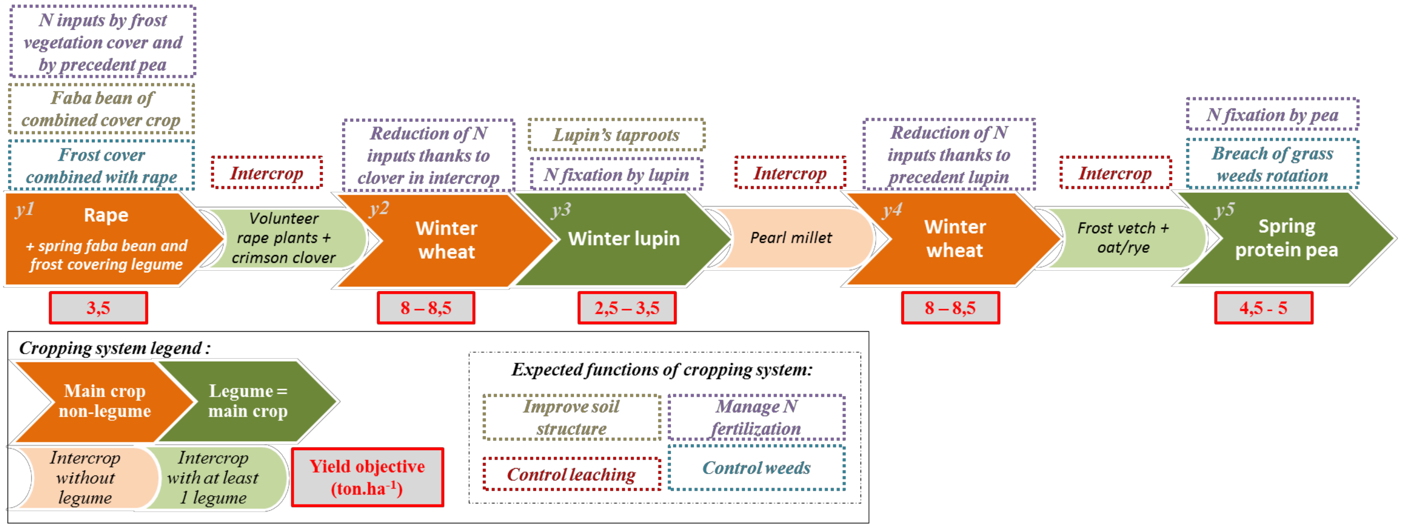

Fig. 1. Description of the innovative cropping system adapted for cereals production systems in Pays de la Loire

At the end of the workshop, stakeholders wrote around five evaluation indicators they found essential to evaluate performances of CSs: some of those indicators will be used in the next phase of our work. Indeed, innovative CSs will be assessed on environmental, economic and social criteria with multicriteria assessment tools: CRITER (Fortino et Reau, 2010), Stephy (Attoumani-Ronceux *et al.*, 2013) and PERSYST (Guichard *et al.*, 2010). Performances of new CSs will be compared to those of current and past CSs managed.
On the final phase of the project, the local socio-economic partners and stakeholders will design legume development scenarios, including crop production and valorization, using the innovative CSs.

4 Conclusion

This approach is in progress and will be implemented also in the two other regions of our work (Midi-Pyrénées and Bourgogne), where agricultural systems are different. Design workshops fuel new exchanges between researchers (which have scientific knowledge) and local stakeholders (agricultural advisers and farmers, which are concerned by local agricultural issues and constraints). Confront this two kinds of knowledge allows to imagine even more innovative CSs while being suitable to local constraints and practices.

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Design and ex ante assessment of cropping systems with legumes in four European countries

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1 Introduction

Cropping systems (CSs) with grain legumes (GLs) provide many agronomical and environmental benefits. However, since the 90ies, the area dedicated to these crops has been strongly declining in Europe and currently represents no more than 1.8% of the arable land (FAOSTAT, 2014). Moreover, the contribution of CSs with GLs to sustainable development depends on their local adaptation and on their fit with most stakeholder priorities and management. The aim of this study was to design, together with local experts, adapted CSs with GLs in four European countries, and to assess their sustainability, accounting for the diversity of stakeholder points of view. The work was performed in Sweden, Spain, Czech Republic and France.

2 Materials and Methods

In order to assess the CS sustainability, we used two different tools: MASC© (Multi attribute Assessment of the Sustainability of CSs, to assess sustainable development at the CS scale; Sadok *et al.*, 2009) and CRITER (calculating most indicators used as inputs in MASC©). These tools were adapted to take into account GL crops, and the socio- economic and pedo-climatic context of each country.

Table 1. Characteristics of the study regions

Country	Region	Soil type	Climate	Reference CS
Spain	Andalucia	Vertisol	Mediterranean	Faba bean-Wheat or Sunflower-Wheat (2 year rotations)
Sweden	Scania	Light clay	Temperate to	Wheat, Barley, Oilseed rape, Sugar beet (6 year rotation)
France	Parisian basin	Loamy clay	Temperate	Oilseed rape-Winter wheat-Spring barley (3 year rotation)
Czech Republic	Olomuc region	Silty sand	Continental	Oilseed rape-Winter wheat-Silage maize-Spring barley (4

The four countries represent various soil types and agro-ecosystems (Table 1). In a first step, a reference CS, typical for each region, was described and assessed with the CRITER-MASC© tools. In a second step, innovative CSs (nature of crops in the rotation, and their management plans) were collectively designed with researchers from each country together with a farmer (Spain) and a technical adviser (France), according to a defined set of objectives and constraints: introduce GLs in the CSs, improve yield stability, decrease fertilizer and pesticide use. All innovative CSs were assessed and then compared to the reference. Data for the description of CSs (soil, climate, crop management plans) were collected for the four countries from local farm managers and researchers or from previous experiments.

3 Results and Discussion

In all countries, designed innovative CSs involved at least two GL species, as sole crop or intercropped with cereals, as for the example of Sweden (Fig. 1). Innovative crop rotations were at least three years longer than reference ones, in order to diversify the crop sequence and respect delay between GL crops regarding diseases. Faba bean and pea were introduced as main crops in each country, as well as lupin in Sweden, chickpea in Spain and alfalfa in Czech Republic. Management of all crops was designed to decrease fertilizer and pesticide use. Cover crops, mostly based on forage legumes, were added to provide green manure. New management methods were applied to decrease agrochemical inputs, such as large rows to allow mechanical weeding, relay and companion crops or variety mixtures.

In France, the assessment showed that introducing GLs may increase the overall sustainability. It mainly improves the environmental component by decreasing negative impacts of fertilizers and pesticides. It did not systematically decrease the economic sustainability, mostly depending on the selling price of the grain legume introduced and differing between the innovative CSs: pea in FrI 1 and lentil in FrI 2 (Table 2). In Sweden, the reference CS was quite diversified (6 year rotation and three different crop families) and already had a good sustainability rate. However, introducing GLs in the crop rotation allowed improving air and soil quality as well as preservation of non-renewable resources. In the chosen region in Spain, the most important problem was soil erosion. The tool was modified to be adapted to those specific local conditions. The innovative CSs did not seem to improve the environmental dimension. This lack of changes may be explained by a low use of fertilizers on the reference CS and a choice to apply low tillage in the reference and innovative CSs, which did not allow decreasing the herbicide use.

In all countries, introducing GLs was usually linked with a lower input use (especially N fertilizer) and allowed diversifying the crop sequence. The use of less chemical inputs may therefore explain some of the better results for the environmental dimension. The social dimension is defined mainly as a balance between health risks for the farmer linked to pesticides and the CS complexity (number of crops and management). This explains that the social sustainability did not highly differ between innovative and reference CSs. The economic dimension also includes the long term production capacity which can explain why reference CS and innovative CSs may have the same sustainability, even if GLs are usually less profitable in the current economic context. It is important to keep in mind that the tools CRITER and MASC were not designed first to deal specifically with GLs (especially in intercrops or relay crop) and the calculation of some criteria still needs improvement based on additional scientific knowledge. The results of their assessments could evolve with improvement of the calculation of those criteria.

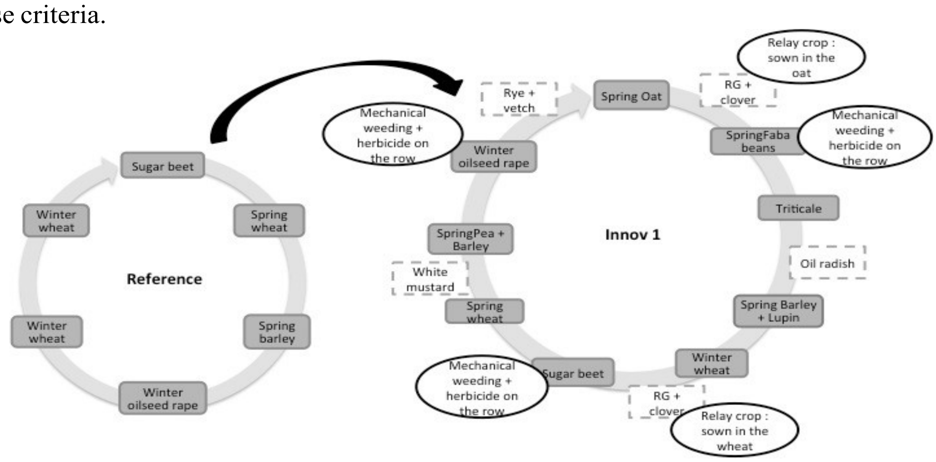

Fig. 1. Reference and designed cropping systems for Sweden

Table 2. Sustainability assessment of cropping systems for three countries

	Spain			Sweden			France		
The higher mark the better	SpR 1	SpR 2	SpI 1	SwR	SwI 1	SwI 2	FrR	FrI 1	FrI 2
Economic (between 5 and 1)	5	4	5	5	5	5	4	2	5
Social (between 5 and 1)	3	3	2	3	4	5	3	4	3
Envir. (between 5 and 1)	4	3	2	5	5	5	3	5	5
Overall sustainability (between 7 and 1)	6	4	4	6	7	7	4	5	6

As the characterization of sustainability can highly differ according to different stakeholders, the sustainability assessment of these CSs has to account for this diversity. Thus, in a next step, meetings with stakeholders will be organized in each country to catch their points of view on sustainability and integrate them to assess the sustainability of the designed CSs. Current and innovative performances will then be compared within each country. This meeting with stakeholders will also allow us to discuss the feasibility of innovative CSs and to identify the innovative ones accepted by most (or even all) stakeholders (Ravier *et al.*, 2015).

4 Conclusions

This design and assessment work on CSs allowed us to compare different innovative CSs with GLs in different contexts. Even if results differ between situations and innovative CSs, the introduction of GLs brings some changes in the CS sustainability. It usually improves the environmental dimension while keeping a good economic sustainability. These assessments give to each country a more concrete frame to start working with farmers and stakeholders in order to improve CSs sustainability.

Acknowledgements. The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/ 2007-2013) under the grant agreement n°FP7-613551, LEGATO project.

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Designing legume-supported cropping systems

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1 Introduction

Given the negative side-effects of agricultural practices, changes in land use, climate and international trade conditions, resource-efficient and climate change adapted production systems need to be developed. This is especially relevant for legumes since less than 30% of the plant-based protein feed is produced within Europe, so protein security is an issue, while rotations have become narrow and questions about their sustainability are often raised. Legume cultivation declined in Europe from 4.7% in 1961 to 1.7% in 2013 (FAOstat, 2014) due to agronomic and marketing constraints, increased specialisation and despite several agronomic, environmental and farm-economic benefits (Preissel *et al.*, 2015; Reckling *et al.*, 2014a). To design competitive cropping systems, we applied a framework developed in the Legume Futures project (Reckling *et al.*, 2014b; Stoddard *et al.*, 2014). Our objectives were to generate new legume-supported cropping systems as an alternative to current farming and to assess the impacts of legume-supported, legume-free and current cropping systems on economic agronomic and environmental parameters in five sites: Västra Götaland (SE), Eastern Scotland (UK), Brandenburg (DE), Sud-Muntenia (RO) and Calabria (IT).

2 Materials and Methods

The cropping system framework consists of a rule-based rotation generator and a set of algorithms to calculate impact indicators considering rotational effects of all crops (Reckling *et al.*, 2014b). The framework follows three steps: i) generating rotations, ii) designing production activities and evaluating their impact using environmental, economic and agronomic indicators, and iii) assessing and designing cropping systems. In this paper we concentrate on arable cropping systems with grain legumes excluding forage crops. The following cropping systems were selected and compared: i) 'current farming without legumes' (based on regional statistics and knowledge from farm advisors), ii) 'economic best without legumes' (generated systems with highest gross margins), iii) 'economic best including legumes', iv) 'ecologic best without legumes' (generated systems with lowest N_2O-emissions) and v) 'ecologic best including legumes'. Impact indicators from all generated systems were normalized to allow a systematic comparison (0=the lowest value from the generated systems e.g. 100€ gross margin and 1=the highest value e.g. 600€ gross margin). A high value is considered positive for gross margin and N-efficiency (N output/external N input) and considered negative for N-fertilizer use, N_2O-emissions and N-leaching.

3 Results – Discussion

Adding legumes to cropping systems increased the options for crop rotation design in all regions. E.g. in RO where most farmers grow sunflower, maize and wheat (82% of the arable land), soy bean, pea and common bean are options to diversify cropping systems. The impacts of different cropping systems are shown in Fig. 1. In RO and UK, legumes were economically more attractive than legume-free alternatives and in three regions, legume-supported systems were more profitable than current farming. In IT cereals dominate current farming with high gross margins but a high risk of severe phytosanitary problems. Systems with legumes reduced N_2O-emissions because of a lower N-fertilizer use. With less N inputs, comparable or higher N outputs could be produced (higher N-efficiency). For 'economic best' systems, N-leaching was lower with legumes except in RO and IT. The systems with the lowest N_2O-emissions ('ecologic best') were less profitable and resulted in higher N-leaching in SE, UK and IT.

These findings indicate a site-specific potential for including more grain legumes into European cropping systems. However, constraints of legume cultivation that are not covered in the analysis i.e. low yield stability and few marketing options make the cultivation unattractive in many European regions. Legumes were found to be economically more attractive when assessed at the rotational level compared to assessments at the crop level (not shown here). This is supported by a recent meta-analysis on farm-economic values of grain legume pre-crop benefits (Preissel *et al*., 2015).

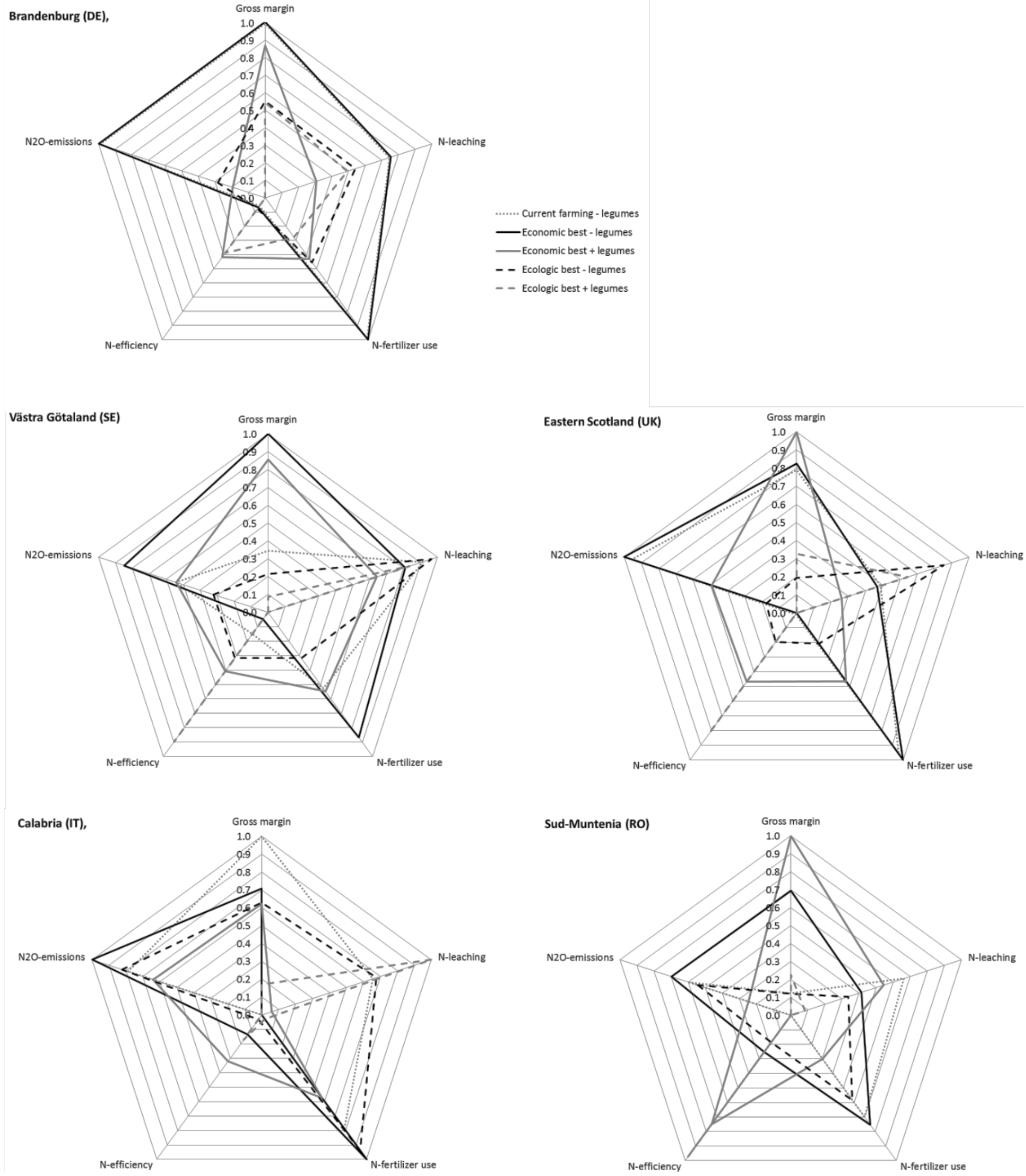

Fig. 1. Assessment of different cropping systems with and without legumes in five sites across Europe.

4 Conclusions

We conclude that legumes have an underutilized potential for European agriculture and that analyses with this framework support agronomists to design new cropping systems and to systematically assess their impacts.

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Design of innovative legume-based systems: the case of soybean-based cropping systems in Oise, northern France

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1 Introduction

The diversification of crop rotations has been proposed as a solution to increase the sustainability of farming systems (Wezel *et al.*, 2013). In arable crop-oriented agricultural regions, the diversification of the crop rotations has often been based on the introduction of annual legume grain crops such as peas and faba-bean, which suffer from irregular yields (Jensen *et al.*, 2010). Farming systems of the Oise region (Northern France) are mainly crop-based, since 56% of farms are oriented to cereals and canola or industrial crops (Chambre d'Agriculture de Picardie, 2010). Local stakeholders are particularly interested in assessing the potential for the introduction of soybean in Oise, after earlier maturity cultivars have been developed (Fig. 1). In this context, we wonder which could be the potential for innovative and sustainable soybean-based rotations at the regional level to create a new supply chain.

2 Materials and Methods

Answer to this question required an integrated (technical, economic and social) and multi-scale (crop rotation, farming system and region) methodology. In a first step, agronomic yield potential of adapted soybean cultivars was assessed based on soil (11 soil types) and climatic (temperature, rainfall, ETP, solar radiation for 4 whether stations) assets of the region using the STICS model (Brisson *et al.*, 1998). Then, in the suitable climatic areas, crop rotations where located using the French Land Parcel Identification System (LPIS) on the last six years and soil type specified for each of them based on a combination of soil data base and soil map at 1/250 000 and agronomical rules. Subsequently, each crop rotation x soil type suitable for the introduction of soybean was identified and mapped according to the rules illustrated in Fig. 2. Furthermore, a comparison of gross margin (GM) between the current and innovative soybean-based cropping systems was provided for each combination of suitable crop rotation x soil type. In this model, crop yields per soil type were expert-driven and main costs and sales estimated from technical institutes data. Finally, we tested soybean introduction impact on labour flows on a sample of local farms representative of the 72% of the Usable Agricultural Area (UAA) of the regional farms more suitable for soybean introduction (Chambre d'Agriculture de Picardie, 2010) using the Mecagro calculator (Mousset, 1996) on actual and innovative farming systems introducing soybean.

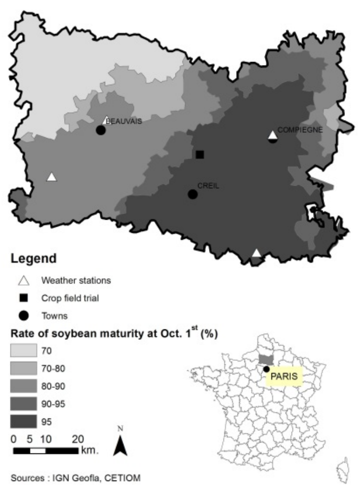

Fig. 1. Location of the Oise region and climatic suitability for soybean.

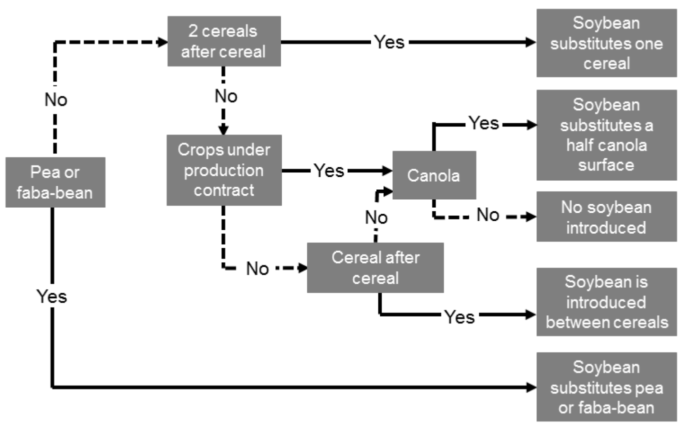

Fig.2. Decision diagram rules about introducing soybean in regional crop rotations.

3 Results and Discussion

On the whole UAA censed in the LPIS of the Oise region (376,450 ha), the potential soybean surface was 9534 ha according to the climatic, sol and agronomic selected criteria. Of these surface, 38% derived from a faba-bean or pea-based crop rotation, 37% from canola-based one, 21% from a cereal after cereal and 4% from a cereal after two cereals one.

The modelled yields of soybean at the regional level under different climatic conditions and according to the main practices (e.g. rainfed) appeared heterogeneous, mainly depending on the spring drought affecting the germination and seedling growth (data not shown). These modelled yields are coherent with those measured in the field trials (Fig. 1). Nevertheless, in those years not suffering of spring droughts and on the more favourable soils (e.g. silt loam), modelled yields are comparable to those already obtained on irrigated soybean on later maturity cultivars (CETIOM, 2015).

At the crop rotation level, the difference in the GM appeared very variable even within the same decision rules on introducing soybean (in Fig. 2) and mainly depending on the initial crop rotation length. However, average and median values of the GM are proximal to zero (Fig. 3) for each considered crop rotation, indicating a very low difference of average annual GM in current and soybean-based cropping systems. In sub-samples of field blocks located in homogeneous soil types, this appeared less variable, especially in suitable soils, although no significant differences have been found in the average GM for different soil types.

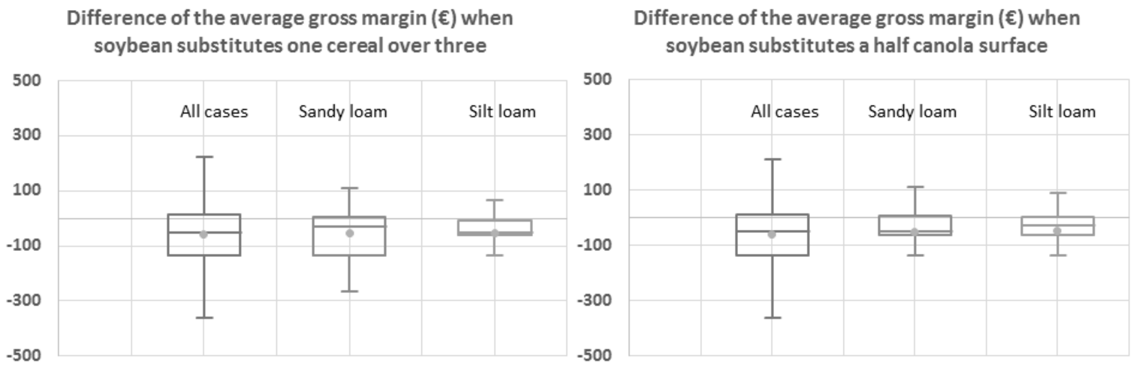

Fig. 3. Examples of the variation of GM in different types of crop rotations before and after introducing soybean: left, case of one cereal after two (n=2270), right, case of canola and contract crops (n=1975). In both cases, the difference is assessed on different soil types: sandy loam (n= 41 and 466 respectively) and silt loam (n= 683 and 630 respectively).

At the farm level, the introduction of soybean improved, or at least did not change, the labor flow in all the farm types (data not shown). The modeled labor variation seemed favorable both in terms of total worked hours and of management of the busy periods (early spring and late summer/early autumn).

4 Conclusions

Our first results on the suitability of soybean introduction in the Oise region has shown that soybean potential (yield and surface) could sustain the creation of a new supply chain even though yield variability has to be expected with spring droughts. However, gross margin difference nor yield variability reduction do not seem to be sufficient for farmers to introduce soybean beside the positive impact on labor at the farm level.

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Comparison of yields, protein contents and environmental impacts of grain legumes for designing legume-based cropping systems in Europe

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1 Introduction

The European Parliament has recently emphasized the importance of increasing grain legume production in Europe (Häusling, 2011), to reduce soybean imports from the Americas, to diversify European cropping systems (Bues *et al.*, 2013), and to reduce the negative environmental impacts of intensive cereal production. Numerous experiments were already carried out to evaluate performances of different grain legume species in local conditions but so far, no global quantitative synthesis of available data has been performed. Based on a comprehensive analysis of published experimental data and of FAO crop yield data, we estimated the agronomic and environmental performances for a large range of grain legume species across contrasted environments and crop management techniques.

2 Materials and Methods

The aim was to globally compare the yields, protein contents and environmental impacts derived from the nitrogen cycle of grain legume species that may be grown in Europe. First, we estimated inter-annual yield variability and risk of yield loss for major legume and non-legume crops using yield time series from the Food and Agriculture Organization statistics database (FAOSTAT, 2014) over the period 1961-2013. Normalized yield residuals were computed from the yield time series in Western, Eastern, Northern and Southern Europe, and North and South America. Measures of yield variability and risk of yield loss were then calculated from the distributions of normalized yield residuals. These risk measures were used to rank grain legume species in each region. Second, we carried out a meta-analysis of published experimental data in order to compare the yields, protein contents, and environmental impacts of several grain legume species grown in various conditions. The studies included in the meta-analysis were reporting data collected in experiments comparing at least two different grain legume species. Grain legume crops were compared using both direct and indirect comparisons. Variables related to climate conditions, soil types, and crop management techniques were used to explain variability in outcomes.

3 Results and Discussion

The measures of variability and risk estimated from the FAO yield data show that grain legume yields were significantly more variable than non-legume yields in Europe over 1961-2013 (Cernay *et al.*, 2015). Levels of yield variability and risk of yield loss differ strongly across species and European regions. In general, yield variability for grain legumes is higher than wheat. Lupin is the species showing the highest level of variability in Northern, Eastern, and Western Europe (Fig. 1) and bean ranks first in Southern Europe. Among grain legumes, fababean is the least variable crop in Southern and Western Europe (Fig. 1), whereas soybean and pea are the least risky in Eastern and Northern Europe respectively. Expected yield losses can exceed 25% of expected yield values in some situations, especially for lupin and soybean in Western Europe. By contrast, differences between grain legumes and non-legumes are smaller in the Americas. Several factors may explain the contrasted species rankings, such as local agroclimatic conditions and crop management techniques.

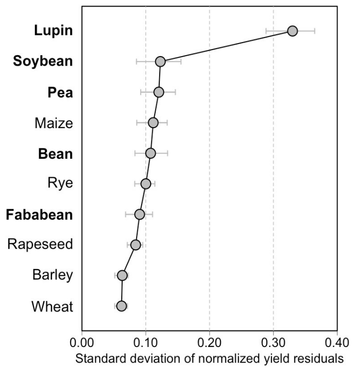

Fig. 1. Standard deviation of normalized yield residuals for 10 crops in Western Europe over 1961-2013. Polynomial regression models are used to calculate normalized yield residuals. Horizontal lines correspond to 95% confidence intervals calculated by 10,000 bootstrap samples. Among the 10 crops, 5 are grain legume crops (bold names) and 5 are non-legume crops (non-bold). All crops are ranked according to standard deviation of normalized yield residuals

The meta-analysis of published data allowed performances of 25 non-legume and 28 grain legume species to be compared. Due to the very high number of possible comparisons, a network representation was used to identify the pairs of species that were tested at the same experimental site(s) (Fig. 2). Results show that pea, chickpea, fababean, lentil and narrow leaf lupin were frequently tested together in Europe, North America and Oceania, whereas field experiments testing groundnut, cowpea, soybean, and pigeon pea were frequently conducted in Africa or Asia. The next step will consist in ranking all these species using direct and indirect comparison methods (Laurent *et al*., 2015). The rankings produced by the meta-analysis will then be compared with the rankings derived from the measures of variability and risk (Fig.1) in order to provide an overall assessment of grain legume species. Several factors characterizing experimental sites and cropping systems will be used to explain part of variability in outcomes.

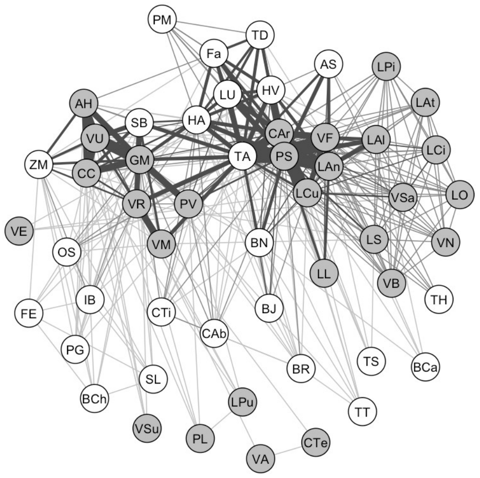

Fig. 2. Network of grain legume species (grey points) and non-legume species (empty points) reported in the meta-analysis. The links represent the pairs of species tested at the same experimental site(s), either as preceding or succeeding crops. The thickness of the links increases with the number of experimental sites at which the species are compared. The Latin names are abbreviated as follows: AH: *Arachis hypogaea*; AS: *Avena sativa*; BCa: *Brassica campestris*; BCh: *Brassica chinensis*; BJ: *Brassica juncea*; BN: *Brassica napus*; BR: *Brassica rapa*; CAb: *Crambe abyssinica*; CAr: *Cicer arietinum*; CC: *Cajanus cajan*; CTe: *Cyamopsis tetragonoloba*; CTi: *Carthamus tinctorius*; Fa: Fallow; FE: *Fagopyrum esculentum*; GM: *Glycine max*; HA: *Helianthus annuus*; HV: *Hordeum vulgare*; IB: *Ipomoea batatas*; LAl: *Lupinus albus*; LAn: *Lupinus angustifolius*; LAt: *Lupinus atlanticus*; LCi: *Lathyrus cicera*; LCu: *Lens culinaris*; LL: *Lupinus luteus*; LO: *Lathyrus ochrus*; LPi: *Lupinus pilosus*; LPu: *Lablab purpureus*; LS: *Lathyrus sativus*; LU: *Linum usitatissimum*; OS: *Oryza sativa*; PG: *Pennisetum glaucum*; PL: *Phaseolus lunatus*; PM: *Panicum miliaceum*; PS: *Pisum sativum*; PV: *Phaseolus vulgaris*; SB: *Sorghum bicolor*; SL: *Solanum lycopersicum*; TA: *Triticum aestivum*; TD: *Triticum durum*; TH: *Triticale hexaploide*; TS: *Triticum sativum*; TT: *Triticum turgidum*; VA: *Vigna aconitifolia*; VB: *Vicia benghalensis*; VE: *Vicia ervilia*; VF: *Vicia faba*; VM: *Vigna mungo*; VN: *Vicia narbonensis*; VR: *Vigna radiata*; VSa: *Vicia sativa*; VSu: *Vigna subterranea*; VU: *Vigna unguiculata*; ZM: *Zea mays*.

Both methods provided interesting information on the performances of a large range of grain legume species. Based on historical time series, the first method is able to rank species according to their inter-annual yield variability and risk of yield loss at a large scale. Based on field trials, the second method evaluates the performances of grain legumes for various criteria and explains part of their variability in function of agroclimatic and technical factors.

4 Conclusions

Our results are expected to provide a solid basis to analyze the risks associated with the growth of grain legumes and to assess their values for improving the sustainability of European food systems. Comparing the yields, protein contents and environmental impacts for a diversity of grain legume species under contrasted environments and crop management techniques may help agronomists designing legume-based cropping systems in Europe.

Acknowledgements. This work was supported by the French National Research Agency (ANR) under the program Investing in the future Grant n°ANR-10-IDEX-0003-02 and is part of LabEx BASC (ANR-11-LABX-0034).

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Pushing for intensified protein per capita production on smallholder farms in Malawi through 1000+ farmers experimenting with diverse grain legumes

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1 Introduction

Low land productivity undermines potential food production, stifles income growth from the lack of surplus food and keeps many farming hosueholds impoverished and undernourished. Over reliance on cereal crop production for 'food security', with little investments in grain legumes is one of the major contributing factors to poor nutritional outcomes (Bezner-Kerr *et al*., 2006). For Malawi, where farm sizes are small ranging 0.5-1.5 ha, grain legume production suffers from low prioritization, as maize takes up the bulk of the land, yet for a farming system with an insiginificant livestock component for meat products, intensified grain legume production would address part of the protein deficits in diets. Using simple but proven and effective agronomic practices, several initiatives on harnesing bilogical N_2-fixation in southern Africa (Mpepereki *et al*., 2000), have established that there is untapped potential in grain legume production. The purpose of this methodological paper is to present a co-learning approach in which researchers can work with hundreds of farmers who experiment with grain legume technologies at scale on their own farms, with deliberate emphasis on local grain legume processing to stimulate local consumption. We hypothesize that increased local consumption of grain legumes is a much stronger driver to grain legume production in an environment where extenal grain legume markets are volatile.

2 Materials and Methods

Between 2013 and 2015, we worked with smallholder farmers organized in 16 action groups in two districts of central Malawi (Dedza and Ntcheu) as part of the Africa RISING (Research in Sustatinable Intensification for the Next Generation) project, to enhance farmer knowledge and support sustainable intensification pathways for productivity gains in maize-legume diversified systems. We employed approaches that would increase primary productivity of grain legumes, that would in turn enhance productivity of cereals grown in sequence. In a step-wise co-learning system, farmers in each of the action groups firstly worked with researchers to establish 'mother trials' that acted as platforms for initial learning (snapp *et al*., 2002). These trials had a strong bias on grain legumes, but also encomapsed other technologies on soil fertility managment. High yielding and 'specific' soyabean varieties were innoculated with *Badyrhizobium japonicum*, while groundnut, pigeonpea and cowpea varieties most suited to the different agroecologies were used. Based on earlier research insights, a 'doubled-up legume technology', in which pigeonpea is additively intercropped with another grain legume with a contrasting growth habit, was included in the experimetal designs. Phosphorus was applied to all legumes at planting at a modest rate of 5 kg ha^{-1} P. After co-establishment of the mother trials, small packs of improved grain legume seeds were then distributed to farmers who went on to establish their own 'baby trials' composed of a subset of the treatments drawn from the mother trials. Farmers were encouraged to expand to beyond the initial 200 m^2 that could be covered through the free seed, by use of other networks and own resources. In subsequent years, the strategy to increase planted area would be achieved through seed retention after harvest. A series of hands-on training workshops on local processing, especially for soyabean to remove antinutritionl factors, were held during each postharvest season to produce tasty and nutritious food products.

3 Results - Discussion

During the first year of action resaerch, farmers were not familiar with some of the technologies, notably the the double-up legume technology. This was reflected in the small promotion of farmers of only 7% of the baby trials that included a doubled-up legume technolgy. As farmers interacted with the technologies over the next two seasons, there was evidence of increased uptake of the newly introduced technologies.

Across sites, sole cropped groundnut had yields ranging from 0.80 –1.63 t ha^{-1}, soyabean 0.64–2.64 t ha^{-1} and cowpea 0.70–1.41 t ha^{-1} (Fig. 1). Soyabean demonstrated the greatest elasticity, yielding poorly in a hot and low agroecology potential zone, and responding remarkably to both inoculation and P fertilization in cooler and high potential agroecologies. While farmers already had significant knowlege on local utilization of groundnut and cowpea, the greatest impact of our interventions on nutrition outcomes were related to the training of both men and women farmers on local processing of soyabean. With crude protein of 40%, and average productivity of nearly 2 t ha^{-1} with inoculation and some P fertilizer application, famers could potentially generate 800 kg ha^{-1} protein with a 4-month cropping season.

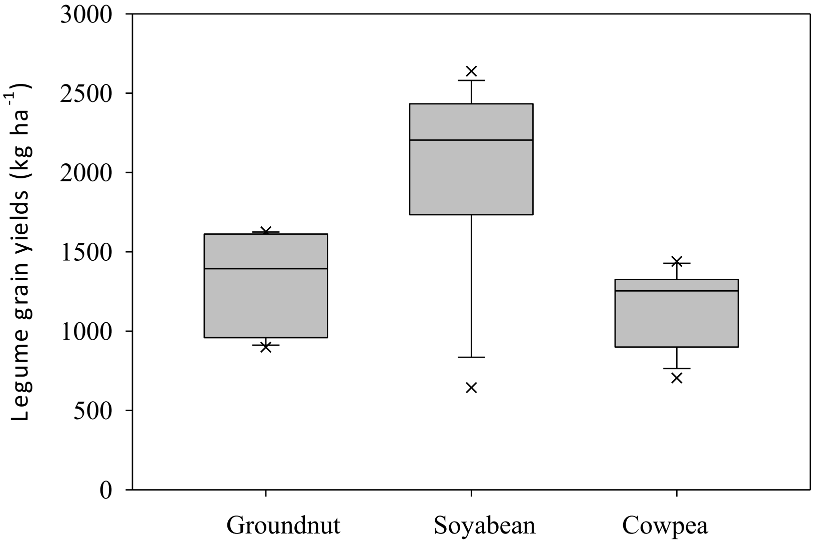

Fig. 1. Groundnut, soyabean and cowpea productivity across mother trial sites in central Malawi

This approach, which couples 'conventional research trials' to 'farmer experimentation' organized in learning groups, accelerated learning and knowledge acquisition, among farmers, including the illiterate ones that often exclude themselves in knowledge intensive initiatives. Over the next cropping cycle, we will investigate the proportion of farmers who are now independently implementing variants of the grain legume technologies and assess any changes to farm decison making and trade-offs in the design of the cropping patterns at farm-scale.

4 Conclusions

Many potentially game-changing technologies have remained unsued by farmers due to various biophysical challenges, but we contend that poor packaging of the technologies as they are presented to farmers remains one of the critical handicaps. While still using conventional field experimention methodologies, we have presented an action-oriented approach in which hands-on training of farmers from production to consumption shows great promise for revolutionlizing smallholder cropping patterns in central Malawi, creating a niche for increased farm protein production in the absence of a vibrant livestock component.

Acknowledgements. Funding of this work is through the USAID-funded Africa RISING program

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Below and aboveground pigeonpea productivity in a novel doubled-up legume cropping system across three agro-ecologies in central Malawi

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1 Introduction

Agro-ecological intensification improves the performance of agriculture through integration of ecological principles into farm and system management. Enhanced use efficiency of limited nutrient and land resources is key to viable farming systems in densely populated African countries. Use of legumes that biologically fix nitrogen, provide high protein grain, and recycle nutrients is one approach that has shown promise in Malawi. However, empirical data on legume root and shoot biomass additions to the systems have largely remained scarce (Myaka *et al.*, 2006).

2 Materials and Methods

The objectives of the study were to determine aboveground and belowground biomass of pigeonpea in doubled-up legume cropping systems involving groundnut and soyabean, and also in pigeonpea/maize intercrops. Field experiments were established across three agro-ecologies in central Malawi during the 2013/14 cropping season. Pigeonpea was planted as a sole crop or in an additive intercrop system with soyabean and groundnut—a novel system known as the doubled-up legume technology. Additionally, a pigeonpea/maize intercrop was included as a control. The success of the doubled-up legume systems hinge on the initially slow growth of pigeonpea, facilitating the growth of companion crops as if sole-cropped (Snapp *et al.*, 2015). Six months after planting, pigeonpea plants across treatments were cut at ground level, and aboveground components were separated into stems, twigs, pods, and leaves. Senescent leaf litter was collected using traps. Roots of the same plants were excavated from the 0.20, 0.20– 0.40, and 0.40– 0.60 m layers, and soil samples were collected from each layer.

3 Results - Discussion

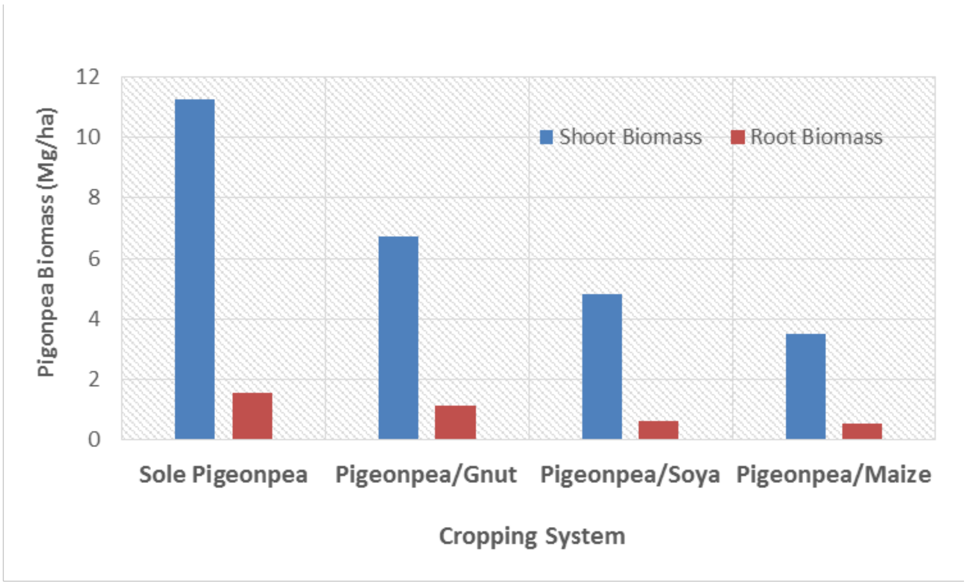

Fig. 1. Total shoot and root biomass of pigeonpea

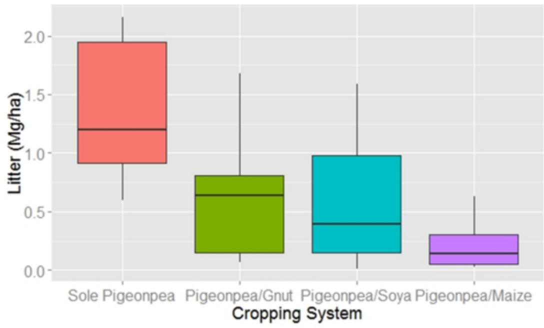

Fig. 2. Total senescent litter of pigeonpea.

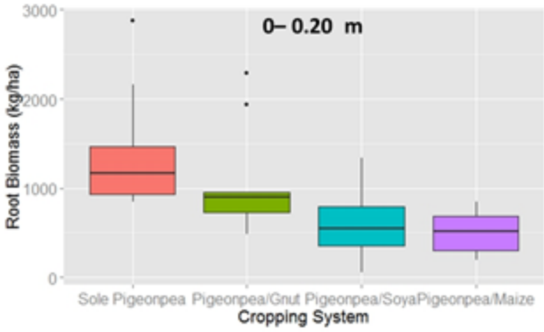

Fig. 3. Root biomass of pigeonpea in the 0– 0.2m layer.

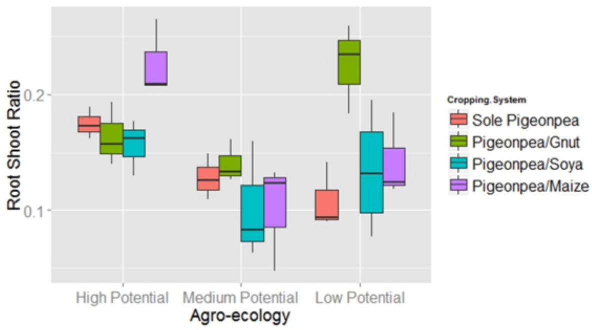

Fig. 4. Root shoot ratios of pigeonpea in three agro-ecologies.

Aboveground biomass of sole pigeonpea was 11.28 t ha^{-1}. The pigeonpea shoot biomass component of the pigeonpea/groundnut, pigeonpea/soyabean, and pigeonpea/maize intercrops was 6.73, 4.84 and 3.35 t ha^{-1}, respectively (Fig. 1). Senescent leaf litter was highest for sole pigeonpea and lowest for the pigeonpea/maize intercrop (Fig. 2). The root biomass was largely confined in the 0– 0.20 m layer, with trends similar to that for shoot biomass (Fig. 3). Below the 0.20 m depth, fine pigeonpea roots were dominant. The root shoot ratios varied with agro-ecologies and cropping systems (Fig. 4)

4 Conclusions

Pigeonpea productivity in a pigeonpea/groundnut system is comparable to sole cropped pigeonpea, with additional grain benefits. However, intra-specific competition in a well fertilized pigeonpea and maize intercropping system is rather large. We conclude that both below-and aboveground biomass of pigeonpea can significantly increase nutrient and water use efficiency by fixing nitrogen, building soil carbon, and establishing a root system with the ability to capture and recycle nutrients.

Acknowledgements. Many thanks to Africa RISING, USAID and all of their partners

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Combination of undersown catch crops and row-hoeing for optimizing nitrogen supply and weed control in organic spring barley

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1 Introduction

Current organic cereal production faces two main problems: nitrogen (N) deficiency and high weed pressure. The use of catch crops, including legumes is an important approach to improve soil fertility and also to reduce the environmental impact of agricultural activities. In Europe, catch crops are usually grown to take up N remaining in the soil after main crop harvest. However, in practice farmers prefer an early termination of catch crops or not establish them to allow intensive autumn soil tillage for weed control, especially perennial weeds, strongly reducing or withdrawing their desired effects. Therefore, an innovative weed control strategy is tested, which should reduce the need for tillage and allow the efficient use of catch crops as green manure and weed suppressor. In the current study, we aim to develop a row crop system for organic cereal production with an increased row-distance of 24 cm, the use of undersown winter hardy catch crops and inter row-hoeing. We test different catch crop mixtures, different sowing times and study the integrated effect of a combined undersown catch crop-row hoeing-row crop system on crop yield, crop and soil N dynamics, N effect (Neff) of catch crops for the succeeding crop and on weed control.

2 Materials and Methods

Two-year field experiments (2014 - 2015 and 2015 - 2016) are established in organic spring barley. The experimental factors include (1) row cropping system or conventional system (with 24 or 12 cm row-distances); (2) with or without catch crops; (3) different catch crop species mixtures and (4) three different catch crop sowing times.

Catch crops were sown at the same time as spring barley in April or delayed 3 and 6 weeks. Depending on the three sowing dates, row hoeing was made either 0, 1 or 2 times between the spring barley rows prior to sowing catch crops. We used different legume-nonlegume mixtures to take advance the biological N fixation of legumes (i.e. white clover, red clover, Lucerne,…) and a more sufficient soil N depletion of non-legumes (i.e. rye grass, chicory, Dyer's woad,…). All of them are winter-hardy species. After the spring barley harvest in August, the catch crops remain on the field during autumn and winter and are incorporated into the soil in March next year. Moreover, to mimic the common intensive soil tillage activities of farmers, the two fallow treatments of both two cropping systems were harrowed three times during September-October. Then, a pure-stand spring barley will be established in April of the second years.

We measure aboveground plant biomass of each plot at four dates: Early August before the barley harvest, November at the end of the growing season, early March before catch crop incorporation and early August before the new spring barley harvest. They are sorted into 4 groups of plant species: 1) legume, 2) non-legume, 3) thistle (*Cirsium arvense)* and 4) other weeds. Then we record their dry biomass and analyze the C:N ratio. We also measure the soil inorganic N content - N_{inorg} (ammonium-N and nitrate-N) of three different soil layers (i.e. 0-50 cm, 50-100 cm and 100-150 cm) at two dates: Mid November and early May after the new spring barley establishment.

We also employ other assessment strategies for studying the effect of row hoeing and catch crops on the thistles: 1) direct counting the thistle population in the entire plots, according to their height categories and analyze their N content; 2) injecting ^{15}N in October, measuring the soil ^{15}N content up to a 100 cm depth in May and measuring the ^{15}N recovery in aboveground biomass of the new spring barley and thistles of the second year.

3 Results - Discussion

Plant growth, yield effect and expected Neff

All of catch crop species had a limited growth as undersown, but a fast development after the barley harvest. Therefore, they did not affect the barley yield in the first year (data not shown). The same or higher total dry matter of white clover/rye grass mixture was obtained in the 24 cm row cropping system than in the 12 cm row system, even at later sowing times (Treatment 4 & 5 compared to Treatment 3, Fig. 1). This indicates that we can delay the sowing date of catch crops, allowing us to employ one or two times of the inter row-hoeing for weed control without reducing catch crop growths. Amongst the sowing dates, a short delay where catch crops are sown three weeks later than the main crop after one row hoeing, the clover species produced twice as much biomass as if sown after six weeks and two row-hoeings. However, they suppressed the growth of their companion grass species. In contrast, the non-leguminous species expressed greater tolerance to later sowing. They obtained a similar dry biomass to in the first sowing date and much higher than if sown at the second sowing date. In terms of weed control, weed biomass were reduced more than 50% in all catch crop treatments compared to the fallow treatments. While two row hoeings and later sowing reduced legume growth, its effect on weeds was not clear. The effects of row cropping, hoeing and catch crops on total N content in the succeeding barley crop and the Neff of different catch crops will be measured. The Neff is expected to vary between catch crop mixtures and different sowing times, being high where a high catch crop N content was achieved.

Table 1. List of treatments presented in Figure 1

Treatments	Catch crops	Row distance (cm)	Sowing times	Number of hoeing
1	No catch crop	12	-	0
2	No catch crop	24	-	0
3	White clover/rye grass	12	1	0
4	White clover/rye grass	24	2	1
5	White clover/rye grass	24	3	2
6	Red clover/orchard grass	24	2	1
7	Red clover/orchard grass	24	3	2

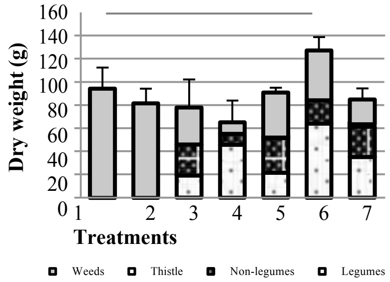

Fig. 1. The mean of total aboveground dry matter of legume, non-legume, thistles and other weeds of different treatments in Novermber 2014 of the 2014-2015 experiment, 3 replicates. Bars show standard errors.

Soil inorganic N and thistle effects

We expect the catch crops will effectively deplete the soil N in the autumn, and their mineralized N_{inorg} will redistributed into the surface layer after their incorporation, leading to increased topsoil N_{inorg} compared to un-covered treatments. Treatments with deeper-rooted species such as chicory, Dyer's woad and winter radish were included in the study, to evaluate their ability to transport N upwards from deep soil layers, thereby reducing N leaching losses (Thorup-Kristensen, 2001). In summary, the reduction of N in subsoil layers and the increase of N_{inorg} in the topsoil in the next season by the catch crop treatments will produce an optimal condition for the N uptake of the shallow rooted crops like spring barley, compared to thistles with a high root density in the deeper soil layers. Therefore, in combination with row-hoeing, this continuous N competition from first the catch crops and then the succeeding barley crop is expected to weaken the thistles, leading to the decline of their growth and regeneration. To consolidate this hypothesis, we expect that the ^{15}N study will show a lower ^{15}N recovery in thistles after the catch crop treatments than after the treatments without catch crops.

4 Conclusions

We aim to contribute to the development of a row crop system which is more optimal for the development of catch crops than the conventional system while at the same time allowing the necessary control of thistles. The optimized row crop system with the employment of proper catch crop species, sowing time and row hoeing will be a promising system for developing higher yielding organic cereal crops and for more environmental friendly weed control.

Acknowledgements. We thank the Danish AgriFish Agency for sponsoring this research within the row crop project.

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A territorial design and assessment of legume-based cropping systems to gain ecosystem services

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1 Introduction

The intensification of French agriculture, that began in the 1950s, and supported both by public policies and market dynamics, has led to an important simplification of cropping systems, which are nowadays mainly based on cereals and oilseed crops (Schott *et al*., 2010). These systems have proved their efficacy in producing large amounts of food and feed, but have led to large negative environmental impacts, in particular due to their high dependency on agrochemical inputs (MEA, 2005). Results from simulations, experiments and farmer's practices have shown that cropping systems based on legumes have agro-ecological advantages (e.g. Nemecek *et al*., 2015). However, the deployment of such cropping systems is limited in France by a technological lock-in involving most stakeholders and actors directly influencing agricultural practices (Meynard *et al.,* 2013) such as collecting firms according to the expectations of manufacturing processors to respond to food demand. Yet, societal demand and public policies ask for the development of diversified agroecosystems that might allow an agroecological management on territories. We assume that the introduction of a higher proportion of legume species in the fields could help to reduce environmental impacts and the use of rare resources (such as fossil energy), to stabilize production and contribute to food challenge for the future. As technical means will not be sufficient to reach this target, we assume that the territory scale is consistent to mobilize organizational levers, linked with the stakeholders' activities. The aim of our study is to build, with the actors influencing the crop choice in three French regions, the conditions that could lock out the situation and support the development of grain legume crops.

2 Materials and Methods

We implemented the study in three areas in France: Bourgogne (East), Midi-Pyrénées (South-West) and Pays de la Loire (West).
We first analysed the factors that led to the huge decrease of legumes area in France. Interviews were realized with various stakeholders: agricultural and environmental institutions, economic organizations and farmers, in order to build a diagnosis of the factors that contributed to the lock-in of the agricultural system around the decrease of legumes.
Then, we explored combined dimensions that could help to a better acceptance of legumes by farmers, in particular: i) by analyzing with the stakeholders the impacts of past cropping systems evolution ; ii) by sharing knowledge and references, built or assessed in local conditions, about ecosystem services provided by various legume crops according to their crop management; iii) by tracking innovative systems including legumes implemented by farmers with high performances; iv) by designing some innovative legume-based cropping systems, based on technical and economical local references from advisors and farmers; v) by proposing new organizations of supply chains between cooperatives, farmers and industry.

3 Results and Discussion

The factors explaining the decrease of legume areas are numerous and strongly linked to each other, highlighting coevolution dynamics that could result in a strong socio-technical lock-in (Kallis & Norgaard 2010; Geels 2011). The increasing intensification of French agricultural systems since the 1950s led to a high specialization of cropping systems, around a small number of crops (wheat, barley, oilseed rape, sunflower, maize according to the region). The dominant species were those with a higher short-term profitability. In return, the large investment dedicated to these crops led to an increase in their productivity, while mean yield of the minor crops stayed low. Moreover, the sensitivity of these crops (particularly pea) to climatic stress (heat and water stress during seed formation), frequently occurring in the recent years, explained the inter-year variability and the decreasing average yield, two causes leading most farmers to give up these crops. Finally, the occurrence of a disease, due to the soil-borne pathogen *Aphanomyces euteiches,* resulted in the impossibility of growing pea in the infested fields. Indeed, breeding and pesticide certification focused on species grown on large areas. At farm scale, the few information available on the legume pre-crop effect, on the adaptation of the management plan of the crop following a legume, and on the economic benefits estimated at the crop sequence scale (and not only at the crop scale) does not encourage farmers to grow these species. The collecting firms, the processing industries and the trade organizations aimed at cost saving, thus focusing their activity on dominant species and imported species such as soybean, to minimize logistic costs. Finally, it appeared that most actors were not aware of the environmental benefits from legumes, while those are drivers for deep change in agriculture. Research also contributed to the lock-in, having more invested in the « genetic paradigm » than in the « agroecological paradigm », which led to the low valorization of the environmental benefits of legumes in the necessary change in agriculture (Vanloqueren & Baret, 2009).

The analysis of the cropping systems evolution from the 1970s showed a strong decrease of the legume species in the three territories, increasing the crop management dependency on synthetic inputs, and thus leading to increased environmental damages. Yet, legume crops can provide numerous ecosystemic services, which can be reinforced by the diversity of the species and of their crop management. They can be grown as sole crops in the crop sequence (pea, faba bean, lupin for example), or as intercrops (pea-wheat; lupin-triticale; lentil-durum wheat in the territories), or as cover crops between two main crops, or as relay intercrops, or as living mulch intercrop (such as frost-sensitive legumes intercropped with oilseed rape).The main services generally provided are (1) an increased yield of the following crop (or of the intercrop), (2) an improvement of the grain quality of the following cereal or cereal intercropped with the legume, (3) a reduction of N fertilization on the legume and on the following crop thus decreasing the associated impacts, (4) the decrease of N_2O emissions compared with fertilised crops, (5) the decrease of fossil energy consumption at the crop and cropping system scales, (6) a reduction of weed infestation in intercrops compared with sole legumes or from relay cover crops, (7) a decrease of disease (and insects) infestation on both crops of intercrops, (8) the introduction of N in the system not dependant from N fertilizer, (9) a stable net margin in comparison with cropping systems without legumes, (10) a reduction of soil-disease pathogens infesting the dominant crops, and (11) the production of protein-rich seeds. On the contrary, the risk of nitrate leaching is generally increased after legumes, but this withdrawal can be overcome by growing catch crops after legumes.

While most cropping systems include sole crops in France, more and more farmers grow intercrops, due to their agronomic, environmental and economic interests. A survey of farmers growing intercrops showed a large diversity in the species associated, mainly linked with the targeted outlet and uses. The innovations were more diverse by cattle breeders than by cereal producers, due to the on-farm use of the harvested product.

In the three territories, innovative legume-based cropping systems were designed, based on technical and economical local references from advisors and farmers.

Finally, new outlets, mainly based on the use of plant proteins in the human diet, were explored as drivers for the development of legume areas. An increased need for plant proteins has been shown to be necessary to ensure food security at the global scale (Esnouf *et al.,* 2011). Moreover, the second nutritional transition, consisting in the substitution of animal proteins with plant proteins, already occurred in several developed countries. Several innovations were already designed in the agro-food process: for example, technological progress has been made in processing pasta with both durun wheat and legume flours (Petitot *et al*., 2010), even if those new food products are not yet developped in european countries. In France, several cooperatives developped quality signs and labels of origin, thus improving the economic interest of farmers for growing these species.

4 Conclusions

Finally, we showed that grains legumes have mainly high perspectives in the transition to a sustainable agrifood system, combining a reduction in synthetic inputs use in the fields with the development of new food products based on plant proteins. Yet, this transition would require a strong coordination among supply chain actors, involving farmers, cooperatives, breeders, processing industries, advisors, public policies, and consumers.

Acknowledgements. This work was supported by a grant overseen by the French National Research Agency (ANR) as part of the LEGITIMES project (ANR-13-AGRO-0004).

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Legume-grass mixtures grown on arable land under the conditions of water deficits

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1 Introduction

Legume-grass mixtures grown on arable land are an important part of crop rotations. Forage produced from these mixtures is an essential part of feeding rations. Clovers and grasses are tolerant to colder climate and require supply of water. In lowlands with precipitation deficits. Alfalfa-grass mixtures are a populr forage crop. In these mixtures, grass assures high yields in the spring and at the beginning of summer. Later on the intensity of grass growth is usually decreasing due to lower precipitations and alfalfa begins to dominate as the main yield component. At present, some regions of the Czech Republic suffer from severe periods of drought, which result in a minimal growth intensity of grasses. For that reason our trials were focused on those grass species and varieties, which are tolerant to aeid conditions.

2 Material and Methods

In 2011, several experiments were established in the locality Troubsko (South Moravia, Czech Republic) with the following legume-grass mixtures: Mixture 1 – alfalfa (*Medicago sativa,* cv. 'Zuzana') and orchard grass (*Dactylis glomerata,* - result of a new breeding denominated as VV 115-132/10) in the seed ratio 80:20 %; and Mixture 2 – alfalfa (cv. 'Zuzana') and orchard grass (a new breeding denominated as VV 115-132/10) in the seed ratio 50:50 %. Mixtures 3 and 4 with the same seed ratios were used as controls; In these control mixtures, however, the orchard grass was replaced by an interspecific hybrid 'Felina' (hybrid of rye grass and tall fescue) This hybrid is commonly used under arid conditons of growing (dlf, 2013 [on-line]). Evaluated were results obtained in years 2012 and 2013. In each experimental year, altogether three weighed harvests of crops cut in the stage of an optimum maturity were obtained. No fertilisation was used in this experiment. Prior to each harvest, samples from one square meter of experimental polts were collected to determine percentages of both mixture components.

Tab. 1. Monthly sums of average precipitations and temperatures as recorded on the experimental site in the course of the growing season (Kožnarová & Klabzuba, 2002)

Month	Year 2012				Year 2013			
	Temperatures ° C]		Precipitations [mm]		Temperatures [° C]		Precipitations [mm]	
	Average	Evaluation	Total	Evaluation	Average	Evaluation	Total	Evaluation
March	6.2	1	1.8	-3	1.0	-1	42.1	1
April	9.9	0	12.1	-2	9.9	0	18	-1
May	16.0	1	25.4	-2	13.7	0	105.6	1
July	18.8	1	60.6	0	17.4	0	116.2	1
June	20.4	2	60.0	0	21.5	3	4.8	-3
August	19.7	2	72.4	0	19.9	2	68.8	0

Evaluation scales of monthly temperatures and precipitaions:
3 – extremely cold; 2 – very col; 1 – cold; 0 – normal; 1 – warm; 2 – very warm; 3 – extremely warm.
3 – extremely dry; 2 – very dry; 1 – dry; 0 – normal;; 1 – wet; 2 – very wet; 3 – extremely wet

3 Results – Discussion

Percentages of individual components in mixtures with alfalfa

In the first experimental year (2012), the shares of orchard grass in individual mixtures were as follows: Misture 1 – 12.5 %; Mixture 2 – 17.7 %; Mixture 3 – 22.3 % and Mixture 4 – 19.7 %. In the course of the growing season, this year was extremely dry and there were practically no differences in percentages of grass in individual mixtures. The obtained results indicate that, under arid conditions, the competitiveness of orchard grass was similar to that of the hybrid 'Felina'. In 2013, however, supranoamal precipitations caused an increase in percentages of orchard grass in individual mixtures (Mixture 1 – 41.6 %, Mixture 2 – 34.1 %); In harvest years 2012 and 2013, the differences in percentages of the hybrid 'Felina' were not significant .(Mixture 3 – 26.3 % and Mixture 4 – 40.4 %, respectively). In 2013, however, a higher percentage of orchard grass in Mixture 4 indicated a better competitiveness of orchard grass under conditions of sufficient humidity. Vorlíček *et al.* (2009) recommended that for production of quality forage the percentage of the grass component in the first cutting should not be higher than 25 %. This means that under arid conditions the share of grass component in mixture would be as much as 50 %. In localities with abundant precipitations, the share of orchard grass should be reduced to less than 20 % while that of the hybrid 'Felina' can be 20 %.

Yields

DM yields were influence above all by the weather. In 2012, higher yields of alfalfa-orchard grass mixtures were statistically significant. In 2013, the yield of Mixture 4 was significantly lower.

No.	Mixture	Yield of DM in 2012 [t/ha]				Yield of DM in 2013 [t/ha]			
		1.harvest	2.harvest	3.harvest	total	1.harvest	2.harvest	3.harvest	total
1	alfalfa + orchard grass	2.03	3.59	2.33	7.95	5.58	4.22	5.22	15.02
2	alfalfa + orchard grass	1.63	3.54	2.46	7.64	5.65	4.17	5.83	15.65
3	alfalfa + Felina	1.67	2.80	2.31	6.79	5.16	4.43	5.40	14.98
4	alfalfa + Felina	1.89	3.29	2.26	7.44	4.93	4.19	4.69	13.81

4 Conclusions

It can be concluded that dry matter yields are naturally influenced by the weather course during the year. Under conditions of an optimum humidity, the tested orchard grass cultivar 'Zuzana' was a stronger competitor than the hybrid 'Felina' and for that reason it is recommended to use less than 20 % of its seed material. As far as the hybrid 'Felina' was concerned, the optimum share of its seed material was 20 %. Under arid conditions, the competitiveness of orchard grass was comparable with that of the hybrid 'Felina' and the share of its seed in mixtures should be increased to as much as 50 %. From the viewpoint of yields, the late orchard grass cultivar VV 115-132/10 represented a suitable component of mixtures sown in both dry localities and those with normal precipitations. The late cultivar VV 115-132/10 seemed to be a suitable alternative (substitute) of currently used festucoid hybrids especially in legume-grass mixtures grown on arable land even in dry localities.

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T7. Scaling up from farm to landscape and multiscale scenario analysis of agricultural systems

Chair: Martin Van Ittersum, Wageningen UR
Co-chairs: Bernard Hubert, Agropolis International
Marc Benoit, INRA

INTEGRATING FIELD, FARM AND TERRITORY SCALES IN THE DESIGN OF AGRICULTURAL SYSTEMS

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1 Introduction

In order to cope with several actual and future major issues like climate change, natural resources depletion, protection of biodiversity, ensuring food security, innovative agricultural systems have to be developed. These systems have to satisfy a set of objectives at the field, the farm and the territory scales and their design has to take into account explicitly the interactions between these scales (Veldkamp & Lambin, 2001). We propose a simple framework to this end and apply it to two questions in Guadeloupe: 1) the *ex ante* assessment of low-input innovative cropping system and their potential of adoption by heterogeneous farmers and 2) the design of new mosaics of cropping systems satisfying several sustainability goals at the territorial level and taking into account farms' constraints.

2 Materials and Methods

The framework presented in Fig. 1 shows how the nature of the innovations that have to be implemented into current cropping systems (field scale) can be orientated by the farm and the territory scales. Firstly the innovations at field scale can perform differently in the territory, because farms are heterogeneous in terms of biophysical situation and socio-economic resources. Secondly the effective implementation of innovations at field level is conditional upon farmers' decision of adoption which can be influenced by the three levels. Finally reaching sustainability goals at territorial scale requires an optimal combination of innovative cropping systems at field scale while taking into account farm level constraints.

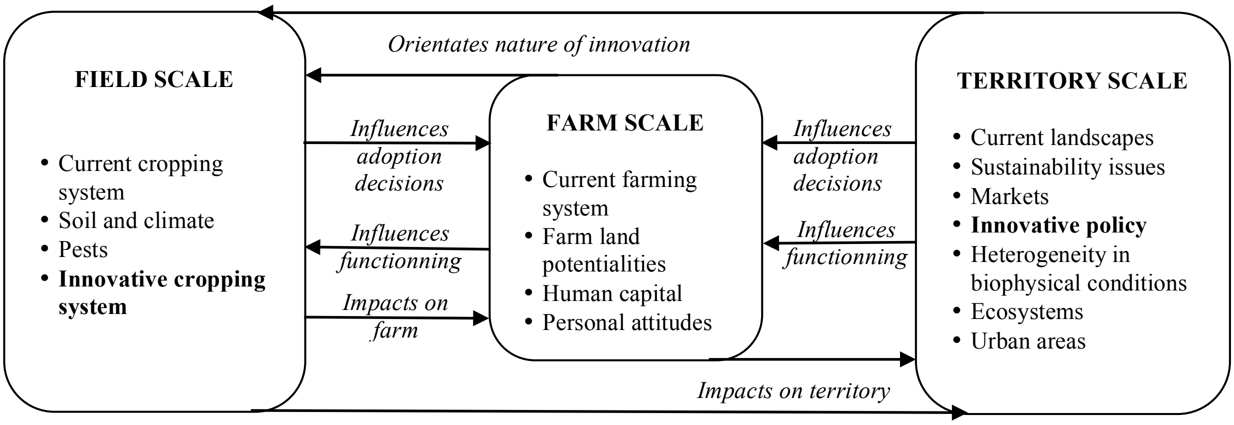

Fig. 1. Framework of interrelationships between field, farm and territory scales in the design of agricultural systems

From a practical point of view, the framework is aimed at building an architecture of models to design and assess new agricultural systems emerging from innovations at several spatial scales. It could also serve to assess trade-offs beetween sustainability goals and across scales. The use of a combination of tools is required to implement the framework. We tested three types of tools combinations: 1) quantifying the impacts of innovation on cropping system performances at field scale with a biophysical model parameterized with a regional typology of farms, 2) modelling farmers' decision of adoption of new cropping systems as a function of cropping system performance, farmers individual characteristics and economic incentives and 3) integrating information from field and farm scales into a bio-economic multi-criteria regional model to prototype mosaic of cropping systems satisfying several sustainability goals.

3 Results - Discussion

First we present in Table 1 the *ex ante* assessment of the introduction of new intercropping techniques in banana cropping systems in Guadeloupe and Martinique (Blazy *et al.*, 2010). Our results show that performance of the innovative cropping systems are clearly influenced by the farm type. Then the willingness to adopt is also different according to the farm type and depends upon the performances of the system (size of workforce seems to be crucial for adoption) and the territorial context (compare Guadeloupe and Martinique islands). This verify the hypotheses that effective increase of the sustainability at the territorial scale requires accounting for adoption constraints and heterogeneity at the field and farm scale.

Table 1. Ex ante assessment of two innovative banana cropping systems based on intercropping for two farm types.

Farm type	Highlands smallholders		Flatlands industrial farms	
Innovations (service crop intercropping)	*Canavalia ensiformis*	*Impatiens sp*	*Canavalia ensiformis*	*Impatiens sp*
Banana yield (t ha^{-1} yr^{-1})	+15.9	0.0	+4.4	+0.4
Work (days ha^{-1} yr^{-1}))	+75.4	+10.4	+42.0	+16.8
Net income (€ ha^{-1} yr^{-1})	+3472.1	-426.4	-830.9	-1390.5
Willingness to adopt in Guadeloupe (%)	58%	81%	46%	54%
Willingness to adopt in Martinique (%)	16%	47%	35%	54%

Then we present the results of the design and assessment of a multi-objective mosaic of cropping systems satisfying the principles of climate-smart agriculture (Lipper *et al.*, 2014). To this end, the bioeconomic model MOSAICA (Chopin *et al.*, in press) was used by i) optimizing the satisfaction of the objectives of “an adaptation scenario” made of innovations at the farm and policy levels (introducing energy crop, organic fertilization and environmental incentives) and ii) taking into account spatial heterogeneity, resources availability and risk attitudes of the diverse farm types of the island. The results showed that the landscape evolves greatly under the “adaptation scenario” (Fig. 2) and that the objective of reducing by 10% all GHG emissions of Guadeloupe could be achieved while also increasing other sustainability indicators (Table 2).

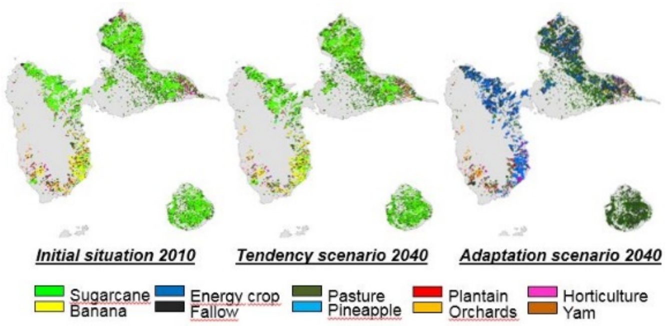

Fig. 2. Prototyping climate-smart mosaic of cropping systems.

Table 2. Assessment of mosaics of cropping systems.

Indicators	Units	Initial situation	Adaptation Scenario
Mean farmers’ income	€ ha^{-1} yr^{-1}	3510	4940
Energy self-sufficiency from energy crop	%	3%	13%
Food self-sufficiency	%	15%	17%
Proportion of rivers potentially polluted	%	39%	8%
Total amount of subsidies	M€ yr^{-1}	75	61

4 Conclusions

Our framework provides a conceptual representation of the interrelationships between the field, the farm and the territory scales. The application of the framework in Guadeloupe through two different combination of models confirmed that taking into account the complexity of these interrelationships is crucial for the design of new agricultural systems. Innovations at field scale have to target heterogeneous farmers’ objectives and constraints for adoption. Policy can be an efficient way to impulse and promote the adoption of these innovations. Bio-economic models are necessary for building new optimal agricultural landscape because of the complexity in hierarchical organization. The results that agronomist can obtain with such approaches offer promising perspective in designing scenarios of transition of agricultural systems toward a higher sustainability level, which is of interest for helping decision making of policy makers.

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PARTICIPATORY SCENARIOS' DEVELOPMENT AND ASSESSMENT FOR SUSTAINABLE FARMING SYSTEMS IN CAMARGUE, SOUTH OF FRANCE.

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1 Introduction

In Camargue, South of France, rice cultivation plays a crucial role in desalinating the soils by being cultivated in flooded conditions and provisioning fresh water to the natural wet areas. Rice cultivation also generates employments in the rice chain and plays a crucial role in tourism sector by maintaining traditional landscapes. However, rice fields are a major source of pesticide losses (Comoretto *et al*., 2008) and most probably of greenhouse gas (GHG) emissions (Linquist *et al.*, 2012). Alternative farming systems, such as organic or low input systems, are expected to improve the sustainability of agriculture in the region (Lopez Ridaura *et al*., 2014). However, to engage actions to facilitate the development of such alternatives, policy makers and stakeholders need information about their sustainability in various possible future contexts (e.g. changes in policy, price of energy or inputs, etc.). Participatory scenarios development and their integrated assessment aim at providing information to the stakeholders about future sustainable farming systems (Delmotte *et al.*, 2013). In this paper, we present the application of such an approach in Camargue.

2 Materials and Methods

To generate such knowledge, we first developed four explorative and narrative scenarios for the future of agriculture in Camargue with key stakeholders from the regional natural park (defending stakes of nature preservation), the French Centre for rice development (promoting new rice cultivation practices) and an association of livestock breeders (defending traditional bull rearing activities). Three successive focus group sessions were organized, in order to: (i) identify the main current and future drivers of change on farming systems in Camargue, (ii) design and discuss the four scenarios and (iii) define the possible impacts of the scenarios on farming systems and the subsequent possible adaptation strategies for farmers and stakeholders.
Secondly, we assessed these scenarios using a multi-criteria methodology at farm and territorial scale (i.e. considering the whole cultivated areas of Camargue). We used a bio-economic optimization model, which identifies optimal crops' allocations under sets of objectives and constraints (Delmotte *et al.*, 2013). In this study, each of the four scenarios led to a specific set of objectives and constraints for the model, which were explored with a group of simulations, in order to assess trade-offs among different objectives and indicators: for example gross margin and labour at the farm level, and food production, GHG emissions, and pesticide use at the regional level. For each scenario, the parameterization step consisted in (i) considering only the drivers of changes that could be included in the model (e.g. not the livestock, and agrotourism activities), and (ii) quantifying remaining drivers, using existing databases, expert knowledge and bibliography.
We present below the results of one scenario designed by the stakeholders, compared with a baseline scenario (current situation) in term of crops allocations and performances.

3 Results and Discussion

The main drivers identified are related to economic, environmental and regulatory features (public subsidies, commodity prices, environmental regulations, climate change and water availability; Table 1).

Table 1. Characteristics of the Scenario 1: "Camargue is classified as a region with specific handicaps"

Main drivers of changes	Scenario 1: "Camargue is classified as a region with specific handicaps"
Public subsidies	- Modulated SFP (projection PAC reform) : 326€/ha to 387€/ha - Aid for the maintenance of organic farming 100€/ha - Agroenvironmental measures for : i/ploughing the rice straws : 74€/ha; ii/ sowing the rice in dry conditions : 66€/ha iii/including leguminous in rotations : 60€/ha - Compensatory allowance for permanent natural handicaps (due to salt pressure) : 150€/ha
Prices of commodities and market	- Current prices - Organic market : saturated when 20% of the Camargue is converted to organic farming
Climate Change	- Higher temperatures during rice cultivation : increase rice yields by 10%
Energy and inputs prices	- Prices of all inputs increased by 30% (water, energy, fertilisers, pesticides, seeds)

Under the scenario "Camargue is classified as a region with specific handicaps", conversion to organic agriculture and legumes incorporation in rotations seems to respond to the increase of inputs and energy prices and Single Farm Paiement (SFP) decrease (Fig.1 A&B). Legumes cropping is promoted by the creation of a specific agro-environmental measure (AEM), at the expense of rice and cereals. Although efficient regarding to gross margin and to reduce fertilizers inputs, rice straw incorporation and rice dry sowing and corresponding AEM are not chosen by the model as best options for such context of changes (Fig.1 B). In this scenario, the alternative agricultural activities lead to a reduction on GHG and particulate emissions, and a reduction in energy and water consumption (Fig.1 C).
Under this scenario, rice and cereals production volumes decrease, (Fig.1 C) which may weaken the supply chains and local processing industries. The large increase in fodder production volumes may have a negative impact on fodder prices, except if, according to stakeholders, farmers shift to export their fodder. To reduce the risk of a strong fodder price decrease, decisions makers can seek on support the livestock sector, to ensure a larger local market for this production. Better crop-livestock integration systems (such as pastured cover-crops) should also be supported in this case by public policies. Such policies can be justified by the positive impact of these fodder-based systems on environmental externalities. The adaptations to this scenario of changes also lead to a decrease in energy value of the production (Fig.1 C), i.e. fewer people can be fed by the Camargue crop productions. However, the energy efficiency remains constant due to less energy consumption. Others simulations show that intermediate adaptations, with less fodder acreages and more rice and cereal acreages, can generate different trade-offs between crop and livestock systems, and between socio-economic performances (such as labour and energy value of the production) and environmental performances. These result, as well as results at farm scale will be exposed in the final presentation.

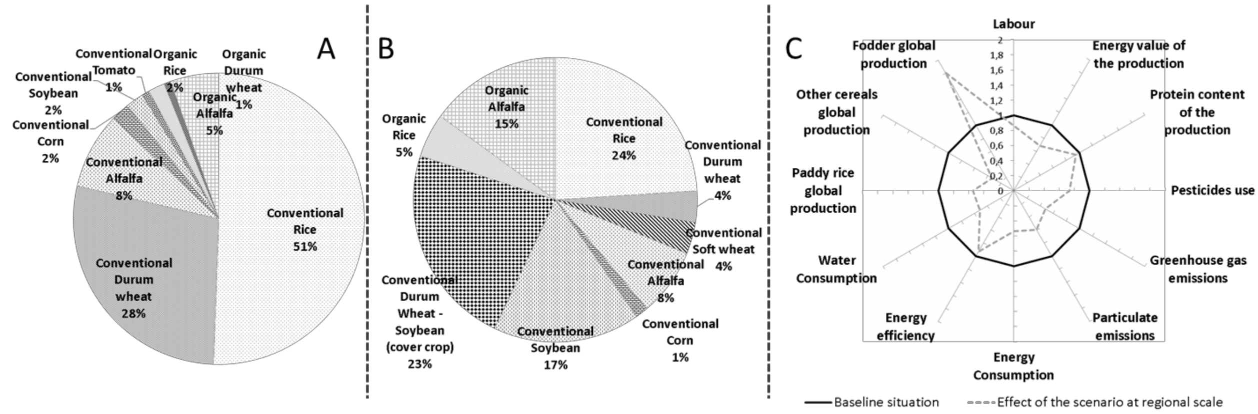

Fig. 1. Crops allocations at regional scale for baseline situation (A) and under scenario 1 (B1), and Comparison of performances for the baseline and the simulated scenario at regional scale (C)

4 Conclusions

The next step of this work, which will be exposed in the final presentation, is to compare the crops allocations and performances under the four scenarios of changes. These four scenarios are sufficiently contrasted to highlight robust adaptations under different contexts of changes. The participatory development and integrated assessment of scenarios is expected to (i) help the identification of sustainable adaptations in farming systems at both farm and territory scale, (ii) favor cooperation and negotiation by collectively stimulating knowledge, sharing opinions and exploring trade-offs between several objectives, and (iii) highlight territorial specificities to help local adaptation of public policies.

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The farm and landscape gap - partial versus emerging global efficiencies in agricultural systems

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1 Introduction

Resource Use Efficiency (RUE) has historically attracted extensive attention and debate in relation to agricultural production (De Wit, 1992, Lopez-Ridaura *et al.*, 2007). Trenbath (1986) distinguishes the efficiency of resource capture and the efficiency of resource conversion to describe RUE, stating that increased RUE can be attained by either increasing capture efficiency, conversion efficiency or both. RUE in agricultural research has largely referred to the interactions between the resources most often limiting crop yield under field conditions (i.e. water and/or nutrients) or feed conversion rates in animal production.
One important feature of these theories is that they describe RUE in general terms and therefore can, in principle, be applied to different resources at different scales. The same laws can be used arguably for resources such as labour, land and capital invested by the farm household and their efficiency in the generation of wealth or food security. Also, at regional scale, these analyses can relate resources such as infrastructure, markets and public/private investment to the value of agricultural production. Efficiency in agricultural systems is not scale-agnostic and it often depends on cross-scale interactions, such that apparent inefficiencies at one scale may represent net efficiencies at another one. Likewise, high efficiencies observed at small scales may not necessarily translate into high efficiencies when scaled up to whole farming systems or landscapes.

2 Case studies

This can be illustrated with the following example on fertilizer applications to grasslands in the highly productive dairy systems of Western Europe, using data from the literature (Table 1). When measured in controlled experiments grass productivity (Lolium perenne L.) responds positively to increasing N application rates of up to 600 kg ha-1, leading to high productivity levels while achieving N use efficiencies > 20 kg grass DM per kg N applied. Back in the 1990s, this was used as an argument to plea for greater rates of fertilizer N applications than the current limit of 250 kg ha-1. It was argued that the most efficient system is the most productive one (de Wit, 1992). Yet when measured in real farm conditions grass productivity and its N use efficiency did not improve at application rates beyond 250 kg N ha-1, due to losses associated with direct grazing (trampling, selectivity, harvesting efficiency) and/or silage. This points out to the need of taking whole-farm system perspectives in designing efficient N management strategies at the field scale in dairy farming.

Table 1. Grassland production and N use efficiency (NUE) in response to N additions under controlled conditions and in real dairy farms in The Netherlands (data source: Lantinga *et al.*, 1999)

N application rate	Biomass production in controlled experiment (clippings)		Production in actual dairy farms, subject to losses and trampling (direct grazing, silage)	
	Yield (t dm ha^{-1})	NUE* (kg kg^{-1})	Yield (t dm ha^{-1})	NUE* (kg kg^{-1})
0	4.4	-	4.0	-
250	10.5	24.4	9.4	21.6
400	13.2	22.0	10.5	16.3
550	15.8	20.7	9.7	10.4
750	15.1	14.3	10.2	8.3

*In this example, NUE is calculated as the partial factor productivity of N: $NUE = (Yield_N - Yield_0)/N\ applied$

In smallholder contexts, high farm-scale resource use efficiencies are not necessarily achieved on farms that can afford their access to external inputs, but rather in farms that achieve greater internal recycling. An example from ecological network analysis of N flows in smallholder crop-livestock systems of sub-Saharan Africa illustrates this (Fig. 1). Wealthier farms that can afford greater N throughputs were less efficient at converting N into biomass than farms that exhibited greater N recycling. In the latter, modest N inputs to the farm will meet stronger responses in terms of biomass productivity. And, since recycling is tighter, such inputs of N may come into the system through different entry points (e.g. as animal feed) allowing for more flexibility.

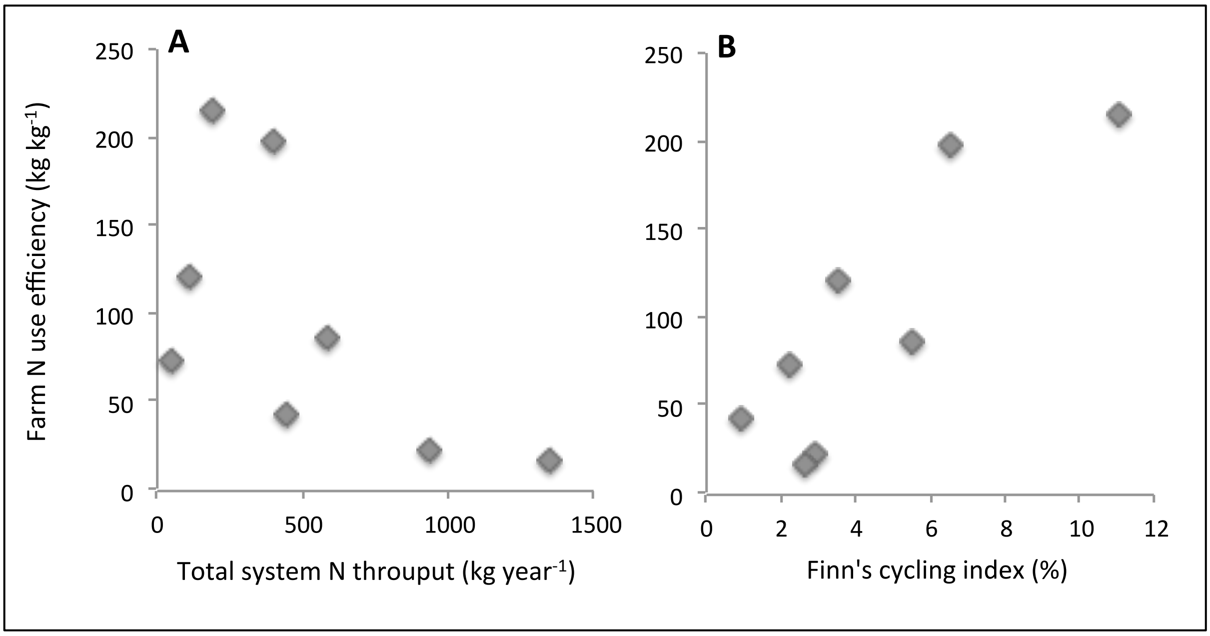

Fig. 1. Calculated farm N use efficiency (with respect to total plant and animal biomass production) as a function of (A) the total farm N throughput (sum of all inflows and flows within compartments) and (B) the Finn's cycling index, as calculated for smallholder farms in Ethiopia, Kenya, Zimbabwe and Madagascar (adapted from: Rufino *et al.*, 2009 and Alvarez *et al.*, 2014)

3 Discussion and Conclusion

Farms and landscapes represent examples of systems with complex feedbacks across scales and where social and ecological dimensions interact. A farm or an agricultural landscape can be seen as a system in which fields and farms (and other entities) represent nested system components, or as a mosaic of ecological units that exhibit lateral interactions. These two alternative visions of landscapes have shaped the way in which we analyze their functions and design management interventions. In farming systems design, understanding the relationship and tradeoffs between partial efficiencies at different scales is essential to "target" the systems levels and components at which increased efficiency is sought. A form of farm and landscape agronomy is needed that goes beyond pursuing partial results such as closing crop or animal yield gaps, to propend to resource use efficiencies that emerge at scale (farms, landscapes) as a result of interactions between system components and spatial units at lower integration levels. Our hypothesis is that such 'emerging global efficiencies' might be better targeted for increased sustainability, as efficiency at higher levels is more than just the sum of efficiencies at lower levels.

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Coll-ICLS: a participatory tool to support crop-livestock integration among farms

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1 Introduction

Farm-level crop – livestock integration is a theoretical ideal to improve the sustainability of agriculture. It promotes ecological interactions over space and time between system components (i.e. crops, grasslands and animals) and create opportunities for synergistic resource transfers between them (Hendrickson *et al.*, 2008). They offer opportunities to at least partially substitute external inputs used in intensive and specialized systems with ecosystem services, such as symbiotic nitrogen fixation or biological regulation of pests and diseases. Nevertheless, integrated crop – livestock farms have declined in number in Europe, and the trend towards specialization continues. The drivers of specialization (supply chains, technical consulting services, education of farmers) reduce the chance of re-diversifying farms. Moreover, the necessary skills and knowledge to manage integrated crop–livestock farms have often been lost after specialization.
Several authors (Lemaire *et al.*, 2014; Russelle *et al.*, 2007) now suggest that crop–livestock integration can be organized beyond the farm level through local groups of specialized farmers negotiating land-use allocation patterns and exchanging materials (manure, straw, etc.). In regions with high animal density, straw-manure exchange among farms is a common example of crop–livestock integration. The levels of spatial, temporal and social coordination among farms defines the nature, area and spatial configuration of the crops, grasslands and animals in the different farms and landscapes concerned, which in turn influences the provision of ecosystem services like soil fertility, erosion control and field-level biological regulation services. At this stage, the question for research is that of the participatory design methods to be developed to support candidate farmers in designing coordination among farms.
In this article, we present Coll-ICLS (Collective Integrated Crop-Livestock Systems), a simulation tool aimed at supporting crop-livestock integration among farms.

2 Coll-ICLS to support the design of crop-livestock integration among farms

Participatory design of collective integrated crop-livestock systems with Coll-ICLS is implemented through three iterative steps (Fig. 1a): (i) problem specification (current farm functioning and associated multi-domain issues); (ii) design of (spatial, temporal and social) coordinations among farms and farmers and subsequently of new farming systems; and (iii) assessment across space and time of their potential effects and of trade-offs between the individual and collective levels. It is also expected that Coll-ICLS will structure the negotiation process between farmers to identify consensual solutions through the three iterative steps and achieve legitimacy at both the individual and collective levels.
Coll-ICLS relies on the conceptual framework that supports adaptation of agricultural systems proposed by Martin (2015). It has already been applied to several agricultural design support systems like Forage Rummy. This framework builds on collective workshops involving researchers, agricultural consultants and farmers who collectively manipulate boundary objects (e.g. cards and computer models).
Problem specification builds upon a diagnosis of each individual farm prior to collective workshops in order to assess sustainability issues within each farm. For instance, where grain and forage price is concerned, self-sufficiency for animal feeding is measured within each livestock farm. Similarly, where maintenance of soil fertility is at stake, consistency of tillage and fertilization practices are regarded with respect to land use. The scope for coordination among farms permitted by their resources (land, animals, human workforce, machinery, buildings), their current and potential productions (products: grain, forage, meat, milk; and co-products: straw, manure) and their needs (fertilizers, animal feed) is also evaluated. Individual farmers' desires with respect to coordination among farms are also gathered at this stage and confronted with opportunities at the collective level.
Following Martin (2015), manipulated objects during collective workshops are of two types: (i) material objects (e.g. cards) enabling modeling (representation) of the current situation and design of possible solutions to the problem, and (ii) computer objects (e.g. computer models) enabling simulation, i.e. assessment of these solutions. Material objects represent physical and functional entities managed by farmers, e.g. fields, cropping systems, animal groups and crop products. They are intended to create a connection between workshop participants (Klerkx *et al.*, 2012). Computer objects provide instantaneous integrated evaluation (in the form of maps, graphs and indicators) of candidate solutions designed by workshop participants to stimulate their reflections and negotiations. Such collective workshops are also expected to foster hybridization of scientific (to ensure credibility) and empirical knowledge (to ensure saliency and legitimacy).
During the workshops, farmers use first, as material objects, a map of their fields and current land use. They also use a table dedicated to describe the intended coordination with other farms (type, amount and timing of product and co-

product exchanges and consequent changes in land use and herd management). Changes in cropping systems and allocation of animals at grazing (e.g. introduce cover crops to be exported to livestock farms as fodder) are reported on the map of their fields. Throughout this process, discussions among farmers enable them to integrate individual projects into a collective solution to be simulated. The last kind of material object is a sheet synthetizing the outputs of successive simulated scenarios.

The computer model of Coll-ICLS (Fig. 1b) incorporates (i) biophysical models simulating the different investigated activity-location combinations (i.e. cropping and grassland systems), animal reproduction, feeding and production, etc.; (ii) decision models representing farmers' management of the farm components (crops, grasslands, animals, feedstuffs, etc.) and coordination among farmers; (iii) logistics models representing raw material fluxes between farms and associated resource use (workforce, machinery, etc.). This computer model allows simulating impacts of weather variations within and between years on crop, forage and animal production, resulting exchanges among farms and ecosystem services promoted. Therefore, it is possible to assess the variability of individual and collective performances and to identify acceptable trade-offs between individual and collective performances under constraints such as suitability of land, labor availability, etc.

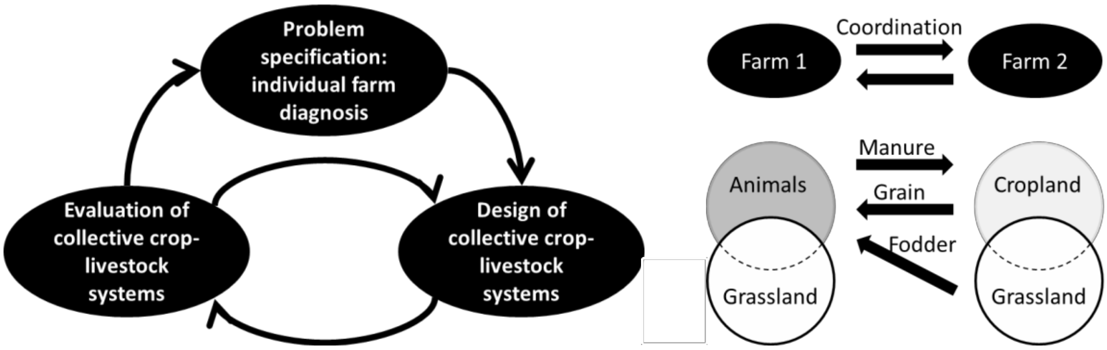

Fig. 1. Overview of Coll-ICLS: overall approach (left: 1a) and simplified view of the conceptual model of an example of collective integrated crop-livestock system (right: 1b)

3 Conclusions

Coll-ICLS is currently being tested in the framework of a research and development program with organic crop and livestock farmers in southwestern France. Its potentialitiesto supportcrop-livestock integration among farms might be challenged by current projects being set up to organize crop-livestock integration at the regional level through e.g. alfalfa supply chains involving crop farmers as alfalfa growers and livestock farmers as alfalfa consumers.

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Does the recoupling of crop and livestock production at the district level lead to environmental benefits? A case-study approach in Europe.

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1 Introduction

As the resources required for agricultural production become scarcer, and environmental regulations designed to reduce agriculture's impact on the environment become more restrictive, farmers will have to reorientate their production systems to better utilise the natural resource base. This can be done by taking advantage of synergies between farm enterprises through complementarity between crop and livestock production (Villano *et al.,* 2010). Integration can occur at the farm-level when livestock are incorporated into farm operations specifically to capture positive synergies among enterprises (Clark, 2004). Integration may also occur at district-level where spatially separated crop and livestock farms cooperate for mutual benefit via contracts and partnerships, through material exchange for instance.
Despite the potential of such arrangements to improve nutrient recycling, few research studies have assessed their efficacy (Asai *et al.,* 2014). Questions remain as to whether collaboration among-farms might achieve the same range of synergies as within-farm integration (Russelle *et al.*, 2007). Therefore, our objective is to develop an empirical assessment of the ecological benefits and drawbacks of crop-livestock integration strategies currently employed at the district scale in Europe.

2 Materials and Methods

We assessed four district-level crop-livestock integration strategies already employed in different biogeographical regions of Europe: (1) Local exchange of manure for straw among farms in the Ebro Basin, Aragon, Spain; (2) Provision of high quality forages for dairy cows through a forage dehydration facility in Domagné, Ille et Villaine, France; (3) Land sharing between dairy and arable farms in Winterswijk, Netherlands; and (4) Animal exchanges between lowland and highland regions in Switzerland. For each strategy, a farming system approach was employed to compare the characteristics and performances of three existing farming systems: non-cooperating specialised (i.e., no integration between crop and livestock), mixed farms (i.e. farm-scale integration) and cooperating specialised farms (i.e. district-scale integration through among-farm mixing). Within each group, farms were selected to be as representative as possible of their group. For each farming system, data were collected for ca 5 farms and then compared in terms of farming practices, input use, feeding strategies, fertilising strategies, land use, nutrient recycling, and economic performance. The empirical farm data used in this study were collected for 2012/2013via farmer interviews performed in 2014.

3 Results – Discussion

Hereafter, we present only the results related to local exchange of manure for straw among farms in the Ebro River, Spain (Table 1). The results showed that N surplus expressed on a per hectare basis was higher on cooperating dairy than on specialised dairy farms and that mineral fertiliser use on cooperating arable farms was higher than on specialised arable farms. Such results were due to higher stocking rate on cooperating dairy farms and to intensive arable farming on cooperating arable farms, as illustrated by intensive soil tillage and irrigation. Cooperating dairy farms had lower district N autonomy than specialised dairy farms, but cooperating arable farms had slightly higher district N autonomy than their specialised counterparts. Specialised dairy farms outperformed cooperating dairy farms when assessed in terms of crop diversity (as measured using Shannon's Diversity Index (Eiden *et al.*, 2000)) and percentage of land area alternating spring and winter crops. A higher level of plant diversity and a greater land area alternating spring and winter crops, as observed on specialised dairy farms, is evidence of greater potential for natural pest controland may thus reduce the frequency of pesticide use.
There was no evidence of improved efficiency on cooperating arable farms, as they had similar efficiency values to specialised arable farms. Cooperating dairy farms had a slightly lower N surplus per ton of milk produced than specialised dairy farms but had a lower N efficiency in terms of kg of N in sold products per kg of N input.

Table 1. Farm properties and performance for the Ebro Basin, Spain

		Baseline or reference farm groups			Cooperating farm groups	
Indicator type	**Farm properties and indicators of performance**	**Specialised Dairy (n=4)**	**Specialised Arable (n=5)**	**Mixed Dairy (n=4)**	**Cooperating Dairy (n=5)**	**Cooperating Arable (n=4)**
Farm properties	Agricultural Area (ha)	35	195	306	30	159
	Stocking rate (LSU ha^{-1})	3.0	-	0.8	6.6	-
	Milk production ($Lcow^{-1}$)	10510	-	10508	10405	-
N balance	Mineral N fertiliser use (kg N ha^{-1})	2	66	125	72	163
	Slurry exported (e) or imported (i) (kg N ha^{-1})	7.3(e)	0	0	366 (e)	30 (i)
	N surplus (kg N $ha^{-1}yr^{-1}$)	345	23	124	496	80
Intensity	Conventional tillage area (% of UAA)	73	6	70	90	97
	Irrigated area (% of UAA)	100	26	97	82	85
Resistance and resilience	Shannon's Diversity Index	1.15	1.18	1.60	0.83	1.21
	Alternating spring and winter crops (%of UAA)	54	60	53	42	25
	District N autonomy* (%)	24	38	32	16	41
Efficiency	N surplus (kg N ton-$milk^{-1}$)	13.9	-	24.8	12.9	-
	N efficiency (kg N sold kg^{-1} N^{-1}input)	0.31	0.70	0.60	0.25	0.71
	N surplus per output (kg N kg^{-1} N^{-1} sold)	2.20	0.49	0.78	2.16	0.48

*District N autonomy: N input (via material exchange of straw or manure, biological fixation and deposition)/total N input.

Similar results were observed in the other biogeographical regions of Europe: in Ille et Villaine, cooperating dairy farms had a higher no. of milking cows per hectare and milk yield per cow compared to specialised non-cooperating farms. In Switzerland, cooperation via animal exchanges (i.e. sending of lowland purebred calves to mountain heifer rearing farms before they return as pregnant heifers) was expected to afford lowland dairy farmers the land and time required to diversify their system and engage in cropping activities. However, lowland farmers chose to intensify their operations and increase milk production (dairy farming is more profitable on a per hectare basis) as opposed to diversifying them by growing more cereals (cropping is more profitable on a per hour worked basis) for livestock feeding. Farmers chose to intensify dairy operations because land availability is more limiting than labour availability in the region.
Overall, these results show that crop and livestock integration at the district scale does not necessarily lead to environmental benefits. Instead, in most cases, cooperation had the counterintuitive effect of increasing input use: cooperating farms had more intensive farming systems than non-cooperating specialised or mixed farms (eg, in terms of stocking rate or milking cow per ha, input use and N balance). Therefore, the benefits of integration were restricted by farmers choosing to use cooperation as a means to overcome environmental regulations and intensify their operations (since it provides a way to handle the large N excess that accompanies intensification) as opposed to diversifying them.

4 Conclusions

Our study provides first empirical evidence that cooperation among farms at the district scale does not necessarily lead to environmental benefits. Instead, in most cases, cooperation had the counterintuitive effect of increasing input use. However, it is not clear yet if cooperation helped farmers to intensify their system, or if cooperation is required to sustain already intensive systems. These results provide a platform to discuss about integration strategies between crop and livestock and to design resource efficient farming systems at different spatial scales.

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A system analysis of crop rotations with sugar beet and/or silage maize for biogas production - ecological and economical approaches

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1 Introduction

Like all arable systems, the production of biogas from biomass crops needs to reach economic, ecologic, and social standards in order to contribute to a sustainable development of energy production (European Commission, 2010 ; Tilman *et al.,* 2002). This target applies for the entire production chain: For the biogas production itself, for the farm cultivating the biomass crops, and for the field with its cultivation system. Nowadays, silage maize is the most important biomass crop in Germany and the high concentration of its cultivation provokes social and ecological problems (Zegada-Lizarazu & Monti, 2011). Our joint project (five subprojects) questions if and where sugar beet as a biomass crop offers an ecological and economical efficient alternative. Within this, the aim of the study was to implement a systematic methodological approach linking reliable data from field trials with different modeling approaches which focus on region-specific yield levels, farms, and biogas plants in Germany (Jacobs *et al.*, 2014).

2 Materials and Methods

Field trials were located on highly productive sites in Bavaria, Lower Saxony, and Saxony Anhalt, Germany, (2010-2014; Jacobs *et al.*, 2014). The biomass crops, silage maize and sugar beet, were grown in continuous cultivation and in crop rotations (one year of biomass crop followed by twofold winter wheat). In practice, sugar beet are not-self compatible and its continuous cultivation was part of the methodological approach. (i) We assessed the potential methane yield (Weißbach, 2008 ; Weißbach, 2009) in the field trials (2011-2014). (ii) Further, the economic preference of silage maize and sugar beet for biogas production (costs per Nm^3 methane) was evaluated in a nation-wide but district-specific modeling for Germany (own model including storage losses and field trial results). (iii) The contribution of sugar beet for biogas production to the stabilization of the profit margin of farms with different socio-economic structures (e.g. size, equipment, risk-acceptance by farm manager) was modeled (own model after Lehmann *et al.*, 2013 based on field trials). We further estimated the ecological impacts and risks of crop cultivation in the field trials on (iv) soil health, indicated by balance of humus-C (soil organic matter; REPRO-model; Hülsbergen, 2003; 2011-2014) and by soil compaction risk in the top 20 cm (REPRO-model; Rücknagel *et al.*, 2015; 2010-2012), on (v) water bodies (N-balance; Sieling & Kage, 2006; 2011-2014), and on (vi) air (greenhouse gas emissions; De Klein *et al.*, 2006; IFEU, 2013; 2011-2014). The ecological assessments were done for entire crop rotations in order to avoid allocation mistakes.

3 Results – Discussion

(i) In the field trials, we found silage maize's methane hectare yield, as the mean of 2011-2014 and of continuous cultivation and crop rotations, of 8,365-8,782 Nm^3 ha^{-1} (Bavaria), 6,837-7,069 Nm^3 ha^{-1} (Lower Saxony), and7,135 Nm^3 ha^{-1} (Saxony Anhalt). Methane hectare yield of sugar beet taproots was lower (Bavaria: 7,652-7,861 Nm^3 ha^{-1}; Lower Saxony: 5,152-6,244 Nm^3 ha^{-1}; Saxony Anhalt: 3,206 Nm^3 ha^{-1}) due to generally lower dry matter yield. However, differences in dry matter yield were negligible when entire crop rotations (triennial sum of yield) were assessed (not shown). (ii) The nation-wide modeling pointed out those German districts (13%) where the costs per Nm^3 methane produced out of sugar beet were lower than for silage maize. This economic preference of sugar beet was shown in regions where either sugar beet yield is relatively high (along the Rhine and the Danube) or where silage maize yield is relatively low (North of Germany, around Berlin). Further, 20% of the German districts showed a slight economic preference (max. 5% higher) of silage maize compared to sugar beet as crops for biogas production. (iii) Moreover, when sugar beet for biogas production was introduced into the cropping system, the socio-economic farm model predicted a reduction of fluctuations in the profit margin. However, for the experimental sites in Lower Saxony and Saxony Anhalt, this economic risk reduction was achieved only for low and very low risk-acceptance by farm managers and decreased in the mean profit margin by 1% and by 3%, respectively. For the site in Bavaria, the cropping system including sugar beet for biogas production was associated with an increase in the profit margin by 6%

and the economic risk reduction was achieved even for a risk-neutral farm manager. In terms of ecological impacts and risks, (iv) humus-C balance showed similar values for silage maize and sugar beet and was reported here as the mean of both biomass crops. It was clear that the crop rotations better-preserved a sustainable humus-C level in the soil by matching the threshold regulated in Germany of (-75 to 125 kg C ha^{-1}; Anon., 2004) (crop rotations: Bavaria: -10 kg C ha^{-1} a^{-1}, Lower Saxony: -47 kg C ha^{-1} a^{-1}; continuous cultivation: Lower Saxony: -614 kg C ha^{-1} a^{-1}; Saxony Anhalt: -869 kg C ha^{-1} a^{-1}). The soil compaction risk index was more inhomogeneous and showed low to very high risks (Rücknagel, 2007) for single years of the crop rotations. However, in average, soil compaction risk was lower in crop rotations than in continuous cultivation where high to extremely high risks were indicated for three out of four cases (more often for sugar beet than for silage maize). (v) The N-balance ranged between -111 and 33 kg N ha^{-1} in average among sites, crop rotations, and continuous cultivation (lower values for silage maize than for sugar beet) and never exceeded the threshold for farms regulated in Germany (60 kg N ha^{-1}; Anon., 2007). (vi) The triennial sum of greenhouse gas emissions of crop cultivation were higher for crop rotations (Bavaria: 11.1-11.9 t CO_2eq ha^{-1} $3a^{-1}$, Lower Saxony: 11.6-11.7 t CO_2eq ha^{-1} $3a^{-1}$) than for continuous cultivation (Lower Saxony: 8.0-8.6 t CO_2eq ha^{-1} $3a^{-1}$, Saxony Anhalt: 7.6-8.3 t CO_2eq ha^{-1} $3a^{-1}$). Again, values of both biomass crops were similar but, in general, the emissions were lower from sugar beet cultivation. However, the ecological parameters need to be related to the methane yield in order to evaluate the intensity of the respective impacts and risks. Moreover, the biogas production itself is to be included in the methodological approach which will be presented and discussed during the conference.

4 Conclusions

Overall, we concluded that sugar beet for biogas production is economically not in general preferable opposing silage maize due to higher cultivation costs and lower methane hectare yield. However, in 13% of German districts, the opposite was shown. Especially when production costs can be reduced, sugar beet offers an economically good choice as a crop for biogas production and was further concluded as a mean to stabilize the profit margin of a farm's cultivation program. Regarding the absolute results (not related to methane hectare yield) about ecological impacts and risks, we considered that neither silage maize nor sugar beet was outstanding from the other and values were even more similar when the biomass crops were cultivated in crop rotations. Consequently, we suggested that the entire crop rotations or cropping systems are generally to be evaluated for holistic conclusions. Overall, sugar beet can contribute to a sustainable development of biomass crop production especially when it is supposed to reduce silage maize cultivation, to increase crop rotation variability, or to reduce the economic risk for the farm.

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Design of cropping systems at territorial scale: methodological lessons from case studies

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1 Introduction

Water quality in France is highly degraded, and must be improved according to the European Water Framework Directive. As agriculture has been recognized liable for diffuse water pollution, measures have to be taken in water catchment areas, often including a redesign of cropping systems to efficiently limit nitrate and pesticides transfer to water while keeping an economically powerful agriculture. Such a redesign at a territorial scale raises methodological issues: who should be involved on the design process and how, to allow a sustainable and long-term change of local practices? Which knowledge should be used, in order to take into account the characteristics of the local situations? As the change is thought to last several years, which process should we start to favor actors' learning? From two methods developed and implemented in six case studies, we analyzed the main characteristics and specificities of a process of design at territorial scale in order to be efficient.

2 Presentation of the two methods of design at territorial scale

Two methods aiming at collectively designing cropping systems at territorial scale were developed: Co-click'eau, based on the adaptation to a water catchment area of the method proposed by Jacquet *et al.* (2011) and Brienon, named after the place the approach was built (Burgundy, France) (partly described in Ravier *et al.,* 2015).

The Co-click'eau method includes 6 steps (Gisclard *et al.*, 2014): (1) the choice of indicators for the assessment of cropping systems and territory scenarios, (2) a synthetically characterization of the present situation of the area (water quality issues and current cropping practices), (3) the building of a grid describing crop*soil*current and alternative practices combinations, with their main performance (yield, pesticide and N fertilizer use or gazeous losses emissions, work load, gross or direct margin, …), (4) the collective identification of the main territory objectives and constraints (e.g. maximum profitability, minimizing pesticide use, a maximum area in organic agriculture), (5) the design of scenarios with a mathematical programming model satisfying the aims, and the assessment of the various scenarios (described as percentages of the cultivated area corresponding to each combination of the grid), and (6) a discussion on the results to build the action plan (if the results were not satisfactory, a new loop with steps 4+5+6 began). Steps 1, 4, 5 and 6 were realized by a steering committee, involving diverse stakeholders, including consumers, while steps 2 and 3 were implemented by a technical committee (farmers, advisors knowing the area).

The Brienon method includes8 steps: (1) the analysis of the requirements built from interviews with the various stakeholders in the catchment area, (2) a collective identification of the targeted aim for the water quality, with the steering committee, (3) a diagnosis on the cropping systems in the area, (4) the design of new cropping systems, realized by local farmers (5) the assessment of the new cropping systems regarding the targeted aims, with adapted tools, (6) the building of an action plan, after a discussion of the possible cropping systems to be implemented with the local farmers, (7) the proposal and discussion of the action plan with the steering committee, (8) proposal for the monitoring of the action plan.

3 Results and Discussion

Since 2011-2012, these two methods have been tested in several water catchment areas located in the Northern part of France, each measuring between 17 and 47 km², and used predominantly for field crop production, winter wheat and rapeseed in particular (see Chantre *et al.*, 2014). Action plans were validated in each of these areas, sometimes following the actions plans built from our methods, sometimes not. Where the action plans were in line with the one built thanks to one of the two methods, change of practices has begun to be implemented. In Brienon for instance, the dynamics is very promising and the monitoring shows that the actions and results are in line with what was expected.

From these different experiences, their successes and their failures, we propose to discuss five characteristics of both methods that seem important to design cropping systems at territorial scale. First, both methods involve the various actors concerned by the agriculture in the territory, including citizens, with their specific aims and values. Rather than building a common aim to reach, we propose various means to explore and take into account the diversity of the actors' targets, agree on their assessment criteria, and identify the agricultural solutions which respect as much as possible the diverse aims (Ravier *et al.,* 2015). Keeping the objectives of each stakeholder helps to alleviate tensions between differing opinions, thus facilitating the dialogue between them, particularly between farmers, the suppliers and water consumers, asking for a service. Considering together water quality and economic, social and environmental performance of agricultural practices in the targets helps at involving the various stakeholders in the approach.

Second, both methods show that describing and characterizing the current cropping systems, and their estimated impact on water quality, is a crucial step before designing new cropping systems and territory scenarios. This step allows the actors to build a shared vision of this territory and issues, by identifying and sharing the main practices that prevent to reach the targeted aims, justifying the need to design new cropping systems and territory scenario.

Third, both methods show that a step in sharing scientific and expert knowledge among actors about local agricultural conditions, and about innovative practices, together with their performance, is powerful. It also appears important that the results of the *ex ante* assessment of the innovative cropping systems and/ or scenarios, designed for the territory, be collectively discussed in order that every participant learns from the links between these results and the characteristics of the combinations practice*soil type in the area.

Fourth, exploring possible solutions, even if obstacles to their implementation exist (lack of market opportunities, economic performance…) and assessing their impacts at the territorial scale helps at defining the final scenarios in the action plan. Creativity can be enhanced by the exploration of breakthrough scenarios. This step is more powerful when assessment or optimization tools are used.

Fifth, choosing together the timescale of the action plan (what is possible to do and when), and the intermediary indicators that monitor the actions implemented and results obtained, contributes to the motivation of the participants. The monitoring of the implemented process allows the participants to assess the efficiency of the solutions proposed or to collectively imagine other solutions if the results are not as good as expected.

4 Conclusions

Finally, it appeared, from these case studies, that the implication of the actors all along the process, together with regular discussions on the intermediate results of implemented innovative practices, is required for a full and continuous implication of stakeholders. Sharing the information, diagnosis, knowledge, objectives at each step of the approach allows a learning loop for the participants, about the challenge, the methods, the organization, innovative technical practices, but also about the diversity of points of view in the catchment area (Chantre *et al.,* 2014). Several tools are needed for this approach that should be adapted to the activity and learning of the stakeholders: tool for representing the diversity of practices, tool for identifying optimal scenarios, tool for assessing solutions at the territorial scale, tool for monitoring the action…

The success of the process greatly depends on the management of the stakeholders' positions and motivations: taking into account the diversity of the opinions, working with an open mind in order to find innovative solutions, accepting that the first solutions proposed do not allow to reach the targets and motivate the farmers to be more innovative.

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Indicators for the evaluation of nitrogen efficiency and nitrogen balance in agriculture for 27 Member States of the European Union

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1 Introduction

In the European Union, only 31% of nitrogen (N) inputs in agriculture are recovered in intended products (Leip *et al.*, 2011). This low N use efficiency results in major N losses, which have serious impacts on human health and the environment. Improving N efficiency is one of the key options to reduce this environmental impact while ensuring the needs of a growing population (Sutton *et al.*, 2011). Indicators are necessary to assess N efficiency. The most used N efficiency indicator is derived from farm-gate balance (FGB; Kaffka *et al.*, 1989) and is called nitrogen use efficiency (NUE; Halberg, 1999). However, both FGB and NUE suffer from several limitations (Godinot *et al.*, 2014).
Novel indicators called system N efficiency (SyNE) and system N balance (SyNB) solve some limitations of NUE and FGB (Godinot *et al.*, 2014). However, as animal production is less efficient than crop production, those indicators cannot help indentifying possible improvement margins for mixed farming systems. A third indicator, called relative N efficiency (RNE), deals with these biological differences by expressing efficiency relative to the maximum attainable efficiency of each product (Godinot *et al.*, 2015).
These three indicators (SyNE, SyNB and RNE) have been applied and validated at farm scale (Godinot *et al.*, 2014, Godinot *et al.*, 2015). The goal of this work is their application on 27 Member States of the European Union, in order to test their interest in describing N management and N efficiency progress margins at the country scale.

2 Materials and Methods

Indicator caculation includes indirect N losses due to the production of inputs and soil N change.Net N fluxes are calculated when used inputs are similar to produced outputs. Potential efficiency is defined as the highest efficiency found in the literature for each net output. This leads to the following formulas:

SyNE = net outputs / (net inputs + indirect N losses – soil N variation)
SyNB = net inputs + indirect N losses – soil N variation – net outputs
RNE = SyNE / potential efficiency

Data used for calculation were collected for each of the 27 EU Member States from years 2000 to 2008. Land use, crop and animal production and import data were provided by the statistical service of the United Nations Food and Agriculture Organization. Inorganic and organic fertilizer use, biological N fixation by legumes crops and energy consumption for the agricultural sector were provided by Eurostat. Atmospheric N deposition was calculated from the European Monitoring and Evaluation Program. N losses related to the production and transport of crop, fertilizer and energy inputs were estimated from life cycle inventory data (Godinot *et al.*, 2014). The annual change in soil organic N content was estimated for permanent crops and grasslands (+43 kg N ha^{-1}) and annual crops (-70 kg N ha^{-1}) based on average organic carbon change at the European scale (Vleeshouwers and Verhagen, 2002).

3 Results – Discussion

SyNE was first compared to the usual indicator NUE. SyNE varies from 0.16 to 0.42 with an average of 0.23; NUE varies between 0.20 and 0.49 with an average of 0.35 (Fig. 1). The 12 points difference illustrates the lack of consideration of some fluxes in NUE. Including indirect N losses leads to a low decrease (-1 point on average). However, considering them allows comparing small input importers such as Eastern European countries (Slovakia, Latvia, Lithuania, Romania) with large importers (Malta, the Netherlands and Belgium). Net fluxes calculation results in a 5 points decrease on average. It mostly penalizes countries that import feed and grow similar crops (Malta, Belgium, Portugal, Greece). Considering soil N changes results in a7% decrease on average (Fig. 1), especially in countries with more annual crops (Romania, Hungary, Bulgaria) while it increases the efficiency of countries with more permanent crops and grasslands (Ireland, Greece, United-Kingdom). Compared to NUE, SyNE expresses the global efficiency of agriculture from cradle to the gate of the "territory-farm". This perimeter is similar to the N footprint of agricultural production for a given country.
RNE completes SyNE for comparison between countries with different production by expressing the efficiency of the agricultural sector of a country according to its potential, which depends on the nature of agricultural productions. RNE

varies between 0.28 and 0.78 with an average of 0.43 and is correlated to SyNE (r = 0.75; $p < 0.001$) but an individual comparison of countries shows remarkable differences in rankings for some countries (Fig. 2).For instance, Ireland has the same system N efficiency as Czech Republic (0.20) but a better relative efficiency (0.56 against 0.32) due to its higher share of animal production. RNE is an interesting tool to estimate the room for improvement for N efficiency given each country's production mix. Using this indicator, Czech Republic (RNE = 0.32) seems to have more progress margin compared to Malta (RNE = 0.44), and even more than Ireland (RNE = 0.56), although those three countries have a similar SyNE of 0.20.

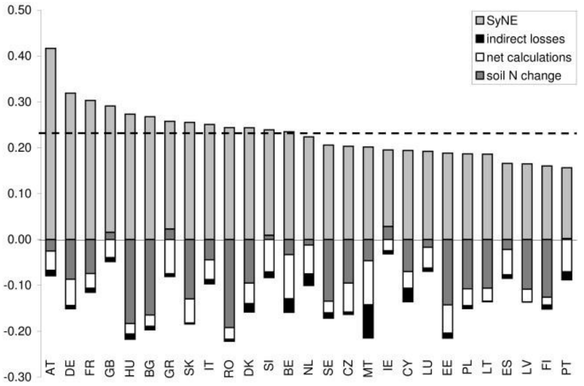

Fig. 1. Differences between SyNE and NUE for EU27

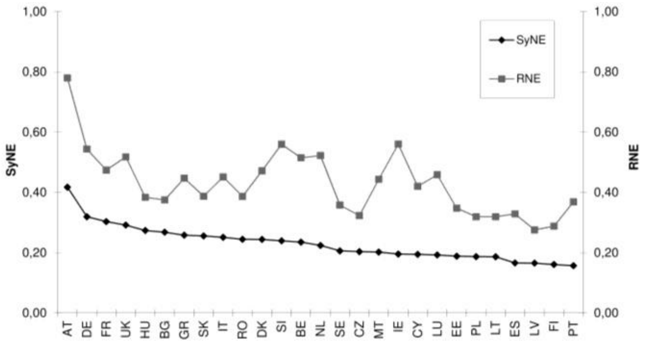

Fig. 2. Comparison of SyNE and RNE for EU27

The average national System N Balance is 113 kg $N.ha^{-1}$ Agricultural Area for the 27 Member States and varies from 31 to 432 kg $N.ha^{-1}$ AA. SyNB shows a strong correlation with net animal production (r=0.96; $p < 0.001$) and net feed input (r=0.94; $p < 0.001$). The combined use of RNE and SyNB gives more insights into N management priorities : countries with high SyNB should reduce their balance first, while countries with low RNE and system N balance could work on improving their relative efficiency.

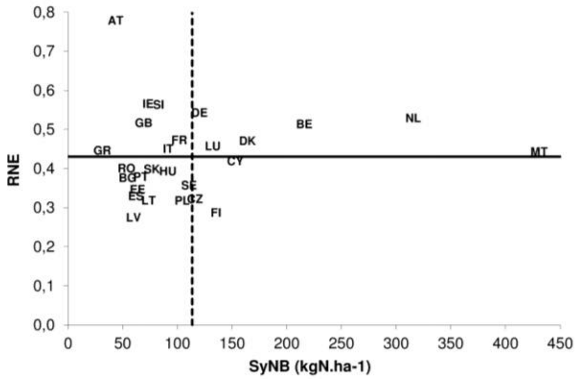

Fig. 3. Interest of combining RNE and SyNB for country analysis

4 Conclusions

This work demonstrates the feasibility and the interest of calculating system N efficiency, relative N efficiency and system N balance at the national scale. Although the proposed indicators present higher uncertainty (mostly due to soil N change) they legitimate comparisons between countries. Their reliability will increase with the progress of knowledge on soil N dynamics. Their combined use gives new insights into N management at country scale: system N efficiency and balance allow evaluating the use of N resources in agriculture as well as the resulting environmental pressure, while relative N efficiency allows assessing the margin of progress of each country given its productions.

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SCALING UP AGRICULTURAL CATCHMENT MANAGEMENT STRATEGIES FROM FIELD AND FARM SCALE TO LANDSCAPE SCALE

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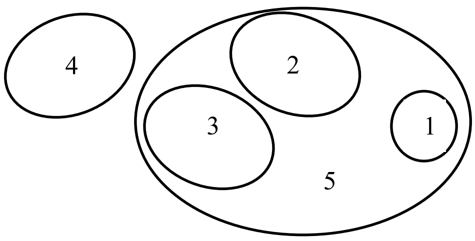
1 Introduction

Targets for water quality set by the Water Framework Directive (WFD) drive monitoring, research and agricultural landscape management accross Europe. Despite this, there is limited understanding of the efficacy of mitigation measures developed at field and farm scale when applied together at the catchment scale, or of the implications for meeting local, national and global targets for food security and viable farm businesses. Since 1992, wide-ranging agri-environmental research has been carried out at the 333ha Allerton Project research and demonstration farm at Loddington (central England) to develop management practices that meet objectives for biodiversity conservation, water quality and other environmmental objectives while maintaining profitable and productive farming (Stoate *et al.*, 2012). Examples of individual management strategies include reduced tillage, contour cultivation, in-field barriers, cover crops, and constructed wetlands. Since 2010, a landscape scale experiment, 'Water Friendly Farming', has been established to test some of these measures within the wider farming community of the upper Welland river basin (Biggs *et al.*, 2014). This work builds on previous catchment initiatives, including a social learning approach to community engagement (Stoate, 2010).

2 Materials and Methods

The Water Friendly Farming project adopts a rigorous BACI (Before, After, Control, Impact) experimental design and the study area comprises three headwaters catchments close to Loddington (Figure 1) covering a total area of approximately 3,000ha of pasture and arable land. Three years of baseline stream nutrient and sediment concentration data have been collected from the base of each catchment, and pesticide data have been collected in autumn/winter. Mitigation measures have been introduced and soil and nutrient maps and advisory visits provided to participating farmers from 2014. The focus is currently on identifying synergies between objectives for water quality improvement and improvements in crop production and soil and nutrient use efficiency. Remote sensing data have been used to identify areas of high runoff risk and poor crop establishment, and soil penetration resistance data have been collected across a sample of affected fields. Links between soil physical and biological properties associated with compaction are being investigated. Crop yields for Loddington have been recorded annually since 1993 and are available for other farms more recently. Research and management are adapted in response to feedback from participating farmers, enabling scientific and farmer knowledge to be combined. An Arable Business Group has been established for benchmarking economic performance of farm businesses, soil organic matter benchmarking has been requested by participating farmers, and a no-till drill is being made available for free trial.



1. Loddington farm
2. Upper Eye Brook catchment
3. Upper Stonton catchment
4. Upper Barkby catchment (control)
5. Wider upper Welland catchment

Fig. 1. Diagramatic representation of upper Welland study areas

3 Results – Discussion

Along with other farms across lowland England, wheat yields at Loddington have not increased in the past two decades (Figure 2) despite increased physiological potential through plant breeding. Yields were exceptionaly low in 2012 when prolonged rain resulted in compacted waterlogged soil which also influenced yields in 2013. Suspended sediment concentrations varied considerably in response to rainfall. Using these data, estimates of soil loss from fields ranged from 0.3 to 0.6t/ha/yr (Figure 2). There was insufficient variation on soil and nutrient maps to stimulate change in farmers' fertiliser application practice. Using remote sensing NDVI data, we recorded variable crop cover. This was associated with soil compaction mainly on the field headlands (Figure 3). Increasing densities of the competetive grass weed blackgrass (*Alopecuris myosoides*) associated mainly with compacted and waterlogged soils have resulted in increased herbicide costs and to elevated herbicide concentrations in watercourese that are used for drinking water supply. Oilseed rape break crops enable blackgrass to be partically controlled but increase slug pressure on following crops, and the use of the molluscicide, Metaldehyde which exceeds statutory limits for drinking water supply. Farmers have identified a need to better understand soil and nutrient management in order to maintain the profitability of their businesses, enhance resilience to climate change, and reduce environmental impacts.

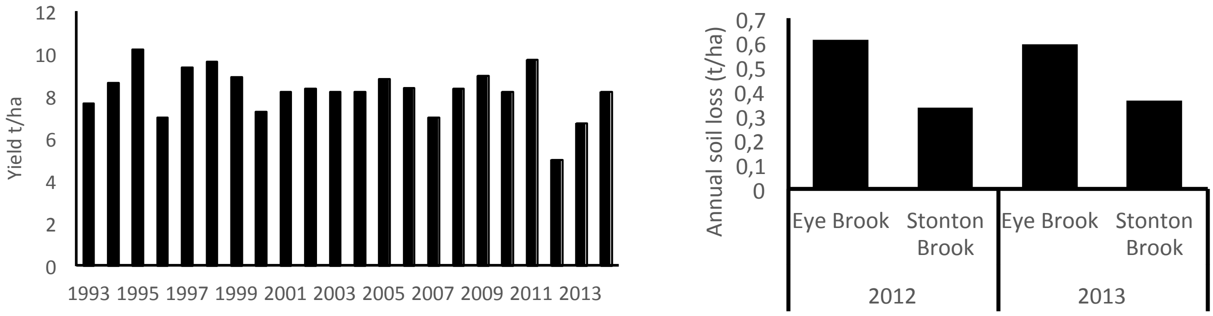


Fig. 2. Winter wheat yields at Loddington (left), estimated soil loss from ‘treatment’ catchments (right)

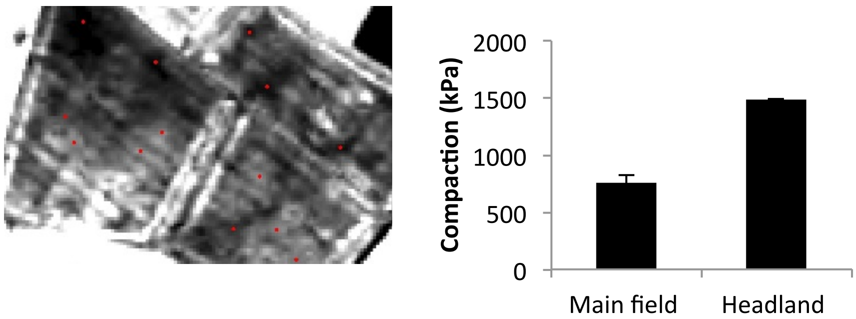


Figure 3. NDVI image showing variable winter wheat establishment (left), compaction in field and headland (right)

4 Conclusions

While WFD policy is concerned mainly with nutrient and pesticide concentrations in water and ecological impacts of sediment, issues that are of greater concerne for farmers are soil function and crop performance, economically efficient use of nutrients and availability of a range of grass weed control methods including herbicides. While these farm-scale objectives are not economically compatible with national objectives for increased food production, we can identify synergies between WFD and farming objectives that can guide the adaptation of current farming systems to deliver public and private benefits.

Acknowledgements. Funding has been provided by the Environment Agency, Chemicals Regulation Directorate, Syngenta, and Catchment Sensitive Farming.

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Integrating agricultural and water policies for more sustainable crop production in arid Northwestern China

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1 Introduction

Overexploitation of water resources constitutes a major threat to future global food security. In arid Northwestern China water consumption for agricultural production has increased tremendously over the last decades. This not only led to the degradation of natural ecosystems, but also increases competition among different anthropogenic water users severely endangering a sustainable development in ecological, economic and social terms. In the Aksu-Tarim Region water for crop production accounts for far more than 90% of total human water use (Feike *et al.*, 2015). The projected increase in domestic and industrial water demand, the increasing importance of ecosystem restoration, as well as the increasing variability of fresh water supply due to climate change exert strong pressure on regional authorities to reduce agricultural water consumption and improve water use efficiency. Therefore it is of vital importance to provide scientific evidence to policy makers regarding suitability of regional policies aiming at water saving in crop production. Hence, the present study tests the effectiveness and efficiency of different agricultural water policies. As the implementation of such policies entails a certain risk of decreasing agricultural production and rural incomes, as observed for other regions in China by Chen *et al.* (2014), supporting agricultural policies are tested in combination, aiming at stable food and fiber provisioning as well as stable farmers' incomes.

2 Materials and Methods

Building on a detailed primary crop management data set of 256 farm households from selected regions along Aksu and Tarim River a positive mathematical programming (PMP) model was developed based on the approach presented by Röhm (2001) and Röhm and Dabbert (2003). The regional agro-economic supply model simulates crop production and respective water demand for irrigated crops in the study region. The model was calibrated for the 12 sub-regions located in the direct vicinity of Aksu and Tarim River. The model is based on the primary crop management data, supplemented by secondary data on production area and yields of all relevant crops (cotton, wheat, maize and melon). A system of non-linear gross margin functions optimizes resource allocation aiming at maximized profits (total gross margin). The non-linear supply model calibrated by PMP method ensures "smooth" model behavior and hence avoids over-specialization.

The empirically observed status quo conditions serve as model baseline, where different policy simulation scenarios are applied. The tested policies include three alternative policy instruments aiming at water saving, i) (increase of the existing) taxation of each unit of irrigated land (TAX), ii) restriction of the quantity of water to a defined share of the quantity available under baseline conditions (QUOTA), and iii) pricing of each unit volume of water demanded for irrigation (PRICE).

In a second step those water policies are tested in combination with agricultural policies, which aim at retaining food and fiber supply and avoid dramatic declines in farmers' income. Those agricultural policies include the subsidization of drip irrigation technology for cotton production (COTTON), as well as the subsidization of the production of wheat and maize (CEREAL). All five instruments were tested at different intensities to determine promising ranges and combinations of instruments. The present paper only presents the results of the entire study region, which are aggregated from the results of the 12 sub-regions.

3 Results and Discussion

The efficiencies of the three water saving policies are compared by their marginal cost curves (Fig. 1), which represent the marginal costs of the next realized unit of saved resource, i.e. water. Comparability of the three policy instruments is realized by displaying the quantity of saved water as units of conserved irrigated crop land. Fig. 1 shows that for intended water savings of up to 18% the instrument PRICE is most efficient, while QUOTA constitutes the least efficient. For water savings of more than 18% the instrument TAX features the lowest abatement costs. However, TAX does not make use of potential comparative advantages of water efficient vs. water inefficient crops, and is thus not considered in the multiple policy instrument analysis.

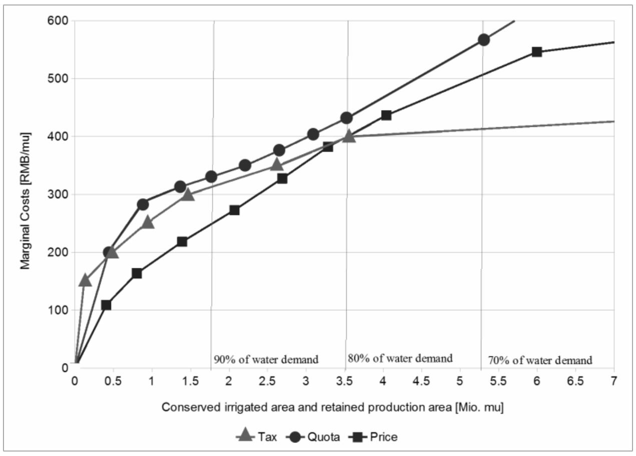

Fig. 1. Marginal abatement cost curves for the three tested water policy instruments. Note: 1 mu irrigated area represents 546 m^3 water; 1 mu = 0.067 ha; 1 RMB = 0.12 Euro

The combined effects of the water policy instruments QUOTA and PRICE with the agricultural policy instruments COTTON and CEREAL at different levels are displayed in Table 1. The P 0.55 and Q 90% levels aim at reducing overall water consumption for crop production by 10%, while the P 0.85 and Q 80% aim for a reduction by 20%. In combination with the subsidies for cotton and cereal production a reduction in water consumption by 10% and 20% results in a decrease in cotton production by 6% and 15%, an increase in cereal production by 17% and 4%, and an agricultural income deficit by 6% and 13%, respectively.

Table 1. Effects of multiple instruments on the different policy objectives

Water price / quota Cotton drip subsidy Cereal subsidy	**RMB cmb^{-1} / % of BL RMB cmb^{-1} RMB cmb^{-1}**	**P 0.55 DS+250 CS+150**	**Q 90% DS+150 CS+150**	**P 0.85 DS+200 CS+150**	**Q 80% DS+250 CS+300**
Cotton production	% of BL	94	93	86	84
Cereals production	% of BL	117	117	106	103
Monetary balance	% of TGM	-6	-6	-12	-14

4 Conclusions

For the Northwestern Chinese Aksu-Tarim region certain differences in effectiveness and efficiency of alternative water policy instruments were revealed, with water pricing constituting the most cost-effective tool. However, to reduce the negative impacts of water policies on other policy goals, i.e. food security and agricultural incomes, a targeted subsidization of cereal production and drip irrigation technology is needed. The applied modeling approach provides plausible results in line with other studies, and the model reactions can be partially validated by empirical data. Future modeling may expand to consider economy wide aspects as well as potential crop productivity increases. Ongoing genetic improvement of seed material and especially the potential improvement of farmers' skills by training may boost crop productivity and related water use efficiencies. Therefore the effectiveness of the investment in farmers' training on crop water saving should be investigated in future modeling studies. Finally, the successful implementation of integrated water and agricultural policy measures demand close cooperation between different regional authorities, namely the agricultural and water resource bureaus as well as other relevant stakeholders.

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Farm type-specific adoption behaviour in sustainable soil nutrient management: the case of smallholder farms in Ioba province, Burkina Faso.

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1 Introduction

Sub-Saharan Africa has failed to ensure sufficient and sustainable food production (Food and Agriculture Organization [FAO] *et al.*, 2013), mainly as a result of soil nutrient depletion (Pimentel and Burgess, 2013). The persisting food insecurity and poverty, despite proven sustainable soil nutrient management (SNM) practices (Vlek *et al.*, 1997; Ingram *et al.*, 2008), denote the failure of policy intervention to leverage farm incentives to adopt SNM practices (Anley *et al.*, 2007). The main objective of this study was to analyse the farming system type-specific behaviour in the adoption and use of SNM practices in a semiarid region of Burkina Faso.

2 Materials and Methods

The study was conducted in Ioba Province, southwestern Burkina Faso. Based on soil degradation information, vegetation index (NDVI) and demographic data, three communes were selected. Six villages (i.e., two villages per commune) were chosen according to the two major soil types in each commune. We randomly sampled and surveyed 360 household-farms to obtain a multidimensional dataset, using the Sustainable Livelihood Framework (Sconnes, 1998) as a guide. Binary logistic regressions were used to analyse the determinants of mineral fertiliser use intensity, separate the adoption of mineral and organic fertilisers and combine mineral-organic fertiliser adoption at the plot level for different farming systems. Only maize plots were considered as it was the main food crop for which the farmers used most of the available fertilisers.

3 Results – Discussion

No multi-collinearity was found among explanatory variables (VIF < 0.5 and tolerance > 0.2). The Hosmer and Lemeshow test at 5% showed a good fit of the bi-logit models to the data. The calculated area under the receiver operating characteristic (ROC) curve was between 0.7 and 0.9, indicating that the models were good and excellent predictors of the outputs compared to chance.

Table 1. Adoption of mineral and organic fertilizers

Explanatory Variable		Adoption of mineral fertilizer				Adoption of organic fertilizer			
		Whole population	Farm type I	Farm type II	Farm type III	Whole population	Farm type I	Farm type II	Farm type III
Intercept		n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s
Cash		1.5E-05***	3.5E-05**	2.8E-05**	n.s	n.s	n.s	n.s	n.s
Remittance		n.s	9.9E-04**	n.s	n.s	1.3E-04*	n.s	n.s	n.s
Cereals		n.s	6.4**	-12.0***	n.s	-2.9**	n.s	n.s	n.s
Legum land		n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s
Cotton land		n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s
Irrigation		34**	73**	n.s	n.s	n.s	n.s	n.s	n.s
Livestock		0.6**	n.s	2.0**	n.s	n.s	0.46*	n.s	n.s
Size		0.2**	n.s	n.s	n.s	n.s	n.s	n.s	n.s
Age		n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s
Education		n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s
Training		n.s	n.s	1.3*	n.s	n.s	n.s	n.s	n.s
Traction		2.5*	n.s	16.5*	n.s	n.s	n.s	8.99*	n.s
Road Access		0.1***	n.s	n.s	n.s	n.s	0.09*	n.s	n.s
Hosmer and Lemeshow test	χ^2	13.2	18.2	4.7	4.4	6.2	4.42	4.49	4.5
	df	8	8	8	8	8	8	8	8
	p	0.12	0.02	0.786	0.8	0.6	0.82	0.8	0.8
% correct prediction		73.2	82.2	76.70	79.4	68.4	72.6	72.6	66.7
Area under ROC		0.8	0.9	0.9	0.9	0.7	0.8	0.7	0.8

Note:Symbols *, **, and *** indicate statistical significance at 10%, 5, and 1% respectively.n.s means not signifcant

The results (Table 1 and Fig. 1) showed that the variables identified as affecting factors in the whole population's adoption and use of fertilisers had different affecting patterns across farm types. Most of the variables were type-specific affecting factors, influencing only a particular farm type (e.g., livestock in Fig. 1a). A type-specific factor might also affect more than one farm type (but not all farm types) and have an aggregate effect on the whole population (e.g., training in Fig. 1a). A common affecting factor would influence the whole population, as well as all farm types. However, it might be an aggregated affecting factor and might have no significant effect on individual farm types (e.g., cash income and cereals in Fig. 1b). Furthermore, the amplitudes and signs (direction of the effect) of the variables' coefficients varied. These results revealed the existence of responsive heterogeneity of farms for the adoption and use of fertilisers. This difference in the farmers' adoption and use behaviour in sustainable SNM practices was driven by their livelihood characteristics.

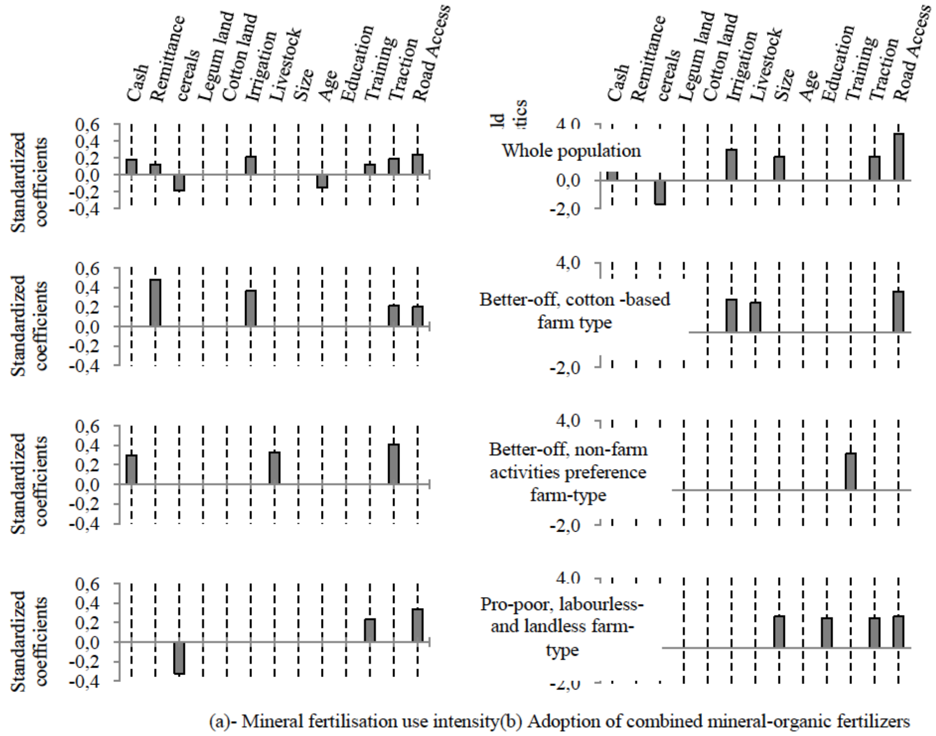

Fig 1. Determinants of mineral fertilizer use and adoption

4 Conclusions

The results generally match those of past studies on the determinants of fertiliser adoption and use (Anley *et al.*, 2007; Martey *et al.*, 2014). Our study additionally showed the existence of heterogeneity in the adoption behaviour and use of sustainable SNM practices. This implies that effective policy interventions promoting the adoption of SNM practices should be designed according to the farming system type for leveraging farm incentives to adopt SNM practices. Farm design studies also need to account for the farmers' behavioural heterogeneity. This study's results can be used for scaling-out research and serve as a framework for policy intervention and further studies in the region.

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A MODELING FRAMEWORK FOR DESIGNING AND ASSESSING MULTI-FUNCTIONAL AGRICULTURAL LANDSCAPES WITH SCENARIO ANALYSIS

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1 Introduction

In order to insure the provision of food and services by agriculture while limiting its negative impacts, innovative agricultural systems have to be designed. The design of such systems has shown some limits in addressing regional and global issues. For instance, at the field scale, some cropping systems may fail to reach the objectives defined at the regional scale due to the low scaling integration and the spatial heterogeneity in the region. Model-based prototyping of agricultural landscapes can allow the impact assessment at regional level of drivers that act at field, farm and regional levels. In order to ascertain whether a combination of levers can drive agriculture towards sustainability, we designed a modeling framework, to explore successive steps of scenario development and assessment with indicators. To this end we introduce an approach based on several types of scenarios.

2 Materials and Methods

The method is built to i) understand the potential levels of sustainability that can be reached by the cropping system mosaics and ii) gain knowledge on the potential levers of change of the cropping system mosaics (Fig. 1). The framework guides the assessment of the consequences of several types of scenario, with a regional bioeconomic model, on the organization of cropping systems. Indicators are used to assess the cropping systems externalities at regional scale. An iterative approach is presented to guide the use of the model with different phases (Fig. 1): scenarios are built in a pre-modeling phase; they are implemented in a modeling phase for visualizing their consequences on the cropping system mosaics; the post-modeling phase assesses the contribution of the cropping system mosaics to sustainable development.

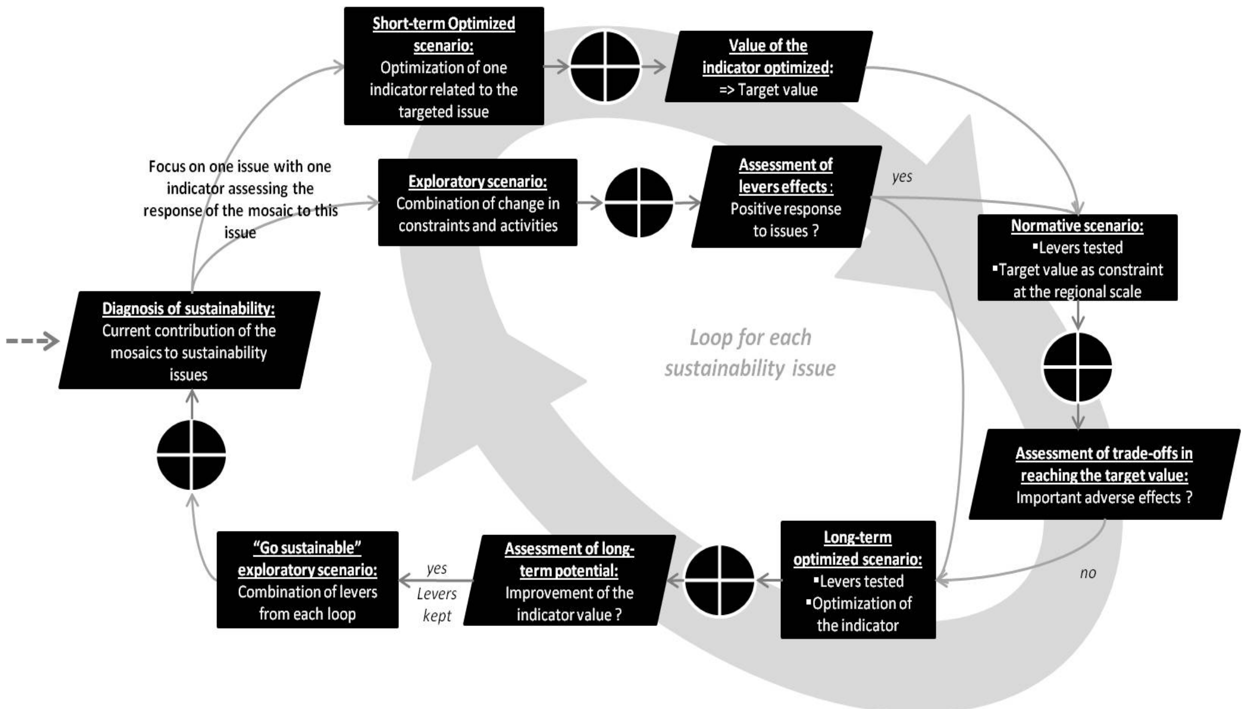

Fig.1. The modelling framework for building sustainable agricultural landscapes

We built our framework around the MOSAICA regional bioeconomic model (Chopin *et al.*, *submitted*). MOSAICA optimizes the overall farmer's utilities by allocating cropping systems to their spatially located plots. The allocation process of cropping systems to plots, recorded in a geographical database, is driven by several types of constraints or objectives implemented at different spatial scales among which biophysical, economic, structure constraints at field, farm, sub-regional or regional scales. The optimization of farmer's utilities or other variables of the system produce new agricultural landscapes that are assessed with a set of sustainability indicators.
In our framework, the MOSAICA model is used with four different types of scenario for prototyping agricultural landscapes for one specific goal (such as energy self-sufficiency). First, short-term optimized scenario provides a target value by optimizing one given sustainability indicator (e.g. the production of biomass for electricity). Secondly, an exploratory scenario combines several types of levers (economic, agronomic...) to reach the target value defined before (the overall farmer's revenue is maximized). Thirdly, normative scenario is introduced to assess whether or not the target can be reached with the levers from the exploratory scenario. Fourthly, a long-term optimized scenario is parameterized to assess the relevance of levers to improve the long-term potential of the system (by optimizing the production of biomass with the levers selected). The levers that improve the state of the system for each objective, (increase food production, employment...) are selected and combined in a last exploratory scenario called "Go sustainable" scenario to improve the overall response of agricultural landscapes to sustainable development.

3 Results – Discussion

Table 1. Results for the energy self-sufficiency objective with the different type of scenario

			Type of scenarios			
Sustainability objective	Indicator	Initial	**Short-term optimized**	**Exploratory**	**Normative**	**Long-term optimized**
Energy self-sufficiency	Potential production of electricity (MW)	30	52	56	56	93

We here present some results from the use of the framework in Guadeloupe, a French archipelago in the Caribbean for the energy self-sufficiency objective (Chopin *et al.*, *to be submitted*). The levers tested are the decrease of subsidies for sugar, the setting up of a biomass industry for electricity production and the addition of a crop energy activity for farmers. The response to the sustainability objective increases with levers (Table 1) that help achieve the objective of producing 56MW.yr^{-1} and also improve the potential of response of the landscape in long-term scenario to 93MW.yr^{-1}.

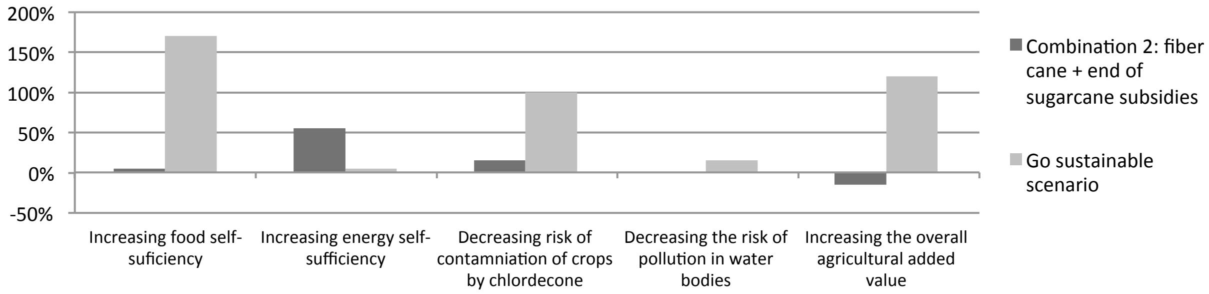

Fig. 2. Evolution of responses to sustainable issues compared to the initial situation

The "Go sustainable scenario" which combines all the relevant levers selected for each of the five objectives improves the system by increasing its contribution to each objective selected (Fig. 2). For instance, the response of the food self-sufficiency objective increased by 150% and the overall agricultural value doubled compared to the initial landscape due to the development of crop-gardening, in the south of Guadeloupe, and energy crops within the entire region.

4 Conclusions

The modeling framework guides the use of the regional model could be used in other regions to help identify the most appropriate levers to increase the response of agriculture to sustainable development. This holistic approach provides analysis of changes that occur at the regional, the farm and the field scale, and can highlight the evolution of externalities of cropping system mosaics in a quantitative and spatially explicit way.

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Crop-livestock farming systems in Australia: what levels of integration result in different benefits?

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1 Introduction

In Australian broadacre mixed farms, cropping and livestock enterprises are integrated to varying extents. The integration can range from the operation of otherwise separate activities within a single business through to tightly integrated systems in which legume pastures supply nitrogen, and weed and disease breaks, for crops and crop biomass provides a substantial proportion of the forage consumed by animals (Bell & Moore, 2012). Farmers' choices about whether and how to integrate crops and livestock will reflect a range of interacting objectives and constraints, including (i) matching production to land types with comparative advantage; (ii) exploiting resources derived from one enterprise in the other enterprise (e.g. nitrogen fixed by legume pastures or crops for forage); (iii) opportunities to allocate resources tactically between enterprises; and (iv) the need to maintain the soil resource in each paddock in the long term (Bell & Moore, 2012). We sought to elucidate the contribution of progressively greater levels of crop-livestock integration to each of these objectives by means of whole-farm biophysical simulation analysis.

2 Materials and Methods

Simulations of a representative mixed farm at Temora, Australia (Köppen climate Cfa) were constructed by linking the APSIM and GRAZPLAN biophysical models. The model configuration and modelled farm were similar to that in Moore (2014). Land resources were modelled as 3 soil types, one of which was non-arable (10% of farm area). Model runs were carried out with 6 different management systems that had successively greater levels of integration: (i) a cropping-only system involving rotations of wheat, canola and barley ("C"); (ii) a livestock-only system ("L") in which breeding ewes grazed a combination of perennial grass-legume, annual grass-legume and alfalfa pastures; (iii) a segregated mixed farming system ("S") in which the "C" and "L" management systems (54% and 46% of farm area) were allocated to the soil types better suited to each activity; (iv) a mixed farm with rotations of 3-5 year phases of legume-based pastures and grain cropson the better soil types ("R"); (v) a "strategically synchronised" mixed farm ("SS") in which the "R" management system was further integrated by allowing livestock to graze crop residues for a fixed period each summer and wheat crops during winter; and (vi) a "tactically synchronised" mixed farm ("ST") in which grazing of crop residues and dual-purpose crops (including canola) was both more frequent and more responsive to seasonal conditions. Stocking rates were adjusted so that the utilization rate of pastures was the same in all systems, but otherwise the enterprises in the modelled farms had similar levels of inputs. Farm gross margins were calculated using detrended historical price time series (updated from Bell & Moore 2011), and the downside financial risk of each farming system was measured using conditional value-at-risk based on the 20% of years with lowest gross margin. Simulated on-farm balances of greenhouse gases were calculated from the changes in soil C stocks, emissions of N_2O from soil and enteric methane using global warming potentials of 34 for methane and 298 for N_2O.

3 Results – Discussion

At Temora, a cropping-only farming system ("C") is more profitable on average than a livestock-only system ("L"), but the latter has lower risk (Bell & Moore 2011). The shift in expected farm gross margin as the system is changed from a naïvely allocated mixed farm to a "segregated" system ("M"→"S" in Figure 1a) shows that exploiting spatial variability in land resources is worth about $20 per farm hectare, and the segregated farming system has marginally less downside risk. The largest changes in profitability as the farm was increasingly integrated arise when crop-pasture rotations are introduced into the farming system (i.e. "S"→"R"); the rotational system captures more water (Figure 1b) and the yields of the wheat crops following alfalfa increase due to improved N supply. The value of production complementarities from integrated crop-livestock production in this region is well-recognised. However, the adoption of crop-pasture rotations also increases financial risk, owing to gaps in forage supply during transitions from crops to pastures and also due to occasional years where crop yields following alfalfa pastures are reduced due to lower water availability. Further integrating to a "synchronised" farming system ("SS") by allowing livestock to graze both crop residues in summer and growing crops in the winter, increases profit and reduces financial risk; however the main financial benefits arise from shifting from a "strategic" to a "tactical" approach to using crops as forage ("SS"→"ST"). As can be seen in Figure 2, the reason for this is that tactical grazing of cropping paddocks during February-April provides extra forage at the time of year when forageits supply is most limiting across the farm.

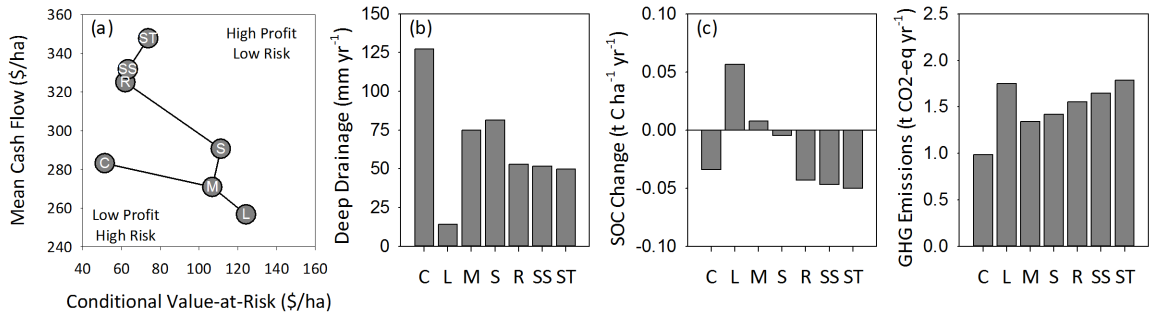

Fig. 1. (a) Relationship between downside risk (measured using the conditional value-at-risk of gross margin) and long-term average gross margin (AU$), (b) farm-scale deep drainage, (c) farm-scale rate of change in soil C stocks and (d) within-paddock greenhouse gas balance for a simulated crop-livestock farms at Temora that operate with successively increasing levels of crop-livestock integration. Symbols for the farming systems are given in the text apart from "M", which denotes a naïve mixture of the "L" and "C" systems with no differential allocation of land uses to soil types.

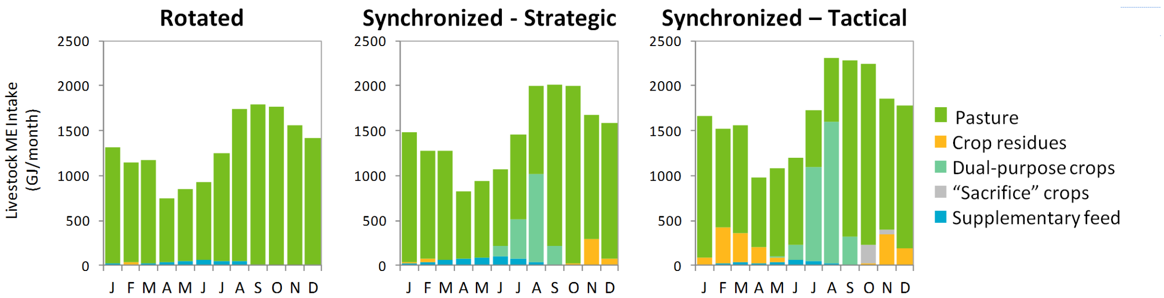

Fig. 2. Changes in the sources of livestock forage as a mixed crop-livestock farm at Temora, NSW is managed with successively greater levels of integration of crop and livestock enterprises.

The modelled livestock-only production system loses much less water as deep drainage than the cropping-only farming system (Figure 1b), and it retains more soil carbon even though its total net primary productivity is lower. Farming systems with crop-pasture rotations lose less water (Figure 1b) but lose more soil carbon (Figure 1c) than would be expected from the areas devoted to each enterprise: the deep-rooted alfalfa pasture phases capture water that is left behind by preceding annual crops, while the introduction of summer fallows between the pasture and cropping phases accelerates soil C decomposition. In-paddock net greenhouse gas emissions are higher for the livestock farming system due to a large contribution from enteric methane (Figure 1d). Each successive step toward crop-livestock integration increases in-paddock net greenhouse gas emissions, but for different reasons: while the GHG emissions increase from the separated to rotated farming system due to changes in the soil C balance, the further increases in in-paddock GHG emissions in the "SS" and then the "ST" systems are due to greater enteric methane from larger and more profitable flocks of sheep.

4 Conclusions

The functioning of integrated crop-livestock systems is notoriously difficult to understand owing to the number of biophysical interactions and the complexity of their management. The approach used here – analysing the differences between successive, smaller shifts in management – has given us insights into the advantages and disadvantages of crop-livestock integration of varying intensity that would not have been obtained had we simply compared single-enterprise and fully integrated farming systems. Environmental and resource management outcomes tended to differ among the levels of integration.

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Co-Designing Organic Residue Recycling Chains in Off-Balance Regions

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1 Introduction

An increasing number of (urbanizing) regions worldwide is increasingly out of balance, in terms of nutrient cycles and organic waste production and use. On the one hand, resulting land tenure and market mechanisms push farming systems of these regions to intensify. On the other hand, resulting social, regulatory and environmental constraints curb the potential for intensification through conventional practices. While crop farming systems of diminishing fertility remain largely dependent on fertilizer imports, organic waste flows out of animal farming systems – and other productive and consumptive systems – threaten ecosystems and socio-economic development. Synergetic connections between these systems, i.e. industrial symbiosis, carry the promise of unlocking development while increasing individual and overall resilience and sustainability.
The small and isolated territory of Réunion, with its fast growing population and standard of living, exemplifies such a region. The island imports large amounts of nutrients, be it to feed its population, its crops or its livestock. In the absence of significant nutrient exports the large structural excess keeps increasing. This hampers the island's development, while its agricultural sector remains largely dependent upon fertilizer imports. The agricultural recycling of raw livestock manure reaches the limit of its regulatory and practical capacity, while these unbalanced applications – with respect to crop needs – lead to very little fertilizer substitution. Beyond agriculture a range of other activities produce substantial amounts of organic waste, each with their own – and often contrasting – characteristics. Co-processing a propitious combination of waste sources may allow to elaborate organic or organo-mineral fertilizer and soil amendments with characteristics that meet both crop and farmer requirements. Within such an integrated waste management system cropping systems would thereby add a (waste) consumptive function to their productive functions. Far from a constraint, this carries the promise to increase their individual as well as the overall system's productive capacity. Designing such system changes calls for a science facilitated, both interdisciplinary and inter-sectorial, participatory process. We developed a method for co-designing realistic and accepted solutions and implemented it in Réunion in an attempt to kick-off an innovation process.

2 Method and Tools for the participatory design of recycling scenarios

The adoption of recycling "innovations" – even though the practice of Returning Organic Residues to Agricultural Land (RORAL) is as old as agriculture itself – by increasingly complex, integrated and globalized production systems is far from straightforward. Still more daunting is the definition of new practices adapted to the multiple (economic, social, societal and environmental) constraints of today's world. Wassenaar *et al.* (2014) detail the epistemological basis of interdisciplinary research exploring the potential for favoring adoption of RORAL in off-balance regions. The proposed problem-solving approach is invariably built around very specific intervention possibilities that favor adaptation and uptake (Hagmann *et al.*, 2002). Conventional technical science encompasses a systemic component in order to feed the co-design process with realistic, technically and agronomically valid ideas. Led by a „facilitator" social science group, the technical science group is then a constituent of the co-design process „following" its own technology, whereas other stakeholders" motivation to participate is that „plausible promise" (initially) made by the R&D team to solve a real (farming) problem(Douthwaite *et al.*, 2002). This implies the value-based choice by science of a technology to „follow", i.e. to catalyze change. Accepting negotiation theory as a basis for organizing the participatory efforts, as argued by Leeuwis (2000), it becomes clear that the „facilitator" research group has a strong interest in having „involved actor" RORAL scientists associated with them: they provide the facilitator (who according to Leeuwis (2000) is not a neutral figure but in need of an active strategy, resources and a power-base to forge agreements) with credibility, insights and the capacity to fill knowledge gaps.
We developed and tested a method favoring collective learning through participatory design exercises. The crop farming systems" demand driven, stepwise design process puts to work tools selected from among those developed for participatory research, as deemed appropriate to each individual step (e.g. problem trees, role playing games). The method comprises five steps: (1) establishing an initial, shared diagnostic of the current situation; (2) the exhaustive description of the characteristics of ideal fertilizer and soil amendment products for all potential uses followed by the analysis of their redundancy; (3) the formulation of hypothetical recycling chains manufacturing and distributing selected fertilizer/amendment products; (4) the combined and coupled representation of these production chains in development scenarios of the study region; (5) feasibility and sustainability assessments of the scenarios. Iterations among these latter steps will in many cases be required. This co-design process takes place at three distinct but

interacting levels of participation: at a "technical" level ad hoc working groups of coopted members elaborate proposals which then constitute the basis for a consultation process at a "practical" level composed of selected representatives of all ground level stakeholder groups. Emerging orientations and problems are then discussed at an "institutional" level by representatives mandated by their institution or company.

In addition to the participatory research tools, in particular steps 4 and 5 of the co-design process call for systems modeling in order to conceptualize the system, to build a common understanding among stakeholders, to identify leverage points for interventions, to analyze different scenarios, to form the basis of decision support systems, to assist in stakeholder negotiations, to identify systems performance indicators and to facilitate impact assessments (Sayer and Campbell, 2002).Multi-agent modeling allows capturing farm/plant/site level knowledge elicited in the process, as well as representing and analyzing – at regional scale – prospective scenarios that constitute the outcome of that process. Coupled to biophysical models and global databases, such a model also allows simulating economic and environmental consequences, at local level and beyond, that contribute to the provision of relevant information for stakeholders feeding back into the process.

3 Application to Réunion

A project team including all major stakeholders (e.g. the main waste producers, collectors and processors; fertilizer industry; the farmer council and the federation of cooperatives) was built around a coordinating science core, legitimate to perform that function as an impartial stakeholder. All were convinced to participate through the proposed conflict- avoiding shift of paradigm from a waste disposal logic in favor of an agricultural demand focused approach. At the "practical" level, representatives of 12 target groups have been invited to a series of 5 workshops from mid-2011 to early 2014. A broad range of institutions was convened to steering committee meetings presided by a local and a national government official. The initial plausible promise – which put substantial accent on soil amendments, some little conventional processing techniques and the potential of some controversial waste sources – has been seriously altered during the co-design process. Largely as a result of local topographic, land tenure, agricultural, economic, regulatory and know-how constraints, but also factors like mistrust, envisaged new resulting recycling chains mainly focus on the production of fairly concentrated fertilizers. Soil amendments would continue to be provided to a structurally small market by improved existing recycling chains (green waste compost and sugar cane filter cake). Fertilizers would result from the co-composting of complementary organic wastes (layer manure with vinasse; poultry litter with pig slurry) using ground municipal green waste as a structuring agent. While vegetable gardening would consume one of these co-composts directly, the majority of the production would supply a fertilizer plant where they would be dried, supplemented and pelletized. Model simulations suggest that resulting fertilizers could potentially satisfy a large share of the major fertilizers demands: the sugar cane and vegetable gardening sectors. But their combined purchasing and application costs would be close to that of mineral fertilizer and the adaptation of policy instruments is required for these recycling chains to be viable.

4 Conclusions

RORAL research does not claim to come up with the solutions alone. It typically generates knowledge and tools to help generate and assess integrated solutions to complex problems. The Réunion proof of concept shows that it takes more expertise and parties to be able to identify effective and acceptable solutions favouring local recycling of organic residues in agriculture, representing a gain in sustainability for the region concerned without harming any of its constituent parts. Although successful, the proof of concept also highlights the importance of a careful planning of the participatory process‟ rhythm and time span. The consolidated definition of broadly accepted scenarios signaled the end of the participatory research process, but the innovation process continues. Qualitropic, a business and research cluster around the island's bioeconomy, currently seeks to develop and accompany industrial projects. Several factors hinder the implementation of such projects, among which the absence of technical references of the envisaged products‟ agronomic efficiency. Although on-going, establishing such references requires fairly long-term experiments.

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The farming system component of European agricultural landscapes

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1 Introduction

Agricultural landscapes are the outcome of combined natural and human factors over time. This paper explores the scope of perceiving agricultural landscapes as specific patterns of farming systems and landscape elements in specific biophysical and administrative endowments. The focus is on the farming systems component of the agricultural landscapes by applying a typology of farming systems to the sample farms of the Farm Accountancy Data Network and scaling up the results to the landscape level for the territory of the European Union (EU). The farming system approach emphasises that agricultural landscapes result from the social praxis of the farmers and takes into account the scale, intensity and specialisation of the agricultural production. From farming system design point of view, the approach can be used to set targets for explorative designs at the farm level. From a policy point of view, the approach offers handles to implement policies that design agricultural landscapes by targeting the farming system pattern.

2 Materials and Methods

For the purpose of this paper, an agricultural landscape is understood as a distinct pattern of farming systems and landscape elements in a specific biophysical and administrative endowment: An agricultural landscape = f(C(t), R(t), S(t), FS(t), STR(t)). Where C is climate, R is the administrative region, S the soils, FS the farming systems, STR the landscape elements and (t) the time. The data used as input for the analyses stems from the integrated project System for Environmental and Agricultural Modelling; Linking Science and Society (SEAMLESS). Firstly, the data offers a spatial framework developed to delineate spatial units with relatively homogeneous conditions for farming (Hazeu *et al.*, 2010). Secondly, the data includes a typology of European farming systems including the three dimensions: a) the scale of production, b) the specialisation and land use and c) the intensity of farming (Andersen *et al.*, 2007). Finally, the data links the spatial framework and the typology of farming systems based on a constrained optimisation model matching farm attributes and spatial characteristics subject to consistency constraints (Kempen *et al.*, 2010). The integrated SEAMLESS database thus provides information on the share of the agricultural area of the spatial units managed by specific types of farming systems. The data can thus be used to map the farming component of the European agricultural landscapes, to describe the pattern of farming systems in each landscape and to calculate indicators of the spatial organisation of the farming systems. Spatial indicators are calculated for each agricultural landscape based on the habitat indicators from the BioBio project (biobio-indicator.org, 2012): The count of farming systems, the average size of land managed by the farming systems (farming systems patch size), the number of farming systems per 100 hectares (farming systems richness) and the evenness of the distribution of agricultural land between farming systems (farming systems diversity, Shannon index).

3 Results – Discussion

Tables 1 and 2 present selected results for four example landscapes from different parts of the European Union.

Table 1. Most important farming systems in four example landscapes and share of agricultural area (UAA) managed.

	Farming system	Share of UAA %
AL1	Large scale, medium intensity, arable/cereal	14.6
	Medium scale, low intensity, mixed farms	14.3
	Medium scale, medium intensity, arable/fallow	9.4
AL2	Large scale, medium intensity, arable/cereal	44.0
	Large scale, high intensity, mixed farms	21.0
	Large scale, high intensity, arable/cereal	5.7
AL3	Large scale, low intensity, sheep and goats	39.7
	Medium scale, low intensity, sheep and goats	27.9
	Large scale, medium intensity, arable/cereal	5.6
AL4	Medium scale, medium intensity, dairy cattle/permanent grass	29.9
	Small scale, high intensity, dairy cattle/permanent grass	27.5
	Medium scale, low intensity, beef and mixed cattle/permanent grass	10.9

AL1: South East France, AL2: Eastern Denmark. AL3: Eastern Scotland, AL4: Northern Austria

Table 2. The diversity of European agricultural landscapes based on the farming system component: Four example landscapes and EU25 average.

	Farming systems count No.	Farming systems patch size hectare	Farming systems richness No. systems per 100ha	Farming systems diversity Shannon index
AL1	38	2 440	0.041	2.8
AL2	36	12 991	0.008	2.0
AL3	32	19 405	0.005	1.9
AL4	17	549	0.180	1.9
EU25	27	1 297	0.161	2.2

The selected results give a first impression of the diversity of the agricultural landscapes of EU25 regarding farming systems present and the spatial organisation of the systems in the landscape. However, this is only a very small fraction of the information available. The farming system approach provides a link to the agricultural statistics in FADN with a large number of variables on farm structure, land management and economics of the farming systems. Furthermore, the spatial allocation to the landscape level enables linkages to information on soil and climate as well as on the socio-economic conditions for farming.

Rizzo *et al.*, 2013 suggested improving the farming system design process by adding a landscape approach. The approach and results presented above provides a landscape approach to farming design in two ways: Firstly, in diverse landscapes the pattern of agricultural systems is equally important as the design of the individual systems. An additional landscape layer in farming system design focusing on the overall pattern of agricultural systems and the compatibility of different farming systems in the specific landscapes could provide a tool for top-down management of agricultural landscapes. For monitoring changes in agricultural landscapes, the farming system component is, together with the landscape elements, the most volatile factor. Using indicators about the farming systems thus enhance the options for detecting changes at an early stage. The detailed description of the farming system pattern also facilitates a discussion of farming systems contributing to the character of the agricultural landscape versus invasive farming systems. In a broader policy perspective, the understanding of the pattern of agricultural systems as a decisive factor in the making of agricultural landscapes enhances the possibilities to identify valuable agricultural landscapes. Furthermore, it provides a handle, i.e. farming systems, for targeting policies aimed at preserving and improving the agricultural landscapes as a public good. Relevant policy issues are for example High Nature Value farming and greening measures targeting the farming system level. Secondly, the detailed information on the pattern of farming systems at the landscape level provides additional input to the design process at the farm level. On the one hand, it will be possible to see the individual farming system in a broader context and to address the contribution of the re-designed system to improvement or maintenance of the agricultural landscape. On the other hand, it will be possible to systematically use the information on agricultural systems within the same agricultural landscape to optimise the environmental and economic performance of the farming system in the design process. Or it will be possible to use the information to set targets for explorative approaches that goes beyond the present farming system.

4 Conclusions

The pattern of farming systems is an important factor the constitution and functioning of agricultural landscapes. The method presented in the paper shows that the farming system component can be mapped and be used to describe the characteristics and the spatial organisation of the agricultural landscapes. From farming systems design point of view, the presented approach provides handles to set targets for explorative approaches in the design process at the farm level. Furthermore, it provides options to link farming system design and design of agricultural landscapes in policy making targeting patterns of farming systems at the landscape level.

Acknowledgements. The paper is based on data from the SEAMLESS Association integrated database and includes aggregated data from EU-FADN - DG AGRI L-3 and JRC/MARS Data Base - EC – JRC.

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FARMING SYSTEM DYNAMICS AND THEIR DRIVERS IN MEDITERRANEAN LANDSCAPES: A CASE STUDY ON THE VAUCLUSE DEPARTMENT BASED ON AGRICULTURAL CENSUS DATA (PACA REGION, FRANCE)

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1 Introduction

Mediterranean agricultural landscape have undergone strong changes on the last decades, such as agricultural intensification in the most fertile plain and coastal areas, extensification on the internal hilly and low-productive zone, until marginalization and abandonment on the more remote regions (Nainggolan *et al.*, 2012; Cots-Folch *et al.*, 2009) These dynamics caused in some cases environmental impact and they can affect ecosystem services fulfilment (Garcia-Ruiz & Lana-Renault, 2011; Hill *et al.*, 2008). In most cases, these dynamics have been evaluated through land use change studies, using land cover as a proxy of agricultural systems.

In this work, we aim to implement a land system approach, combining land use and its management through various indicators in order to identify farming system trajectories occurring on the last 20 years and their drivers, to propose possible future evolution and alternative scenarios.

2 Materials and Methods

The applied methodology was structured on three main phases. The first one consisted on (1) the characterization of the existing farming systems on the study area through principal component analysis and cluster analysis, in order to create some farms' classes considering the main land use and management indicators. The exploited database is the national agricultural census at individual farm level, which is an exhaustive and temporally extended base on farm management, structure and practices. From this database, we extract the farms belonging to the Vaucluse department, obtaining a whole sampling of 7723 farms in 2000 (around 123000 ha) and 5850 farms in 2010 (around 113430 ha). The considered variables for the farming system classification were: percentage of each cropping system on the farm, percentage of irrigated crops, farm dimensions (cultivated area, UAA), presence of quality labels, livestock quantity, farm work units, farmers' age. The obtained classification was discussed with different stakeholders on the study area (i.e. producers associations, agricultural chamber) in order to validate it. Then, we carried out (2) an analysis of the recent trajectories on farming systems: the characterization of farming system has been realized for two time laps (2000 and 2010). This allowed tracing some farming system trajectories, identifying areas where different change processes took place, like intensification or specialization of agricultural system. Finally, (3) the detected trajectories will be related to a set of variables through spatial statistical models, going from agro-pedoclimatic indexes of feasibility for each crop, to the prices dynamics and the different agricultural and environmental policy applications. The objective is to identify possible driving factors of changes and to propose future evolutions of local farming systems and alternative scenarios. This last work phase is currently ongoing. The proposed drivers can be classified among five main categories: geographic (e.g. distance from routes or cities, distance to water sources), topographic (e.g. slope, exposition), agronomic (eco-climatic indices of feasibility for each crop), economic (e.g. cadastral value of the parcels, rentability of the crops), planning factors (e.g. existence of protected areas, building or non-building areas).

We applied the methodology on the Vaucluse department (PACA Region, France), which is a typical Mediterranean region characterized by a strong presence of perennial crops, such as vineyards and orchards (currently around 60% of the total UAA).

3 Results and discussion

From the cluster analysis, we obtained nine classes of farming systems in the study area: AOP vineyards, non AOP vineyards, aromatic crops farms, cereal farms, fodder crops and livestock farms, grapes associated with orchards or small percentage of vineyards, orchards, vegetables farms and nursery farms. Table 1 shows the average values of some relevant variables estimated for each class of farming system on 2010. The nine classes remain rather stable on the two observations (2000 and 2010), unless some tendency for concentration on the predominant crops for some farming systems.

Concerning the farming system changes, Fig.1a shows the amount of surfaces for each farming system on 2000 and 2010. The results show a relevant increase on AOP vineyards and the decrease of the less specialized and rentable farming systems, such as cereal cultivation and table grapes usually cultivated on the mountain areas, which progressively reduce their surface. A specific dynamics observed on the study area was the increase of the number and associated surface of the fodder and livestock farms. This corresponds to the new horse farms set up on the last few years in the region, associated to agritourism. In order to understand the farming system trajectories, a circular plot was produced starting from the contingency matrix for 2000 and 2010. The circular plot obtained is showed on Fig.1b. The observed trajectories have been classified in three main groups: (1) from non AOP vineyards to AOP vineyards, which can be considered as a specialization of the farming system; (2) from cereals, orchards or mixed farming systems to AOP vineyards, which in some cases can be considered as an intensification of the farming system; and (3) from cereal and orchards to fodder crops and livestock, which is a specific type of specialization for the study area, as previously specified.

Table 1. Average values of the variables estimated through the cluster analysis for each class of farming system.

Class	UAA (ha)	Work units	Livestock	Cereals (%)	Aromatic crops (%)	Fodder crops (%)	Vegetables (%)	AOP Vineyards (%)	Non AOP Vineyards (%)	Grapes (%)	Orchards (%)	Nursery (%)	Irrigation (%)
1	18	2226	0	4	0	1	1	79	2	2	3	1	4
2	9	1040	0	1	0	0	1	19	66	5	4	0	4
3	44	1435	3	10	59	8	2	8	0	0	4	0	5
4	36	1528	1	81	0	2	7	2	0	0	3	1	12
5	41	1320	93	10	0	80	2	2	0	0	4	0	18
6	11	2055	0	1	0	0	3	18	1	53	16	0	36
7	11	2489	0	1	0	0	2	6	0	1	83	0	40
8	7	2623	0	3	0	0	75	1	0	0	3	0	72
9	4	3492	0	1	0	0	1	2	0	0	1	93	81

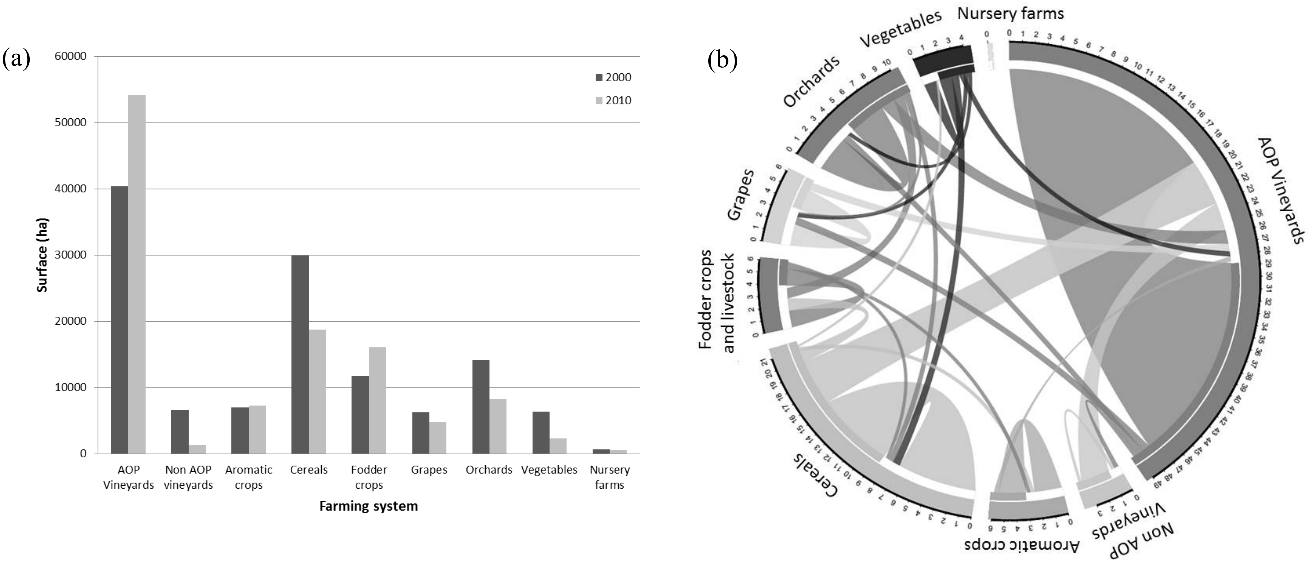

Fig. 1. (a) Changes in terms of surfaces from 2000 to 2010 for each farming system class (all farms) and (b) Circular plot of the farm trajectories on the study area (2500 farms).

4 Conclusions

The methodology applied in this study shows a good capacity to characterize the existing types of farming systems in the study area, and understand the dynamics currently acting. Next development of the study (currently ongoing) will be the test of some possible drivers in order to explain the detected trajectories. Moreover, the data processing will be extended to the 1988 census in order to have a greater time laps and some long terms trajectories. This will be the basis for a modeling process aimed to propose future possible scenarios for agricultural land use changes.

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Meta-analysis of yield gap explaining factors and opportunities for alternative data collection approaches

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1 Introduction

The yield gap concept is based on production ecological principles and can be estimated as the difference between a benchmark potential yield and the actual yield level, which indicates the potential to improve agricultural production in a specific location (van Ittersum *et al*., 2013).
Many studies have examined yield gaps at the scale of the region or agro-climatic zone, using aggregated data (e.g. Mueller *et al*., 2012; Neumann *et al*., 2010) and these are helpful in quantifying the scope for yield improvements in a broad sense (Oliver & Robertson, 2013). Estimating the yield gap is the first step, but especially relevant is to reveal the underlying explanatory factors contributing to the yield gap. As decisions are made by farmers, farm level yield gap analysis specifically contributes to better understanding, and provides entry points to increase production levels in a specific farming system. However, explaining the yield gap at the farm or field level is often constrained by the lack of necessary data; obtaining information about farm management, crop management, farm and farmers characteristics for a large number of farms is costly and time-consuming. The main objective of this research was to assess data availability for yield gap analysis, and to identify the most often considered and explaining crop yield gap factors. In addition, opportunities for bottom-up data collection approaches like crowdsourcing have been assessed for collecting the identified most often explaining factors of yield gaps.

2 Materials and Methods

As part of this research, a meta-analysis of different yield gap studies (50 scientific articles) has been performed. A detailed literature search of yield gap studies was conducted and factors considered and explained the yield gap in each of the 50 selected studies were identified. The identified factors were compiled and included into a database under four main categories (management, edaphic, farm characteristics and socio-economic). In total 270 records with unique identifiers (IDs) were included into the data base and used for subsequent analysis. One record is a unique combination of location, crop, year, benchmark yield estimation method and yield gap explanatory method. Prior to the meta-analysis, factors in the main categories were further grouped into their respective sub-groups (e.g., for the management category resulting in 7 sub-groups like fertilization, planting, etc.). By using the compiled information, the most often considered and explaining factors of the yield gap were identified based on the percentage of unique records in the database. Besides a global comparison of yield gap explaining factors, differences between continents and crops were also analysed.

3 Results – Discussion

Most yield gap studies are performed in Africa and Asia, and focus on rice, wheat and maize (Table 1). In general, management and edaphic factors are more often considered to explain the yield gap compared to farm characteristics and socio-economic factors (Fig. 1). However, when considered, both farm characteristics and socio-economic factors often explain the yield gap. Fertilization and soil fertility factors are the most often considered management and edaphic factors. In the fertilization group, factors related to quantity (e.g., N fertilizer quantity) are more often considered compared to factors related to timing (e.g., N fertilizer timing). However, when considered, timing explains the yield gap more often. At the global level, in general explaining percentage for edaphic factors is lower compared to other categories. For specific continents this may be different; in Africa for example the relevance of the edaphic category to explain yield gaps is larger.
Explaining factors clearly vary between continents and crops. For example, while soil fertility is considered relatively often both in Africa and Asia, it is often explaining in Africa, but not in Asia. Looking at crop specific yield gap explaining factors; fertilization, land preparation and crop protection factors often explain the rice yield gap in Africa, whereas crop characteristics and planting factors explain the rice yield gap in Europe. Fertilization, crop characteristics and planting explain maize yield gap in Africa, whereas fertilization, crop characteristics and irrigation often explain maize yield gap in Asia.
Although the data included in yield gap analysis depend on the objective, knowledge of explaining factors, and method data availability is a major limiting factor. Alternative bottom-up data collection approaches (e.g. crowdsourcing) can be used to overcome this and improve yield gap analysis. Farmers communities could be motivated

to provide data on relevant factors including the timing aspect while receiving advice for improvement of crop management in return.

Table 1:Summary of the studies included into the database

Type of crop	*Studies included*	*No. of studies per continent*						
		Africa	Asia	Europe	Global	N. America	S. America	Australia
Rice	18	7	7	2	2	-	-	-
Wheat	14	-	4	3	2	2	1	2
Maize	17	4	6	1	2	3	1	-
Soybean	4	-	2	-	1	-	1	-
Cassava	2	1	1	-	-	-	-	-
Banana	2	2	-	-	-	-	-	-
Others[1]	8							

1: Millet, Tomato, Peanut, Quinoa, Sunflower, Sugarcane, Mango and Potato

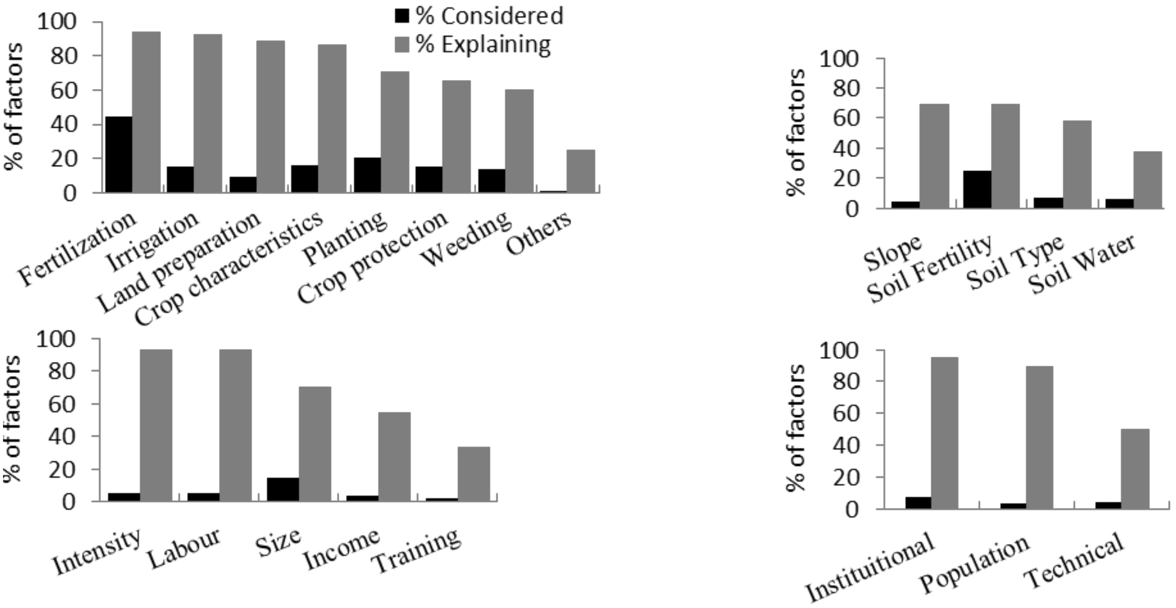

Fig.1. Percentage of considered and explaining factors across all studies for management (a), edaphic (b), farm characteristics (c) and socio-economic (d) sequenced based on explaining percentage

4 Conclusions

• Most yield gap analysis studies concentrate on considering factors from one or two categories (Fig.1). The reason for the less consideration of a specific factor for explaining the yield gap might be lack of availability of data. This information gap could be filled by using ***bottom-up data collection approaches like crowdsourcing*** which might help to collect more of the explanatory factors at the farm level.

• Information related to quantity (e.g. N fertilizer quantity, irrigation amount and no. of weeding operations) is more often collected than timing (e.g. N fertilizer timing, irrigation timing and timing of weeding). However, it would be important that data on timing is also collected. Crowdsourcing based methods (e.g. farmers send timing information via SMS) could be a good way to acquire real-time information about timing of management activities.

• The results of this study show that biophysical factors were most often considered compared to farm characteristics and socio-economic factors. However, when considered both farm characteristics and socio- economic factors often explain the yield gap; thus future yield gap studies might need to collect and consider farm characteristics and socio-economic factors to explain the yield gap as well.

• Explaining factors are clearly spatial explicit and thus region specific approaches for data acquisition could be considered by making a selection of relevant factors region or crop specific.

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Sustainable extensification—breathing new life into Africa's sleeping giant

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1 Introduction

The World Bank's 2009 study "Awakening Africa's Sleeping Giant" highlights the potential of the West-African Guinea Savannah zone for improved agricultural production due to its favorable agroecology and land availability. In the Guinea Savannah areas of Southern Mali, while research has focused on intensifying agricultural production, yields for major crops have stagnated over the past 20 years (Foltz *et al.* 2012). We used a simple farm model to analyze intensification scenarios and their effects on livelihood indicators to understand what incentives farmers have for intensifying or expanding crop production.

Most modeling studies use a few case study or representative farms to explore detailed scenarios of presumed future conditions. The complex and data-demanding nature of such models necessarily reduces the number of farms and scenarios considered. We instead limited the scenario complexity and information required for each farm in order to consider whole farm populations and wide ranging scenarios, of which one is presented here. This allows us to define a solution space: the range of plausible outcomes under a set of explicit assumptions.

2 Materials and Methods

The study area consists of three villages (Sibirila, Dieba, and Flola) in the district of Bougouni, region of Sikasso, in the southern part of Mali. Populations range from 575 to 1159 per village. These villages are in the Guinea Savannah zone, with an average annual rainfall of about 1200 mm falling between the months of May and October. This area forms part of the action zone of the Compagnie Malienne pour le Développement du Textile (CMDT), which provides inputs for cotton and maize on credit.

For the purpose of this study, a household was defined as "a group of people who manage land together." Because Malian farm families are often multi-generational and polygamous, these households range greatly in size, from three to 86 in this population. Farm characterization was based on simple farm characteristics including family size and land allocations by crop. This information was collected for all 109 farms in the study villages in 2013 with assistance from the CMDT. Scenarios were developed using yield information from two sources: first, the Africa RISING Mali Baseline Survey (ARBES), conducted in 2014 in 8 villages in the district of Bougouni including the study villages, and second, a household characterization survey covering two of the three study villages. Data from this second survey was also used to calculate input use and associated costs, crop price information, and proportions of each crop used or sold. Using this data we performed a scenario analysis of yield gap narrowing for each farm. We first characterized the current baseline using data on crop area allocations for the population of households, multiplied by median yields. Then we examined a scenario using the same crop area allocations, but increasing yields of three major crops—cotton, maize, and groundnut—to their 90th percentile values. For each scenario we calculated total farm production, food self-sufficiency in terms of calories produced per adult equivalent, and gross margins, also per adult equivalent. To calculate gross margins we used prices at harvest for grain produced and costs for purchased inputs including fertilizers and pesticides. We performed these calculations first based on total production and then based on the reported proportions sold. Food self-sufficiency scores were based on the median proportion of each crop consumed.

3 Results - Discussion

Crop production in the study area is diverse, as seen in Figure 1. Cotton and groundnut are the key crops for household income, while maize is a staple food crop. The relative area contributions of these crops vary with farm size: the contribution of groundnut is relatively more important for very small and very large farms than for mid-sized ones. Larger farms tend to grow a greater variety of crops, while small farms tend to devote their limited available land to cotton, maize, and groundnut. Those farmers who do not grow cotton tend to grow more sorghum and less maize, as sorghum, while its yields are lower, is less dependent on external inputs than maize.

Of the 109 households in our dataset, 35% (38 households) did not satisfy their calorie requirements from the median consumed fraction of farm production, while 83% satisfied at least 80% of their requirements. Varying the percentage of crops sold only changed the food self-sufficiency status of 3 households. While the majority of food-deficient households are small families with small amounts of land, there are also a few farms with large areas and very large families, resulting in small land area per capita. Gross margins for crop production are generally low. Based on the

median percentages sold, and with median yields, the total annual income from crop production averages only 79 USD per active household member per year (ranging from USD -35 to USD 460). Hence, for all but a few households, income is well below the extreme poverty threshold of USD 1.25/day. When food consumed by the household is included, annual incomes range from 31 to 537 USD per active member, with a mean of 203 USD.
The near-term best-case scenario of increasing productivity of the three key crops from median to 90th percentile yields entails a productivity improvement from 486 to 1020 kg ha^{-1} for groundnut, from 1600 to 2530 kg ha^{-1} for maize and from 930 to 1530 kg ha^{-1} for cotton. In this case, 19 households show a substantial improvement in food self-sufficiency, moving from less than 90% food self-sufficient to over 100%. Only 9 households remain deficient in calories with current consumption patterns. Income from crops ranges from USD -19 to USD 941 (mean USD 186) when considering only the sold fraction, and USD 38 to 1102 (mean 358) when including all production (Figure 2).

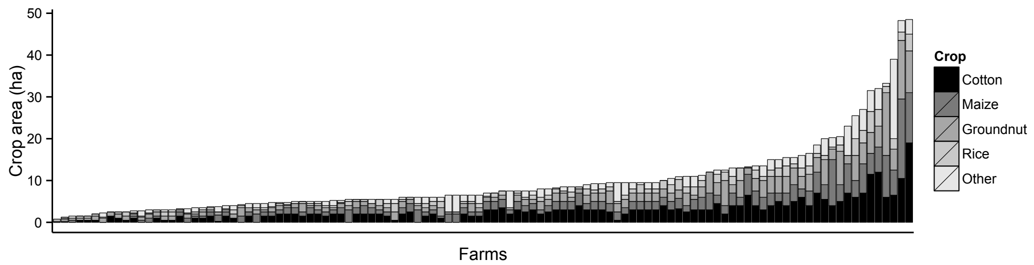

Fig. 1. Crop area allocations for 109 farms in three villages in Bougouni district in southern Mali. Other crops include sorghum, millet, fonio, and cowpea

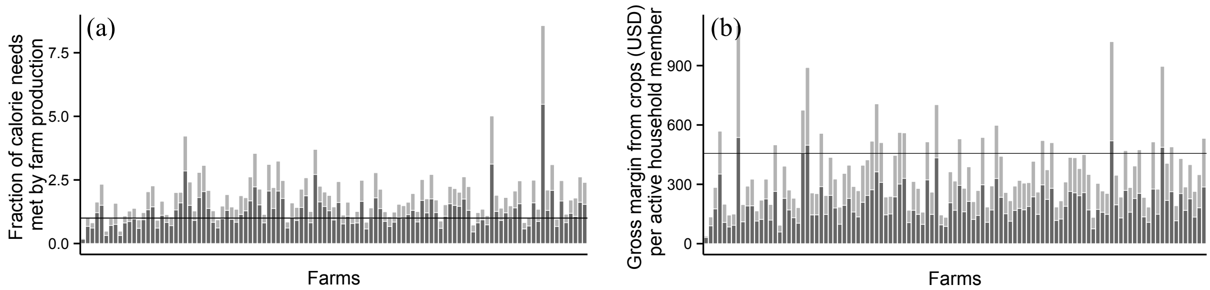

Fig. 2. Food self-sufficiency (a) and gross margin from crops when including all production (b) for 109 farms in three villages in Bougouni district in southern Mali. Dark bars are at 50th percentile yields for all crops, and light bars at 90th percentile yields for cotton, maize, and groundnut. In (a) the horizontal line represents full food self-sufficiency, while in (b) it represents the USD 1.25/day limit for extreme poverty. Farms are ranked from smallest to largest as in Figure 1.

4 Conclusions

From this analysis we can see that there are limited incentives for farmers to intensify within their current crop production systems. For some farmers, increasing productivity has a significant impact on their food self-sufficiency status, and thus may be attractive. However, for those who are already food self-sufficient, even if they achieve near-highest farmer yields for the area they are unlikely to move out of extreme poverty by relying on income from crop production. Larger changes such as dramatic yield jumps, changes in price and cost structure, or reducing labor constraints so as to allow for expansion of crop production area will be needed in order to substantially improve farmer livelihoods through crop production.

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Faming systems analysis and land policy: The case of the *Office du Niger* area in Mali

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1 Introduction

Since the 2000s, the Government of Mali has allocated large tracts of land in the *Office du Niger* area to new investors (Cotula *et al.*, 2009; Hertzog *et al.*, 2012). Up to now, the irrigated area there has been cropped by family farmers almost exclusively (Bélières *et al.*, 2011). Part of the family farmers asked to be recognized as investors by paying an annual contribution to an investment fund aimed at financing new irrigation facilities for family farmers (SEXAGON, 2010). This paper uses the concept of farming system to analyze (i) the conditions under which such a proposal could be feasible from an economic viewpoint and (ii) various scenarios regarding such an alternative land policy combined with a credit policy.

2 Materials and Methods

Drawing on Chombart de Lauwe and Poitevin (1957), we conceived a farming system as the combination of production factors and production activities on a farm. We used this definition in a field survey carried out in 2011 with 380 family farm managers living in 19 villages spread over 5 sectors of the *Office du Niger* area. This survey relied mainly on a questionnaire including both closed-ended and open-ended questions, and aiming to analyse the agricultural activities carried out for the whole family under the responsibility of the family head, thus excluding agricultural activities whose incomes accrue to sub-groups or individuals within the family (Ancey, 1975; Gafsi *et al.*, 2007).
Each of the 380 interviews produced detailed technical and economic information on farm land, labour, equipment, buildings, crops management, livestock management, as well as utilizations of the farm produce (own-consumption, sale, seed reserve...). Some of the data thus collected are numerical and constitute a base of approximately 140,000 data. Others are qualitative and relate primarily to the reasons that farmers allege to explain their practices.
Twelve categories of farming system were distinguished according to the combination of equipment type (3 types: manual, animal-drawn, motorized) and cropping activities type (4 types: wet-season rice only, wet-season rice and dry-season rice, wet-season rice and dry-season vegetables, wet-season rice and dry-season rice and dry-season vegetables).
Peasant families are complex entities in this area: they can include between 1 and 10 households, each having between 1 and 4 maternal cells: we call maternal cell the group formed by a mother and her children. The collected data led to distinguish eight family types according to the number of maternal cells: from 1 to 8. For each farming system category cum family type, we developed an empirical descriptive model representing the variation of the net added-value according to the area cultivated by the family, for three added-value levels: low (20th percentile of our sample), median and high (80th percentile of our sample) (Roudart, 2001) (Fig. 1).

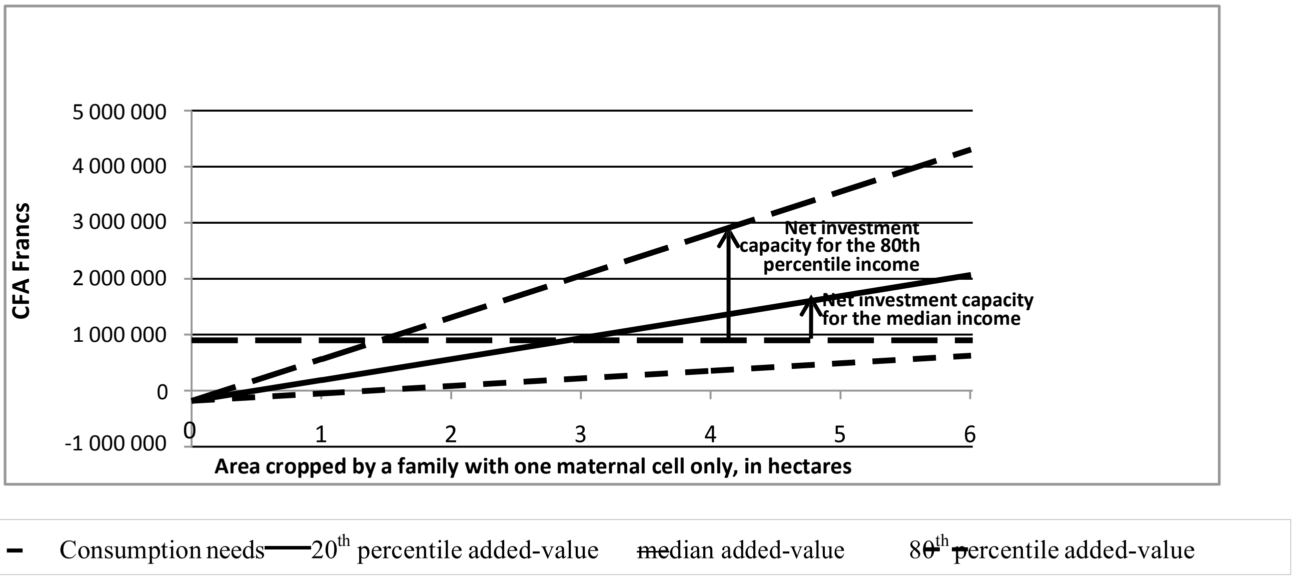

Fig. 1. Family Farm Net Added-Value and Family Consumption Needs Depending on the Cropped Area

3 Discussion

i) Conditions of economic feasibility of the land policy proposal from the SEXAGON

The analysis of the models shows that family farms can contribute to land investments under several conditions: 1) have an animal-drawn equipment at least (which excludes farms with manual tools only); 2) perform at least one dry-season crop in addition to wet-season rice (which requires access to sufficient irrigation water in the dry season); 3) have irrigated areas close to the maximum cultivable by the family labor. Under these conditions, the land contribution can range from 50,000 to 75,000 CFA Francs/ha/year, while leaving room for other investments (Dave *et al.*, 2012).

ii) Various scenarios of land and credit policies

Based on previous analyses, one can test several scenarios of irrigated land allocation policycum credit policy. The scenario 0 corresponds to the situation in 2010. All other scenarios assume that the proportions of family types and of farming system categories remain the same as in 2010, and that the dry-season irrigated area remains the same as in 2010:indeed, during this season, present water withdrawals for irrigation of the *Office du Niger* area already barely enable to maintain a proper flow for downstream populations in years of average rainfall (Schüttrumpf & Bokkers, 2008). Scenarios 1, 2 and 3 rely on the assumption that the irrigated area is extended to nearly 134,000 ha in the wet season (against 86,000 ha in 2010), which is the maximum area considering the current carrying capacity of primary irrigation canals (Sangaré, 2010). The scenarios 1a, 2a and 3a add to scenarios 1, 2 and 3 the hypothesis that a credit policy to purchase inputs allows all farmers to achieve wet-season rice and dry-season rice yields equal to the 80th percentile yields achieved in 2010. Finally, the scenarios 4 and 4a assume that 100% of family farms in 2010 reach their maximum area given their family labor. This implies an enlargement of primary irrigation canals but it remains consistent with several estimates of the irrigable area in the wet season (Couture *et al.*, 2002).

Table 1. Impacts of various land and credit policies scenarios in the *Office du Niger* area

	Scenario 0	Scenario 1	Scenario 1a	Scenario 2	Scenario 2a	Scenario 3	Scenario 3a	Scenario 4	Scenario 4a
	Baseline situation in 2010	Farm areas as in 2010		Maximum areas for part of the farms, given family labor in 2010		Maximum areas for part of the farms, assuming that family labor is maximum		Maximum areas for 100% of farms, given family labor in 2010	
Total cropped area (ha)	86,000	134,000	134,000	132,532	132,532	134,785	134,785	211,263	211,263
Number of family farms	22,500	35,000	35,000	22,500	22,500	22,500	22,500	22,500	22,500
Number of people living in farms	363,870	566,021	566,021	363,870	363,870	363,870	363,870	363,870	363,870
Rice production (t)	332,288	480,005	612,208	503,200	631,045	511,173	642,372	773,461	961,370
Rice own-consumption+ seeds (t)	101,884	158,486	158,486	101,884	101,884	101,884	101,884	101,884	101,884
Rice tradable surplus (t)	230,405	321,520	453,722	401,316	529,161	409,290	540,488	671,577	859,486

Scenario 1 maximizes rice own-consumption. With almost the same total area, the same farming systems and the same yields, scenario 3 maximizes rice production and tradable surplus.

4 Conclusions

A policy of investment in irrigation facilities and of allocation of irrigated land to family farmers, combined with a credit policy for the purchase of inputs, could lead Mali to a situation close to grain self-sufficiency, and even to a grain surplus.

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Land pressure and agrarian mutation, spatial modelling of farming systems evolution from plot to regional scale in West Burkina Faso

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1 Introduction

The cotton region of West Burkina Faso has seen notable transformations these last two decades. In the 70's, the arrival and rapid extension of a cash crop, cotton, has led to a new agrarian organization, with new cropping practices and social patterns. At the same time, the development of the plough has permitted to increase the cultivated surfaces. Those mutations have been enhanced by the huge population increase since the 90's, principal driver of the cultivated area expansion at the expense of forest. The last 20 years have seen the progressive disappearance of fallows, the increase of livestock and the lack of fodder for all animals. The low lands, that were used to water the herds, have been colonized by crops, causing conflicts and bringing about the departure of many breeders. A good understanding of these mutations is required to guide the establishment of adapted public policies. However, the analysis of agricultural mutations and production trends faces important scale issues. Agrarian changes are the result of interacting processes occurring at different scales, which raises the issue of documenting the main trends without distorting the information when trying to upscale or downscale it. The dynamics at plot level are linked to cropping practices, whereas farmer strategy is made at the farm scale. Public policies, the evolution of food prices, and farmer organization will have an influence at the regional scale. Thus a multi-scalar approach is necessary to understand and monitor those dynamics, which takes into account the determinant processes (Veldkamp & Lambin, 2001; Verburg *et al*., 2013). In this study we experiment an approach integrating a crop model (Sarra-H: Baron *et al*., 2005) into a spatial dynamics modelling environment (Ocelet: Degenne *et al*., 2010) to analyse the main processes occurring in an area representative of the cotton region of West Burkina Faso during these last 15 years.

2 Materials and Methods

The study area covers about 6500 km² and is located in the Tuy province in West Burkina Faso (Fig. 1). About 150 plots pertaining to five villages (Koumbia, Gombeledougou, Boni, Dimikuy, Founzan) were followed during the 2014 growing season. Data collected on the plots were used to calibrate the crop model and to evaluate yield spatial variability. At farm scale, based on existing studies we identified three farmer group types (farmers, farmer-breeders, and breeders) and their corresponding strategies. Spatial analyses and expert knowledge have also emphasized essential elements as village organization, migration dynamics, impacting policies and prices variation. Remote sensing archive images (Landsat and Spot) gave information about the landscape and plot structure in the 2000's whereas a time series analysis revealed important land cover changes in the study area.

The model has been built by integrating the crop model Sarra-H into a spatial model, using the Ocelet domain specific language and model building environment. Sarra-H simulates the growth and potential yield of dry cereals (millet, sorghum and maize) in the Tropics. Three processes are simulated with a daily time step: water balance, carbon balance and phenology. Sarra-H uses three types of input parameters: soil, agricultural practices and meteorological (including rainfall) data. Ocelet is a simulation tool for landscape dynamics, based on interaction graphs. Graphs consist of entities, characterized by a set of properties, which are linked together by different kinds of relations (spatial, functional and hierarchical). The scenario contains a series of instructions which, when executed during a simulation, make the entities evolve according to their relations.

The spatialized Sarra-H model was built upon three types of spatial entities: Farm, Plot and Climate. Farm entities were defined according to the typology described in Marre-Cast and Vall (2013). Plot entities were defined their area, crop and soil types. Climate entities were defined as areas with the same meteorological (temperature, relative humidity, global radiation) and rainfall conditions. Plots are linked to the Farm entities to which they belong, where characteristics like surface area, maximum inter-plot distance and distance to the village are considered. Each Plot entity is also linked to a Climate entity of the same area. Each plot therefore has one crop variety (that changes every year) and belongs to one farm that, in turn, has a practice strategy and a Climate entity that defines the meteorological conditions. Moreover, soil characteristics are properties of plots. In this way, Sarra-H can simulate, for several years with a daily step, yield, LAI, biomass, etc. for each crop in each plot.

This model has been applied to the Tuy province in Burkina Faso, by simulating the annual crop production and the expansion of cultivated areas at the expense of forests, between the years 2000 and 2014. Three processes were taken into account when simulating the evolution of the cultivated area: farm expansion, farm division and migrant installation. Each of these three processes had an impact on forests. Clearing is modeled by ranking fallow lands according to soil quality, slope, distance to a road, and whether they belong to protected areas. For example, an expanding farm would acquire new plots one by one, the best available lands first, until reaching a certain surface. The attainable surface area can be parameterized according to farm type (farmers, farmer-breeders, and breeders) and strategies.

3 Results - Discussion

The simulation results are able to highlight both inter- and intra-annual changes like:
- The expansion of cultivated lands in the different sub-zones. For example, the model reproduces the rapid clearing of the forest in the West of the village of Koumbia, where many migrants settled these last years. In contrast, the area East of the Kapo Forest has seen a slower expansion of cultivated lands, as the zone was reserved for pastures and the lands were poorer (Fig.1).
- The difference in crop development between plots, according to their corresponding agro-ecological conditions. The total production of the zone is estimated, taking into account the new crops installed each year.

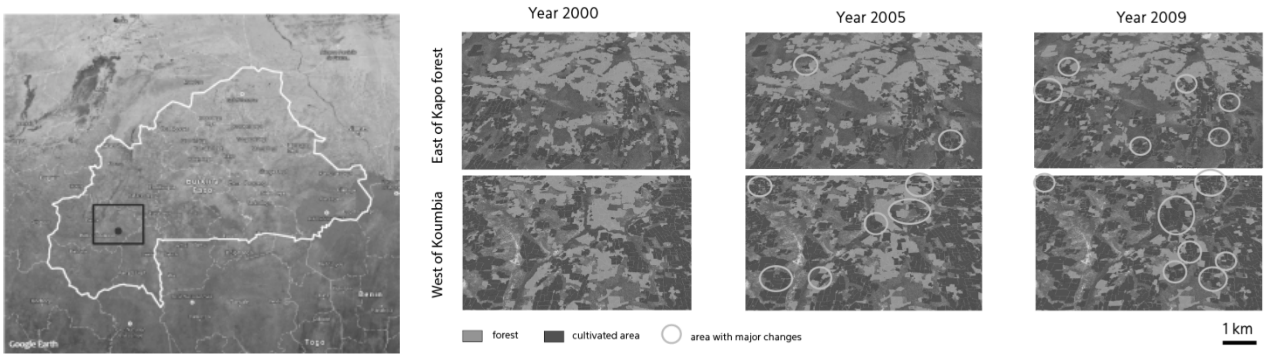

Fig. 1. Localization of the study area in West Burkina Faso, West Africa and results of the simulation of agrarian dynamics in the area of Koumbia.

4 Conclusions

Modelling with interaction graphs allowed us to link information at different scales, and to integrate and spatialize the Sarra-H crop model. The model could be forced with coarser scale processes (migration, farm life cycle) to simulate the annual expansion of cultivated areas, at the expense of forests, and also finer scale information (farm strategy, local agricultural practices) to simulate crop production every year during the last fifteen years. The model developed takes into account farmer strategies, demographic dynamics and spatial heterogeneities. It was able to reproduce the expansion of cultivated lands in the different sub-zones, although the expansion rate was slightly under-estimated.
Work is ongoing to use expert knowledge to better calibrate the model in order to obtain a rate of expansion that is confirmed by observations. The next step is now to extend the model to cotton, a major crop in the zone, to estimate the yearly total production.

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CHARACTERIZATION OF CROP ROTATIONS VARIABILITY BY COMBINING MODELLING AND LOCAL FARM INTERVIEWS

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1 Introduction

The characterization of actual crop rotations on a large territory is a major challenge for local stakeholders in order to understand agricultural impacts on natural resources, e.g., nitrate leaching (Beaudouin *et al.*, 2005). Although various mathematical descriptions and simulations of crop rotations have been proposed (e.g., Castellazi *et al.*, 2010), few models propose to reconstruct actual crop sequences and to simplify their diversity in a reasonable number of crop rotations. The aim of this work was thus to combine modelling and farm interviews to characterize crop rotations which were representative of different soil characteristics and farming systems over a whole agricultural area of 70,000 ha.

2 Materials and Methods

Our study area was the Niort Plain in western France (about 71,000 ha) over the 2007-2012 period. 699 farms with at least one parcel in the study area were identified. This area is characterized by a diversity of farming systems, i.e., specialized farms in cereals or livestock and mixed crop-livestock farms, and a diversity of soils (deep alluvial soils, shallow calcareous soils, etc.).

We developed the RPG Explorer software to facilitate the analysis of the spatially-explicit data from the French Land Parcel Identification System (LPIS), called RPG. The main tasks performed by the software are: (i) classifying farms in two groups according to the proportions of temporary and permanent grasslands in their cropping plans (ii) intersecting yearly LPIS GIS data in order to reconstruct crop sequences over the period 2007-2012, and (iii) modelling the main crop rotations representative of the observed crop sequences, depending on the farming systems and/or soil units. The crop rotation model implemented in RPG Explorer is derived from the linear optimization model CropRota (Schönhart *et al.*, 2011). It uses as input data the agronomic value of all pre-crop – following crop sequences (2-year sequences), the maximal frequencies of each crop in crop rotations, and the observed proportion of each crop, 2-year sequence and 3-year sequence reconstructed by RPG Explorer. The model derives the proportion of each potential rotation so that the agronomic value over all rotations is maximized. The proportions of each rotation are further constrained so that the modelled proportions of each crop, 2-year sequence and 3-year sequence match their observed proportions. In comparison to CropRota, RPG Explorer considers the proportions of observed 2 and 3-year sequences in optimization, which allows to model rotations that better match observed crop sequences, whatever their agronomic value.

To discuss the model outputs, 85 farm interviews were conducted on the study area: 40 cereal farms and 45 mixed crop-livestock farms. The main rotations were requested for each farm, as well as the reasons of their choice and their location (only for 31 interviews).

3 Results – Discussion

RPG Explorer identified 292 cereals farms and 407 mixed crop livestock farms. 5890 6-year sequences were reconstructed for cereals farms and 12381 for mixed crop-livestock farms, including 2112 and 4231 different 6-year sequences over the period 2007-2012. On the basis of the yearly cropping plan and of the 2 and 3-year sequences included in these 6-year sequences, RPG explorer modelled 160 rotations for cereals farms and 230 rotations for mixed crop-livestock farms. The 15 most frequent rotations represented 58 % and 60 % of the area for the cereals farms and the mixed crop livestock farms respectively (Table 1). Rapeseed-winter wheat-sunflower-winter wheat, sunflower-winter wheat and maize monoculture were the three main crop rotations modelled (excluding grasslands and set-aside), and were the main rotations according to the interviews too (28/85). Except rotation 12, all modelled rotations were identified in the surveys. Nevertheless, some farmers declared rotations that were not modelled by RPG Explorer, especially rotations of more than 6 years which were not modelled due to computation limit. For example, the 8-year rotation tG-tG-tG-C-RS-W-S-W was surveyed and partially corresponded to the modelled rotation 12.

Some differences were observed between cereal farms and mixed crop-livestock farms (Table 1). Because of the role of grasslands in cattle feeding, the proportions of rotations with temporary grassland was higher for mixed crop-livestock farms (e.g., rotation 12). Conversely, cereals farms integrated more oil-seed crops and protein crops in their rotations (rotations 11, 14 and 15), which highlighted a higher diversification of cash crops in their cropping plans.

Table 1. Proportions of modelled crop rotations and their occurrence in interviews

Rotation number	Rotation description *	All systems		Cereals farms		Mixed crop-livestock and livestock farms	
		Area (%)	Interviews	Area (%)	Interviews	Area (%)	Interviews
1	RS-W-S-W	17,89%	28 / 85	17,33%	13 / 40	15,76%	15 / 45
2	pG	10,71%	Undefined**	0,64%	Undefined**	15,44%	Undefined**
3	M	7,11%	23 / 85	7,04%	15 / 40	6,17%	8 / 45
4	S-W	6,73%	10 / 85	9,41%	8 / 40	4,15%	2 / 45
5	RS-W	3,98%	1 / 85	6,60%	1 / 40	1,81%	0 / 45
6	tG	3,75%	Undefined**	0,25%	Undefined**	5,38%	Undefined**
7	RS-W-B	2,96%	3 / 85	3,51%	3 / 40	2,21%	0 / 45
8	S-W-B	2,52%	6 / 85	3,14%	4 / 40	1,79%	2 / 45
9	SA	2,10%	Undefined**	3,25%	Undefined**	1,10%	Undefined**
10	M-W	2,07%	3 / 85	1,74%	0 / 40	2,00%	3 / 45
11	RS-W-P-W	1,20%	6 / 85	2,23%	3 / 40	0,40%	3 / 45
12	tG-tG-tG-C-RS-W	1,15%	3 / 85	0,00%	0 / 40	1,70%	3 / 45
13	RS-W-M-W	1,09%	7 / 85	0,00%	2 / 40	1,62%	5 / 45
14	RS-W-B-P-W-B	0,82%	3 / 85	1,24%	3 / 40	0,45%	0 / 45
15	RS-W-O-W	0,76%	1 / 85	1,27%	0 / 40	0,35%	1 / 45

B: spring or winter barley, C: other cereals, pG/tG: permanent/temporary grassland, M: maize, O: other oil seeds, P: protein crops, RS: rape seed, S: sunflower, SA: set-aside, W: winter wheat* * Not systematically asked in the interviews*

There was a spatial structuration of modelled rotations according to soil units (Fig. 1). For example, maize monoculture (rotation 3) was dominant in the valleys while the rotation 1 was dominant on the plateaus. This location of maize monoculture in the valleys was confirmed by 9 out of 15 interviews in which its location was specified.

Fig. 1. Maps of the modelled proportions of two rotations

Soil types were not the only drivers of crop rotations. Farm interviews highlighted that availability of irrigation was a major driver of some atypical rotations, e.g., rotations with field vegetables or maize monoculture on the shallow soils of the plateaus. Agro-environmental schemes also explained some rotations: integration in rotations of temporary grasslands (alfalfa) for biodiversity preservation or of protein crops in order to reduce nitrogen inputs.

Farm interviews allowed us to specify the exact crops included in rotations, e.g., durum wheat, triticale, sorghum or oat, silage maize or grain maize, alfalfa or ray-grass, whereas LPIS data only specified respectively "other cereals", "maize" and "temporary grasslands". This additional knowledge is required to assess the environmental impacts of crop rotations, which can be very different according to the considered crops, e.g., nitrate leaching for alfalfa and ray-grass. In the future, a more quantitative process should be proposed to validate the modelled rotations but raises the issue of the availability of exhaustive and spatialized data at field scale about crop rotations. Other approaches for simplifying the diversity of crop sequences could also be of interest, e.g. the classification proposed by Leenhardt *et al.*, 2012.

4 Conclusions

Our results showed that combining modelling and local interviews can help to define and spatialize the main rotations over an agricultural area. While modelling is needed to define the proportions of rotations that match the observed crop sequences, farms interviews are still mandatory to understand the drivers of rotations and refine their description.

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Use of aerial photogrammetry to minimize erosion threats from broad scale resource developments on farmlands.

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1 Introduction

Broad scale coal seam gas (CSG) development is driving significant landscape change in the Darling Downs and Maranoa agricultural regions of Southern Queensland, Australia. Approved tenements cover some 24,000 km^2 and have identified reserves of 28613 PJ of gas (Huth *et al.*, 2014). While regional scale economic benefits of CSG development are acknowledged, few studies have evaluated the impact on farmers that must now coexist in a "shared space" with large-scale resource extraction enterprises (Huth *et al.*, 2014). Landholders face the prospect of having to negotiate directly with large corporations seeking to superimpose a CSG footprint, driving significant landscape changes in the form of access roads, culverts, pipeline corridors, well pads and water storage reservoirs on the existing farming enterprise. To date, 'ad-hoc' negotiations on infrastructure development with individual landholders has been implemented on a farm-by-farm basis. For this landscape, change, brings with it a high risk of hydrological impact and increased erosion due to extensive addition of roads and infrastructure. Uncoordinated development has the potential to impact stakeholders from farmers (silting of farm dams, loss or diversion of overland flow from catchment areas), local councils (flooded roads, ineffective drainage lines), state government (water quality of streams, river systems) to CSG enterprises (flooding of existing infrastructure). This research evaluates the effectiveness of a high resolution surface water flow model for identifying and monitoring changes to surface water flow or soil elevation which may indicate diversion of water flows, soil loss or build up of sediment, in the future.

2 Materials and Methods

High performance computing based aerial digital photogrammetry was employed in generating image mosaics as demonstrated by the example in Fig. 1a and in the creation of a digital surface model (DSM) at 20 cm resolution (Fig. 1b) for a 1200 km^2 focal region currently undergoing CSG development on the eastern edge of the Surat basin (26.839 S, 150.333 E). Empirical radiometric calibration (to ground reflectance) of each digital aerial frame was carried out in accordance with methods described in detail by Collings *et al.*, 2011). The reflectance-calibrated data allows generalizable and repeatable image processing techniques to be applied to the data as a whole to derive spatially and temporally consistent information. Surface infrastructure and vegetation is then removed to generate a ground elevation model (GEM) (Fig. 1c). Model validation found errors of ~5.0 cm for GEM surface elevations for individual 20 cm pixels compared with 2.0 cm obtained from Real Time Kinematic (RTK) GNSS measurements and is approaching the 2.0 cm precision level expected of DGPS systems currently employed in high-resolution surveys. Flow paths were predicted using the GEM and the terrain analysis as described by Caccetta *et al.* 2010. The prediction is based on estimates of upslope area, and the maps produced are often referred to water accumulation maps. Surface flowpaths for both 100 cm and 20 cm horizontal resolution were compared with ground observations using a DGPS of ±30 cm horizontal accuracy. The water accumulation map (100 cm resoultion) represents the above slope catchment area associated with each 20 cm pixel and is colour classified on a log scale between low accumulation (green) and potential for high accumulation (larger upstream catchment) indicated in red (Fig. 1d).

3 Discussion

While application of satellite acquired remote sensing data for landscape inventory and monitoring is seen as cost effective and has generated reliable information at large spatial scales their value in fine-scale management has been limited by image resolution (Tuominen and Pekkarinen, 2004). Digital acquisition of aerial stereo photography is of suitable resolution for fine-scale terrain modelling and contoured topographic mapping but requires radiometric correction to reduce interpretation error from bidirectional reflectance on spectral intensities. Fig. 1 demonstrates the capacity to generate high-resolution contoured surfaces and water flow maps capable of identifying fine scale erosion rills and depressions in fields, effectiveness of erosion management structures, and changes in surface water flows caused by farm tracks. Surface flow models based on a fine scale digital ground elevation model at the catchment scale are an effective tool for monitoring impact of the wider CSG footprint on surface hydrology and in identifying potential problems during early negotiation and decision planning of infrastructure at the farm, shire and regional level. Exposure of water accumulation maps in discussions with CSG farm managers and agricultural contractors have confirmed that information on location and catchment area of water flows will help inform land holders and CSG staff during planning for CSG infrastructure placement. Repeated surveys can be cost effective in the longer term by highlighting changes in water flow or soil surface elevation that may indicate diversion of water flows, soil loss or build up of sediment within the survey area. Sources of any sediment build-up can be easily identified by following the predicted water flow paths to that location. Concerns by landholders regarding surface water flows can be better communicated through the use of water accumulation maps.

a) **b)**

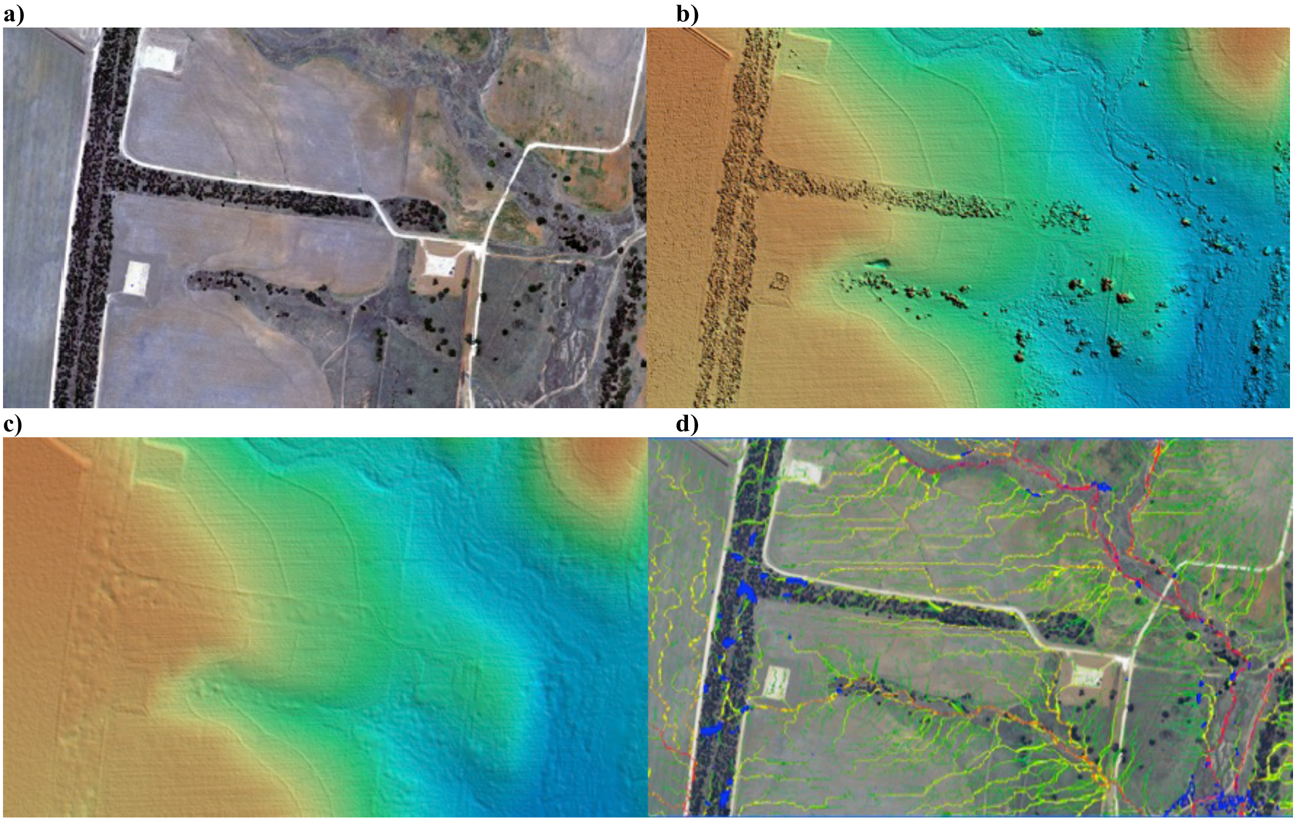

Fig. 1. (a) Aerial photogrammetry derived RGB image. (b) Digital surface model (DSM at 20 cm resolution highlighting treelines and surface infrastructure. (c) Generated ground elevation model (GEM) after removal of above ground structures. (d) Modelled accumulated flow paths indicating low (green) to high (red) accumulation overlaid on RGB image.

4 Conclusions

Results demonstrate that use of high performance computing based digital photogrammetry predicts high-resolution surface elevations, enabling generation of landscape scale surface flow maps suitable for assessing impact at the sub-meter level on surface hydrology. These water accumulation or flow maps have the potential to inform discussion between farmers and the CSG industry and allow for better CSG-farm designs now and ongoing monitoring of changes in water flow or soil surface elevation which may indicate diversion of water flows, soil loss or build up of sediment, in the future. Surface resolution of satellite derived data will only continue to improve in the future and is anticipated to provide a cost effective method, compared with photogrammetry over large areas, for temporal monitoring of surface hydrology and erosion risk in dynamically changing agricultural landscapes. Future research will focus on extending surface flow modelling to predict and map erosion risk at the farm, catchment and regional scale.

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Use of crop sequences for data-mining of remotely sensed time series across multiplescales: opportunities for scaling up research on agricultural dynamics

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1 Introduction

Farming activities are rapidly evolving thanks to technological improvements, even though global statistics indicate a stagnation or a collapse in total yields for major crops. Further improvements require therefore agronomists to enhance the ways they address the farming use of land and water (Acevedo 2011). Considering the limitedness of these two resources farming would definitely benefit from smarter spatial design of cropping and mixed crop-livestock systems (Dury *et al*. 2013; Moraine *et al*. 2014; Murgue *et al*. 2015). Moreover, researchers both from agronomy (e.g., Boiffin *et al*. 2014; Leenhardt *et al*. 2010) and from interdisciplinary approaches, such as the land change science (Rounsevell *et al*. 2012) and the ecoagriculture (Scherr & McNeely 2008), call for stronger integration of farming features in the research on land management systems. Accordingly, it is crucial to scale up the research on farming systems from plot/farm level to landscape level (Rizzo *et al*. 2013; Thenail *et al*. 2009) so as to build farming system design upon an improved understanding of the land patterns determined by the interactions between farming practices and natural resources (Benoît, Rizzo *et al*. 2012). This implies to address a spatially explicit way how farmers are choosing what to cultivate and the way to manage it, hence dealing with farming systems from a landscape agronomy perspective. Such an approach, however, largely depends from the availability of data over large areas and for long periods and on the methods to tackle them. Our aim hereby is to present a data-mining method to handle land cover sequences. In particular, we will discuss how segmenting a landscape by using the observed land cover sequences can help identifying flexible land units and their potential for cross-scale farming system studies.

2 Materials and Methods

The method we present provides a spatial wise synthesis of land cover sequences to get the most out of available datasets in terms of farming features. In this regard, we make the hypothesis that the observation and modelling of land cover sequences, with a focus on crops and pastures, can incorporate a relevant part of the farmers' medium-term decision-making processes (Schaller *et al*. 2012). The method is based on stochastic segmentation with *hierarchical* Hidden Markov Models (HMM) whose spatial states are temporal HMM capable of assigning a probability to a time sequence. It was originally developed to handle large and labor-demanding survey datasets like TerUti (Mari & Le Ber 2006).
The method firstly identifies temporal regularities of the crop/grassland sequences, then use them to segment into homogeneous patches the study area (potentially ranging from farmland to region). In summary, the method includes three steps (Fig. 1a): data preparation, model topology choice and parameterization, model training on data and time-space segmentation (Mari *et al*. 2013). The method builds upon a Markov field hypothesis that considers the land cover of a given location as depending only on the land covers of the neighboring locations. Accordingly, the input data – sampled on a regularly spaced point grid – are scanned with a fractal curve where each point holds a time sequence of land covers. The key features of this approach and its potential for a landscape agronomy perspective on farming systems are illustrated referring to the Yar case study, a watershed of 61.5 km² (Brittany, France) where the main crops – maize, wheat and grasslands – are related to industrial breeding. A 12-year time series (1997-2008) of satellite images was classified into 6 land cover classes for individual field polygons, then sampled with a 20m regular point grid.

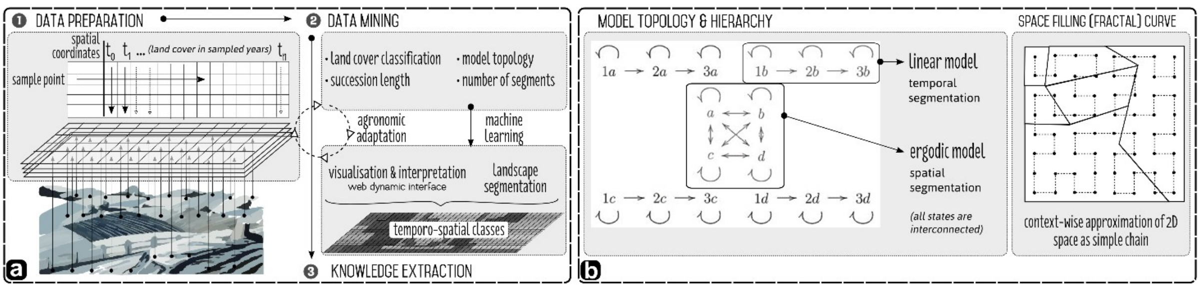

Fig. 1. Schematic diagrams of the method: (**a**) steps and parameters, (**b**) model topology and hierarchy.

3 Results – Discussion

The interpretation of results lead to revise the model parameters in an iterative and interactive process with domain specialists; for instance different sequence lengths and numbers of landscape segmentations were tested and compared. Although input maps derived from remote sensing were thematically less diverse than those derived from field surveys, time-space segmentation revealed some interesting spatial dynamics of land cover sequences. Finally, we distinguished permanent from temporary grassland and identified and localized the type of rotations in which temporary grasslands were involved. Of interest, these crop sequences faced major changes after 2003, identifying possible hotspot zones at the origin of the high nitrogen rates observed for several years in the local rivers. Hence, our approach provided relevant insights to better understand the agronomic relations between landscape patterns and natural resources that can be highlighted at the watershed level (cf. Dusseux *et al*. 2011). Generally speaking, farming system study requires the use of different data sources for being studied in a landscape perspective. Yet, available land cover maps rarely ensure continuity in time, seamless covering of large areas and detailed crop classification. Data about farming management are even more difficult to retrieve, also because of the continuous adaptations of agricultural techniques implemented by farmers in response to complex driving factors (Landais & Deffontaines 1988). Altogether, in-farm surveys still appear the best way to achieve an adequate description of local cropping systems, even though it is a highly time-demanding activity, thus generally limited to small areas or for short periods. However, some land cover dataset like the French TerUti (cf. Xiao *et al*. 2014) or the European Land Parcel Identification System (cf. Murgue *et al*., 2015) appear to provide promising bases to reconstruct agricultural land cover sequences. Advances in remote sensing can further help facing the lack of data, at least about agricultural land cover maps, although improvements are still needed to increase thematic detail (i.e., improving the list of identified crop types). In this perspective, the major novelty of our approach is to processes time-space data in a time-dominant modeling framework, so as to propose an effective approach to visualize specific patterns that occur repeatedly or in sequence and constitute units that are geographically located. It already proved its applicability at different scales (cf. Mignolet *et al*. 2007; Xiao *et al*. 2014). Indeed, fostering patches of similar land cover sequences supports a multi-scale approach ranging from farmland to regional areas including multiple farmlands (Schaller *et al*. 2012) thus allowing to go beyond the inter-annual local variability of patterns and expected rotations.

4 Conclusions

The watershed segmentation into patches of land cover sequences is an innovative approach to identify land management units relating farmers' choices and natural resource management. Accordingly, it could inform local planners' decision-making by providing spatially explicit insights about farming system dynamics. In perspective, this can ultimately facilitate a shared landscape design allowing account to be taken of the diversity in farming systems.

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Are crop sequence evolutions influenced by farm territory dynamics?

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1 Introduction

Crop sequence can be defined as the temporal arrangement of crops and is influenced by four major types of constraint: the timing of agricultural operations, the minimum area of each crop, the minimum return period between the same crop, and the benefits or risks associated to preceding-following crop pairs (Castellazzi *et al.*, 2008).
Crop sequence is a key factor for assessing the environmental impact of farming systems (Leteinturier *et al.*, 2006). Thus, analyzing the evolution of crop sequences and its drivers (*e.g.* European regulations or changes in farm size) is essential to understand farming system dynamics. The aim of this work was to analyze the link between farm territory dynamics and crop sequence evolutions. We specifically analyzed the evolutions of crops preceding winter wheat on cereal farms with contrasted dynamics of their territory (growth or stability of their Used Agricultural Area (UAA)).

2 Materials and Methods

Our study was carried out in the Niort Plain in western France (53,000 ha). We used the spatially explicit data from the French Land Parcel Identification System (LPIS), called RPG, available from 2007 to 2012.
In the RPG, each mapped parcel is associated with a farm identifier which differs from one year to another. So, we established a link between the farm identifiers of two successive years by intersecting chronologically the RPG geo-referenced layers. We thus identified farms in which no change of the UAA has occurred over the 2007-2012 period (stable farms) and farms which have known an increase of their UAA in 2009, 2010 or 2011 (growing farms). We focused on 203 cereals farms, *i.e.* farms cultivating winter wheat and holding more than 50% of cereals or less than 5% of grasslands in their cropping plan. Among them, we identified 61 stable farms and 30 growing farms.
For these 91 cereal farms, winter wheat represents about 45% of the cropping plan. Therefore, crops preceding winter wheat play a key role in the lengthening and the diversification of crop sequences. We analyzed the evolution of the number (lengthening indicator) and the proportion of each crop preceding winter wheat (diversification indicator) on stable and growing farms between 2007-2008 and 2011-2012 (*i.e.* before and after the potential growth in farm size). The preceding-following crop pairs were determined by intersecting RPG layers too (Leteinturier *et al.*, 2006).
In addition, the evolutions of crops preceding winter wheat observed in the RPG were compared with those of 20 surveyed cereal farms (10 stable farms and 10 growing farms). Interviews were conducted to collect information about the composition and the allocation of crop sequences on the farm territory and to determine the drivers of changes.

3 Results – Discussion

On stable and growing farms, the average number of preceding crops remained quite the same between 2007-2008 and 2011-2012 (resp. 2.8 and 2.5 crops in stable farms; resp. 3.7 and 3.5 crops in growing farms). Nevertheless, we observed that the proportion of stable farms with more than 3 preceding crops before winter wheat decreased between 2007-2008 and 2011-2012 (Fig. 1). This highlight a potential slight shortening of crop sequences on stable farms. On growing farms, no specific behavior towards shortening or lengthening of crop sequences was identified: the proportion of farms with 4 preceding crops drastically decreased, but at the same time, both the proportion of farms with 3 or less preceding crops and the proportion of farms with 5 or more preceding crops increased. Besides, it appears that the crop sequence lengthening was often limited on the UAA of stable and growing farms. Actually, even when farms had 5 or more crops preceding winter wheat, two of them represented on average 70% of the farm area in winter wheat.
Rapeseed, sunflower and winter wheat were the 3 more frequent crops preceding winter wheat in 2007-2008 and in 2011-2012. Each of these preceding crops represented 15% to 40% of winter wheat area (Fig. 2). Between 2007-2008 and 2011-2012, the proportion of winter wheat preceded by rapeseed and winter wheat decreased (resp. -11.8% and -7.5 % on stable farms; resp. -12.1% and -11.0% on growing farms) whereas the proportion of sunflower/winter wheat area substantially increased (+20.4% on stable farms; +16.7% on growing farms). Over the same period, we also observed an increase of preceding crops with agronomic benefits (*e.g.* legumes/winter wheat). According to these changes, our results highlight a diversification of crop sequences with an expansion of crops whose crop management is less intensive (reduced needs in pesticides and nitrogen) in the Niort Plain.

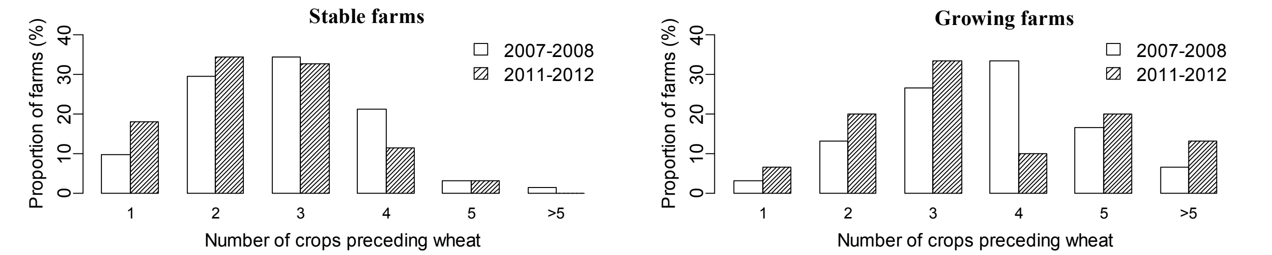

Fig. 1. Proportion of farms according to the number of crops preceding wheat on stable farms (n=61) and growing farms (n=30) (1 - 2: short sequence / 4 - >5: long sequence). Sources: RPG (2007-2008 and 2011-2012).

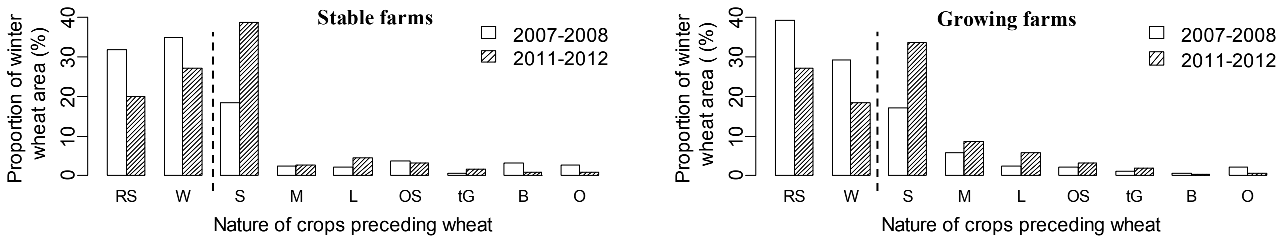

Fig. 2. Proportion of wheat area associated to each type of preceding crops on stable farms (n=61) and growing farms (n=30) (RS, W: intensive preceding crops / S, M, L, OS, tG, B: extensive preceding crops). Sources: RPG (2007-2008 and 2011-2012).

RS: rapeseed, W: winter wheat, S: sunflower, M: maize, L: legumes, OS: other oilseed-crop, tG: temporary grassland, B: barley, O: others.

Farm interviews confirmed the evolutions observed on preceding crops of winter wheat (rapeseed, sunflower and winter wheat). Drivers of changes were similar on both stable and growing farms and can be classified as economic or environmental drivers. On the economic point of view, farms tended to lengthen their rotations with new break crops (sunflower, oilseed-linen, legumes or maize) in order to limit the economic risk related to a large area in one crop (mainly rapeseed). This was especially the case when the farm size increased between 2007 and 2012. However, the lack of irrigation can limit this diversification of crop sequences on shallow soils when irrigation is requested by downstream supply-chain for specific contract (*e.g.* seed contracts). On the environmental point of view, new break crops were often introduced in crop sequences to delay the return period of rapeseed and winter wheat and reduce the pest pressure and nitrogen requirement. According to interviews, Agro-Environmental Schemes (AES) could both contribute to lengthening and diversification of crop sequences (introduction of legumes to reduce nitrogen use) or limit it (suppression of rapeseed to reduce pesticide use). Alongside Schaller (2011), interviews showed that new crop pairs were introduced systematically or according to an opportunistic management. The latter was linked to the subscription to an AES or to the evolution of the collection area of a supply-chain. Duration of theses opportunistic management strategies without CAP subsidies is a new challenge for policy makers and raises the question of the durability of crop sequence changes on an agricultural territory.

4 Conclusions

Our results based on database analysis and interviews showed that farm enlargement was not the main driver of crop sequence changes: the number and the nature of crops preceding winter wheat changed on both stable and growing farms between 2007-2008 and 2011-2012. A slight shortening of crop sequences was observed on stable farms but no fixed orientation towards shortening or lengthening was identified on growing farms. On both stable and growing farms, the main observed evolution was the introduction of new preceding crops in order to replace or delay the return period of rapeseed and winter wheat. Strategies of crop sequence changes did not differ on stable and growing farms due to common environmental and economic drivers. These results might well be of importance either in identifying relevant crop sequence changes for environmental issues at large scale and in determining policy to deal with this issue.

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An Integrated Look at The Diversity, Sustainability and Dynamics of Argentina's Farming Systems

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1 Introduction

Processes like intensification of agricultural production, advance of urban areas, growth of non-agricultural activities (mining, tourism) and climate change produce differentiation, fragmentation and concentration of the agricultural production which impact on farming systems of different regions. The design of development plans requires knowledge and understanding of diverse, complex and dynamic farming systems interacting among them through changing relationships. Specifically, in the center of Argentina (Córdoba province), economic changes have caused annually variations in the minimum required surface for production of 42 to 56 per cent in a period of eleven years, from 1998 to 2009 (Ghida Daza, 2010). Hence, issues like the sustainability of different farming systems in this region should be investigated for a better understanding of the dynamic of farming systems complexity in changing conditions. Sustainability is a broad conception that includes not only an economic side of production but also a balanced social development and environment protection (WCED, 1987; Cáceres, 2004). This paper describes an approach aimed at understanding the diversity and dynamics of farming systems of different regions of Argentina in a context of innovation and territorial transformations. The specific objectives of this approach are included: to adjust conceptual and methodological frameworks to study diversity, logics of functioning, dynamics and sustainability of farming systems, to improve the knowledge of diversity and operation of farming systems in Argentina, to evaluate global sustainability of farming systems (including social, economic and environmental dimensions), to characterize the dynamic of farming systems and their interactions, including a prospective vision and the impact of innovation and to enhance local skills for studying farming systems. The approach is illustrated through the evaluation of the global sustainability of farming systems in the south of Córdoba (center of Argentina) concerning economic, environmental and social indicators of sustainability.

2 Materials and Methods

This nation-wide project works in association with regional projects and other national programmes of the National Institute for Agricultural Technology (INTA) and it is implemented by 60 researchers and extension agents who work in association with researchers from universities and national and international research institutes. Currently, case studies in 36 agro-ecological homogeneous zones are under analysis. The project's approach is shown by presenting the global sustainability performance of six systems belonging to two agro-ecological homogeneous zones of Córdoba, Argentina. More details about the systems evaluation can be found in Ghida Daza (2014).

The study area includes 6.3 million hectare in the humid (6) and sub humid (5) zones of the south of Córdoba. Around 11000 farming systems in this region mainly devote the land to agriculture production, especially soybean (MAGyA Córdoba, 2014). Productive systems for the analysis were classified in agricultural, cattle raising and mixed systems. Economic dimension of sustainability includes net benefits (total revenue – direct cost of activities- fixed expenditures) and global risk (coefficient of variation of net benefits). For the social dimension, the indicator total labour was calculated as hours of work in sowing and protecting crops and for livestock running. In the environmental dimension, the following indicators are included, nutrient balance (i.e., economic value of the balance of nitrogen, phosphorus and potassium, Manchado, 2010), organic carbon balance (Alvarez and Steinbach, 2006) and the risk from chemical contamination (i.e., EIQ coefficient, Kovach et al., 1992). Seven items were included in evaluating the solutions efficiency: average operative result, minimum operative result, coefficient of variation, nutrient balance, carbon balance, EIQ coefficient and total labour. Results for each indicator were normalized and evaluated under four different weigthing schemes to represent different producer's objectives. In this way, the systems were classified according to five options of preference: net benefits, average of all indicators, risk minimization, lowest environmental lose and highest use of labour. A multicriteria or multiobjective method is used in this research to include the different indicators and dimensions of sustainability.

3 Results - Discussion

The performance in economic, social and environmental indicators in different farming systems of two regions of Córdoba are shown in Fig. 1. The multivariate assessment indicates that the agricultural and mixed systems are better in terms of net benefit, but do poorly in labour generation and in environmental indicators. The cattle raising systems improve the social and environmental performance, but the extensive cattle system of zone V C generates very low net benefits. Overall, the cattle raising system of zone VI A is the best considering all sustainability dimensions. The multivariate assessment also reveals the ecological effects of each zone over the evaluated systems. The zone VI systems show a better performance in terms of net benefits and in the variation of those benefits as a consequence of higher and more stable rainfalls. However, zone VI systems exhibit higher nutrient extraction and carbon losses than the zone V counterparts caused by higher crop yields. This diversity of indicators can also be weighted to rank the performance of each system according to different working logics or objectives. Therefore, considering only short-term economic rewards, the farming VI B system is the best. However, according to an average of all indicator criterion, the cattle raising VI A system is the best followed by the cattle raising V C system. Also, the cattle raising VI A system and the cattle raising V C system are the two best performers following a criteria that assigns 50% more weight to the risk aversion, environmental and social dimensions, respectively (Ghida Daza, 2014).

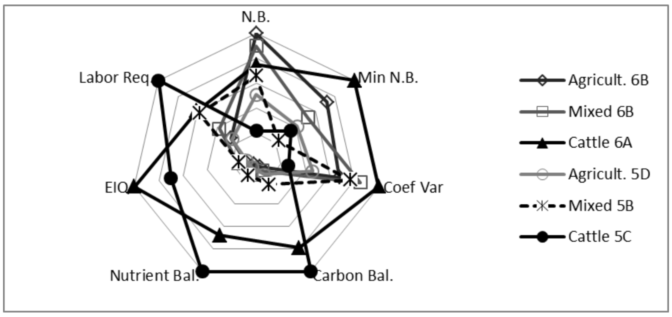

Fig. 1. Multivariate System Assessment (source: Ghida Daza 2014).

4 Conclusions

The paper describes an approach aimed understanding the sustainability, diversity and dynamics of farming systems of Argentina. Preliminary results from six representative systems of the South of Córdoba have been presented. Although further work and methodological adjustments are needed, our results indicate that a wide diversity of systems is present even within relatively homogenous areas and that the ecological characteristics of each zone have important effects on system sustainability. The diversity of system performance can be combined with a diversity of producer objectives to increase the variety of situations. Furthermore, results presented revealed the old-standing conflict between short-term rewards, social inclusion and long-term resource conservation. Current processes such as intensification, advance of urban areas, growth of non-agricultural activities and climate change create growing complexities and interactions among productive systems, natural resources and the society as a whole. Therefore, there is a growing need for a more comprehensive evaluation of agricultural production systems, their innovation processes and dynamics. It is expected that the described approach can generate better knowledge to guide the design of practices and systems that can yield the best combination of multiple sustainability dimensions.

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Linking landscape patterns and farm trajectories: a prerequisite to design eco-efficient landscapes in agricultural frontiers of Brazilian Eastern Amazon

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1 Introduction

The Amazon plays an important role in providing global ecosystem services such as carbon sequestration, biodiversity conservation, water cycle regulation, etc. In agricultural frontiers of the Brazilian Eastern Amazon, the colonisation process by extensive cattle ranching led to landscape changes with a conversion of native forest to pastureland. Recently, legislation became more restrictive prohibiting deforestation and in this context making extensive cattle ranching unsuitable. In response, cattle farmers went into intensification movement and land use diversification. An agrarian transition process has been occurring but until today, it has poorly succeeded in leading to large scale innovative cattle systems, while promoting ecological services at landscape level.

Considering the isolation and the potential of this region, an increased efficiency of natural resources use through new farming practices and spatial reorganisation is relevant. In order to design such eco-efficient farming systems, we need to understand the mutual relationship between farmers' decisions (which lead to farming practices and farm spatial organisation) and landscapes. Therefore, this contribution presents the concepts and methodological framework to analyse the links between farmer's decision systems and landscape patterns in an agrarian transition process. Our hypothesis is that farmer decisions dealing with spatial organisation and natural resources use have changed leading to different landscape trajectories.

We refer to a bottom-up approach (Overmars *et al.*, 2007) focused on farmer and farm. In a first step this approach consists to understand farmer decision-making processes (systemic approach) which led to landscape patterns. In a second step, farmer's decisions are modelled in order to be able to predict landscape patterns (spatial modelling).

The present work corresponds to the first step. To link farmer's decisions and landscape patterns, we borrowed concepts from farming systemic approach (agronomy) and spatial modelling (geography).

2 A systemic approach to understand farmer's decisions

The conceptual representation of farmer's decision process is based on a systemic approach which distinguishes a "production system" (or biotechnical system) made up of interacting crop, animal and soil compartments from a "decisional system" which guides and manage this production system to achieve management purposes. These two systems are connected through a cybernetic relationship: feedback from the production system may lead to a decision that influences future management action and changes, in turn, the production system (Bonneviale *et al.*, 1989 ; Keating & McCown, 2001). The conceptual model defines internal (*e.g.*: characteristics of the farm household) and external (socio-economic, politic or regulation context, pedoclimatic conditions) determinants that can influence farmer's decision which therefore changes farmer's projects.

To understand farmer's decisions, it is important to note that farmers are not rational profit maximizers (Edwards-Jones, 2006). It was particularly true in the frontier of the Brazilian Amazon, where, migrants opted for cattle production not only for the profitability but also for land appropriation, work productivity, social promotion, security, etc. (Vaz *et al.*, 2012).

To test our hypothesis and to embrace the heterogeneity of farming strategies, we established a typology based on expert knowledge. Two variables, considered as relevant indicators of the situation of farmer in the agrarian transition process, were chosen: the level of intensification and/or diversification and the respect or not of the Brazilian environmental legislation. From these variables, three types of farm were defined: (i) farms which have extensive farming systems (similar to migrant's strategies), (ii) farms which began changing some practices, (iii) farms which have been intensifying or diversifying. We also distinguished family farming and cattle ranching.

Semi-open interviews have been conducted aiming at understanding the current global functioning of the farm and spatial organization and at building farm trajectories. We based on three complementary approaches: farm global functioning approach (Bonneviale*, et al.*, 1989), spatial organization approach (Naïtlho *et al.*, 2003) and retrospective surveys (Moulin *et al.*, 2008). The survey is conducted to both collect information about (i) specific facts (farm history and characteristics, livestock and crop system, spatial organization, farm projects) and (ii) farmer outlook. This data collection method, proposed by Girard (2006), aims at understanding the choice of practices of the farmers, adjustments made, and how they justify their choices.

Quantitative and qualitative data are transcribed and analysed to build farmer decision rules and a conceptual model to illustrate the decision making process. These individual decisions are discussed and compared with another sample of farms.

3 Choremes: the use of graphic representation to design landscape patterns

Graphic representations have been used to represent the concept of landscape patterns. Choremes have already showed their ability to represent spatial and functioning organization of farms (Lardon & Capitaine, 2008). They are a relevant support to link farmer decision (the reasoning) and landscape (the result of farmer's action). Chorematic alphabets already exist to design generic graphic representations from structure and process (Piveteau & Lardon, 2002).
As we want to show how farmer's decisions and practices have had impacts on the landscape, we represent landscape spatiotemporal dynamic at relevant intervals. To do that, we use data from surveys and satellites from year 2000. We focus graphic representations on landscape composition (land-use and some landscape elements as riparian forests and trees on pasture) and configuration (spatial arrangement) which are both related at eco-efficiency level. We design the evolution of landscape on two levels: large individual farmer and smallholders community. The results of these retrospective evolutions are showed to farmers and leaders of the community. They are discussed which helps us to explicit farmer's decisions. Cross-analysis of results from systemic approach and graphic representations allow us to build conceptual decision model.

4 Application of the framework

We implemented this framework on two contrasted territories of Pará state (Eastern Amazon), Paragominas and Redenção. In these two municipalities, the process of land occupation by cattle ranching from the 1960s led to a predominance of agropastoral landscapes and livestock extensive farming systems. But, since the last years, the agrarian dynamic have become different. Paragominas is involved in an intensification process. Farmers experiment other options to extensive grazing and stakeholders got involved to get out government's blacklist municipalities with high deforestation rates. This municipality became the first Green Municipality of Pará state. In Redenção, innovation process is more tempered. Farmers didn't necessarily experiment alternatives to extensive grazing, which was a strength of livestock production in this region (Vaz*, et al.*, 2012). The choice of these two heterogeneous situations allows us to outline the lever and impediments to design eco-efficient farming systems at farm and territorial scales.

5 Conclusions and perspectives

Designing eco-efficient farming systems requires understanding farmer's decision making process, in order to be able to promote practices or spatial organization suitable to farmers while improving landscape eco-efficiency.
In the agricultural frontiers of Brazilian Amazon, farmer's decisions were poorly studied in a cattle ranching intensification perspective. The global framework presented in this work will allow understanding and characterizing the links between innovation and landscape dynamics. The results will provide map support and knowledge to monitor an agrarian transition process towards efficient systems at territorial scale.

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Deciphering Corporate Governance and Environmental Commitment within South-East Asia Transnationals in strengthening Farming Systems interactions

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1 Introduction

Promoting tropical forest sustainability among corporate players in agro forest sector is a major challenge. Interactions among stakeholders in the farming systems need to be visualized and strengthen. Furthermore, in agro forest sector, resilient strategies are needed among the corporate players in balancing economic contribution and environmental sustainability. Corporate ownership in Southeast Asian conglomerate is dominated mainly by family, government, or private. Research has shown that there is a powerful relationship between the ownership structure of big business groups and their behaviour (Chandler, et. al, 1982; Almeida, *et al.*, 2006; Todeva, 2006; De Masi, *et al.*, 2012). In the specific case of South-East Asian conglomerates, much research has detailed their propensity to display an extremely complex and opaque structure, or interlaced cross-shareholdings, which need to be visualized and understood.

2 Materials and Methods

Our hypothesis is that financial factors such as ownership structure may have a fundamental role in shaping the corporations' behaviour (environmental policies, investment strategy, etc.). In order to understand if the corporate structure has an impact on the company's commitment to adopt sustainable practices in their farming systems, we adopt the main schemes of sustainable forest management and of sustainable oil palm plantation management as criteria of commitment ("a minima"). We analysed the audited accounts of 4 major Asian agribusiness transnationals. Using network analysis, we decipher how the 931 companies relate to each other and determine the behaviour of the transnationals which they form. We compared various metrics with the environmental commitment of these transnationals.

3 Results – Discussion

The visualization of the ownership structure of the transnationals and the computation of their ultimate shareholders is represented in Figure 1. Ta Ann and Sime Darby are connected through a common shareholder, the Malaysian government. This shareholder controls Sime Darby, but is an extremely minor shareholder of Ta Ann, which is controlled by the Wong family. We found that the size of the transnationals in terms of number of companies is not significant to clearly discriminate them.

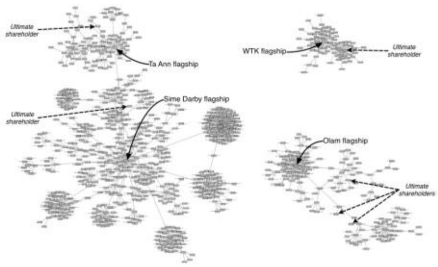

Fig. 1. Ownership structures of WTK, Ta Ann, Olam, and Sime Darby

A Principal Component Analysis was performed on the 931 companies of the data set, with ownership structure, financial factors and environmental commitment proxies as variables. Figure 2 present the factor map for Dimensions 1 and 2, which explains close to 50% of the variability. Dimension 1 ranks the business groups according to their listed capital and government involvement in their ownership structure. It opposes investment strategies of related diversification to unrelated diversification. It opposes also flexible and adaptable groups to Sime Darby, which appear heavily constrained by its lack of cross-shareholdings and its overwhelming government involvement. Dimension 2 ranks the business groups according to their relative number and proportion of subsidiaries, and to their level of decision delay or internal transaction cost. The fact that this dimensions opposes the two big corporations to the two smallest, suggests that the capital is nevertheless a major factor. Indeed, this dimension also ranks the companies according to their uptake of certification, producing a nice diagonal pattern of the companies across the graph of these 2 dimensions. Dimension 3 mainly isolates the ownership structure specificities of Olam. We found that ownership structures reflect differences in flexibility, control and transaction costs, but not in ethnicities. Capital and its control, ownership structure, and flexibility explain 97% of the environmental behaviour. It means that existing market-based tools do not engage transnationals at the scale where most of their behaviour is determined. For the first time, inner mechanisms of corporate governance are deciphered in agriculture and forest sustainability. New implications such as the convergence of environmental sustainability with family business sustainability emerged.

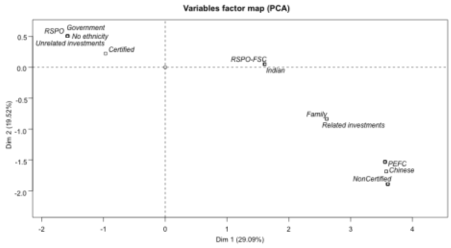

Fig. 2. Factor map of environmental commitment proxies for the companies belonging to WTK, Ta Ann, Olam, and Sime Darby transnationals

4 Conclusions

Ownership structures definitely influence corporate strategies. It is an intrinsic feature of the South-East Asian transnationals analysed here. It enables them to decide to quit a market as easily as they decide to adapt to new economic conditions (such as more or less demand for sustainable products). Basically they constantly choose between various relative transaction or organization costs. The extremely intertwined corporate structures appear to be a fundamental adaptation to country risks and unpredictable conditions. Some uncertainties remain regarding some details of the mechanisms of corporate governance of agribusiness transnationals in South-East Asia. More transnationals with various sets of parameters should be studied to draw conclusions on the role of governments, investment strategies, or the mass of stock exchange smallholders in shaping or influencing environmental corporate governance.

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Observatories of territorial practices: a tool to contribute to sustainable development of territories and performance of production systems

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1 Introduction

In 2014, INTA[1] launched the National Program for Development and Sustainability Territories (PNDST), including its strategy of implementing Observatories of Territorial Practices (OTP) as a socio-technical device to contribute to the definition and implementation of sustainable territorial development projects[2]. The aim is to better understand the pathways of landscape and farming system at territorial scales (Benoît *et al.,* 2012).

Thinking about the observatories on territorial practices

Following the typology of observatories given by Dobois (2006), it is promoted that the OTP understand and influence the practices of the diversity of social subjects and the development of the required skills for managing the territorial complexity. In this sense, the OTP are a strategic device for understanding the complexities (Morin, 1973) and the territorial transformations, and for the design of strategies, policies and planning of INTA itself (Fig. 1).

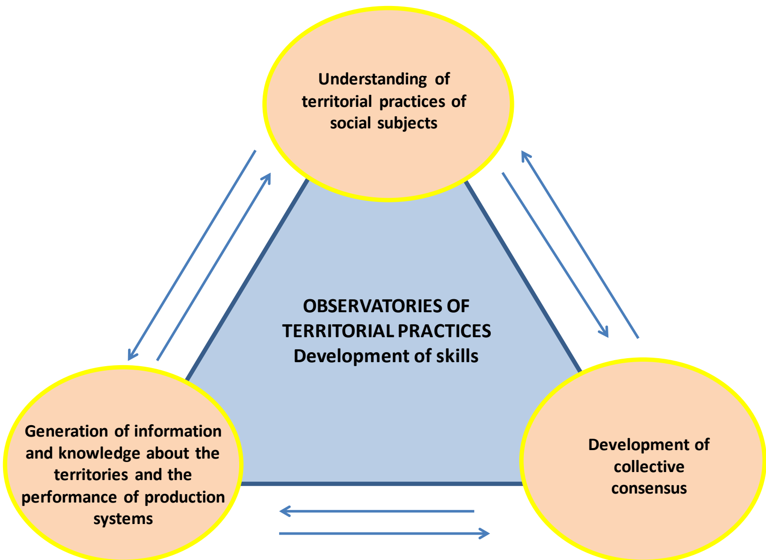

Fig. 1. Dimensions of the OTP.

The implementation of the OTP as PNDST strategy is a complex process involving multiple views of various working groups, interdisciplinary, contexts and different territorial scales, inter- and intra-institutional coordination and participation of social subjects of the territory. The development of the OTP is closely related to the theoretical-conceptual approach from which it the territory is conceived as a web of social relations, within which conflicts occur and materialize, and results of previous actions that reveal disputes, conflicting interests and correlations force. As a result of previous actions the territory reveals forms of the past, while also configures a range of opportunities for future territorial action.

[1] Instituto Nacional de Tecnología Agropecuaria (Argentina).

[2] For OTP, we mean the INTA's Territorial Observatories of the Argentinean Agro-food and Agro-industry System, located in the Regional Centres and articulated with the Regional Projects with Territorial Focus, developed as environments in which INTA facilitates the processes of knowledge construction with territorial social subjects (where Universities have a relevant role) to promote territorial innovation.

INTA's strategy for the development and consolidation of OTP consists of a series of steps or stages (Fig. 2). Among them, during 2014 there have been two important activities: a mission of experts from INTA to France (October) in order to know experiences of observatories and subsequently the organization in Argentina of the First International Seminar and Workshop for Motivation/Awareness on Observatories (December), where about 70 researchers and extension workers from various regions of the country participated.

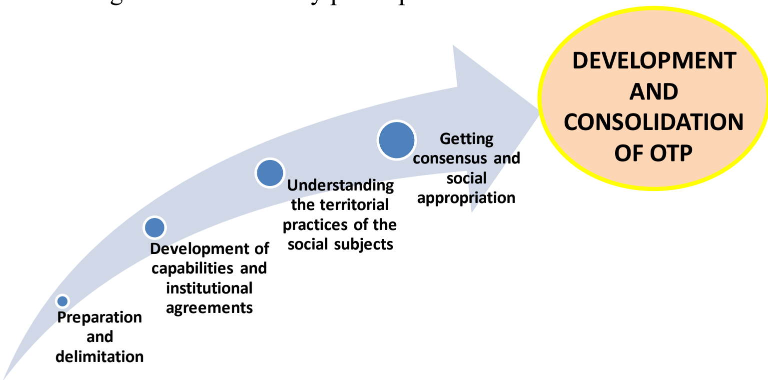

Fig. 2. INTA's strategy for the OTP.

Dialog and reflections

In the Workshop the key debates were centered about the implausibility of the political neutrality of observatories as tools for development and sustainability of the territories; inclusion and participation forms of social subjects to address the complexity and territorial transformations; commitment and institutional support; building political and technical leadership for the implementation of observatories; resource availability and quality of relevant information; articulation and coordination between the various programmatic instruments of INTA and the development of local capacity. Given these tensions, the purpose of PNDST is to understand the complexities and territorial transformations and to influence them from the actions of INTA.

The event allowed us to observe the diversity of perspectives and observatories at INTA and the need to study the territorial practices of social subjects embedded in power and conflicting relations. The need for the establishment of a National Observatory Network of Territorial Practices was also explored, whose main challenge will be to contribute to the development and sustainability of territories from tools collectively constructed for integrating knowledge and action.

In 2015, meetings with management teams of the Regional Centers of INTA are planned, in order to reflect and discuss about the objectives and types of observatories, and the key stages of the cycle, defining an agenda for the implementation of the observatories in different locations and to initiate a process of coordination between the participating institutions.

Acknowledgements. This work has been carried out under the National Program for Development and Sustainability of the Territories (INTA, Argentina), and as a part of Agriterris Project.

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T8. Co-design and co-innovation with farmers and stakeholders: methods, results and challenges

Chair: Michel Duru, INRA
Co-chairs: Santiago Dogliotti, Universidad de la Republic
Marie-Hélène Jeuffroy, INRA

Co-design ecologically intensive fish farming systems using agroecology and ecosystem services

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1 Introduction

The last few decades have shown high growth in global fish farming, whose quantity of production now equals that of fisheries(FAO, 2014). This change is associated with varying degrees of intensification of fish farming among countries. Therefore, many conflicts arise, and the place of fish farming is regularly discussed within regions, both as an opportunity and a risk. Therefore, it is necessary to reconsider the development of fish farming in the context of a growing human population on a planet with limited resources, but also in relation to local issues. Our study aimed to adapt to aquaculture, the concept of ecologically intensive agriculture (Griffon, 2013): use of ecological processes and functions to control pests, reduce pollution, make an efficient use of resources and improve services provided by ecosystems. This approach offers options to re-design aquaculture systems using biophysical and social mechanisms.

2 Materials and Methods

We defined the ecological intensification of aquaculture as a process that considers agroecological principles as defined by Altieri (1995), ecosystemic services supplied by the aquaculture ecosystem (MEA, 2005), and issues facing different types of aquaculture worldwide. The objective is not to propose a pre-existing model for implementing ecological intensification, but to identify a variety of possible pathways and describe driving factors, mainly environmental and technico-economic, but also those related to issues in the coordination and governance. In a first step, we built an expended framework to define the aquaculture ecosystem combining various ecosystem and territorial levels (Fig. 1). Then, we performed biophysical and ecological assessments (in particular, Life Cycle Assessment and Emergy Accounting (Wilfart *et al*., 2013)) coupled with the analysis of the regional stakeholders (fish farming, value chain and administration) perceptions of ecosystem services. Then, we used participatory approach at various stages of our work, in particular, to co-construct with stakeholders various scenarios involving new practices of ecological intensification and performed experiments with the selected practices. The approach is presented in Fig.1. We implemented this approach within six regions selected to cover a variety of aquaculture production systems (from extensive polyculture to monoculture activities in ponds or in recirculating water systems), ecosystems and socio- economic contexts in France, Brazil and Indonesia.

3 Results – Discussion

The project generated different levels of results. We first defined an ecologically intensive aqua-ecosystem, based on the flows of inputs, the variety of services provided and the different ecosystem involved (Fig. 2). We identified seven objectives to guide the adoption and the implementation of ecological intensification combining technical, environmental and social considerations:

1- Minimize dependence on external resource
2- Increase performance of aquaculture production systems and product quality
3- Improve robustness, flexibility, and resilience of systems via integration and functional complementarity
4- Diversify market-oriented ecosystem services of aquaculture systems
5- Promote recognition of services and better use of skills and know-how
6- Improve territorial integration of aquaculture systems by promoting production of non-market ecosystem services
7- Adapt mechanisms and instruments of territorial governance and help stakeholders participate

Then, we proposed a set of indicators to monitor the application and effects of ecological intensification in aquaculture.

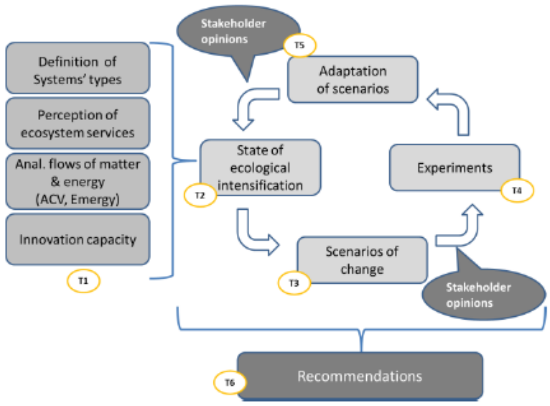

Fig. 1. Approach to co-design ecologically intensive aquaculture

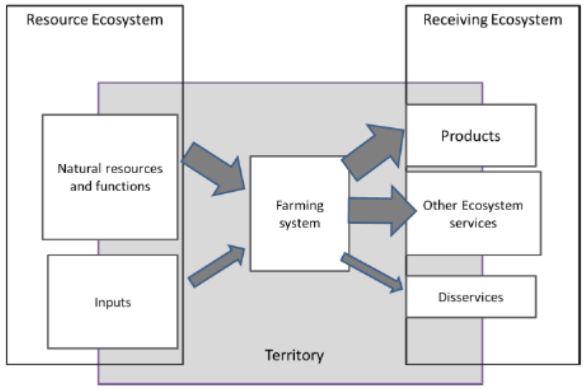

Fig. 2. Framework for ecologically intensive aqua-ecosystem

Different profiles of fish farmers were defined based on their ability to adopt the concept and on the way they apply it: only modifying input/output of the farming system, using the ecosystem services concepts to redefine the goals of their farming system, or to redesign the farming system. Regardless of the situation, adoption of the concept involves concerted efforts that depend on conditions for adopting innovations but also processes of collective engagement. Through learning processes during the various interactions with the stakeholders, the project also helped to modify the perception of the roles of aquaculture at the territorial level.

At the site level, experiments showed the environmental and economic potential of practices based on nutrient recycling, the association of fish and/or plant species, and new production systems were proposed. In Indonesia, a monoculture of panga (*Pangasianodon hypophthalmus*) was changed into a polyculture associating, a cage of panga, a floating plant (*Lemna minor*) and a high value herbivorous species (*Osphronemus goramy*). In France, the reuse of nutrients from outlet of intensive farming of salmon (*Salmosalar*) or carp (*Cyprinuscarpio*) was proposed for macrophytes co-production and for the creation of remediation spaces as a support for biodiversity. In Brazil, the concept of ecological intensification based on ecological services, leaded to propose new practices in pond effluent management and helped to conduct negotiations with territories managers for the sustainability of the activity.

4 Conclusions

The approach developed in this project, offers new perspectives to reconsider fish farming development, taking account its ecological and territorial integration. The generic characteristic of the approach provides a broad potentiality of application for various terrestrial systems. The approach and main conclusions of the project were synthetized in a guide for ecological intensification of fish farming (Aubin *et al*., 2014).

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Re-disigned farming system as a key for biodiversity conservation in Uruguay

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1 Introduction

Only 0,6 % of Uruguayan land is under somehow protection such as National Parks or Protected Landscape. In this context wild life and biodiversity conservation in general depends on private areas which major part are under different production systems. Taking this into consideration, this work was developed in seven livestock farms (cattle and sheep) using a co-innovation approach (Dogliotti *et al*, 2014) that allows re-designing systems increasing meat productivity, reducing environmental crisis risk and reducing overgrazing. As main productive results, after two years of project, meat production increased 23%. Forage biomass availability increased 70%, from 1473 ± 644 kg DM•ha-1 to 2111 ± 979 kg DM•ha-1. These results are mainly based on livestock stocking rate reduction, a decrease of the sheep to cattle ratio and increase forage allowance, considering animal category and physiological state. Although productivity results are promissory, it is necessary to evaluate the effect of these management strategies on ecosystem functions. In the present article we are exposing the status of the measured environmental variables, relative to biodiversity conservation, in the redesigned systems.

2 Materials and Methods

Water was seasonally (four times a year, one on each season) sampled on streams and dams in at least six points of each farm. Turbidity, dissolved oxygen, total dissolute solid, nitrate, pH and temperature were measured with Hanna HI 9828 Multiparameter meter. Phosphorus was determined with Hanna HI736 Handheld Colorimeter -Phosphorus Ultra Low Range. A water quality index -WQI-(Michalos, 2014) was performed with media values of selected variables throw the following formula: WQI =∑ni=1 (Ci.Pi)(∑ ni=1 Pi)$^{-1}$, where *n* represent the number of total variables, *Ci* the value assigned to variable *i* of the normalization and *P* is the value between 1 and 4, were 4 are assigned to the variable more important for aquatic life (e.g. dissolved oxygen).
Biodiversity was evaluated throw studying botanic composition of the herbaceous community, birds and spiders assemblages and an Ecosystem Integrity Index (EII).
Herbaceous plant communities of natural grassland were annually evaluated in the reference units using the point quadrate method. This method was used in each transect relieving all species present at contact points every 50 centimetres. Distribution of species was studied by calculating specific frequencies, richness and diversity indices (Daget & Poissonet, 1971)
Birds were monitored each season following line transects (Sutherland, 2006) at three reference units in each plot, two on natural grasslands (NG) and one in seeded pastures (SP). Transect was performed in 300 m segment, totalizing 900 to 1800 m long depending on the area of the reference unit. In every case the presence of species using habitat and number of individual was recorded.
Spiders sampling was done with sweep netting directly on grasses (Sutherland, 2006). Ten samples of 20 sweeps were taken in every reference unit, determining species presence, number of individuals and the belonging gremmies of each species. Natural grasslands and seeded prairies were sampled.
Ecosystem Integrity Index is a tool on developing phase and its main objective is to make a fast evaluation of the estate of the ecosystem relative to an "optimal" in a low intervention natural ecosystem. It is a 10 points scale index (from 0 to 5, 0.5 step) including four evaluated aspects: structure, species, soil erosion and state of streams including water, riparian zone and vegetation.
In order to display specific results and properly discussion, information of one case study is presented. This case is a livestock grazing system based on natural grasslands (364 ha) located in Eastern Uruguay.

3 Discussion

General water quality was good (>60) in both streams and dams, although we found turbidity and dissolved oxygen values at suboptimal levels for dams, which significantly reduce the index. WQI was 91 and 68, for streams and dams respectively. In table 2 selected parameters for the WQI are presented.

Table 2. Parameters registered for analysed water (mean± SD)

Type	DO ppm	pH	Turbidity FNU	TDS ppm	NO^3	TP ppb	WQI
Streams	7.1±2.7	7.5±0.4	5.5±10.8	87.8±21.2	0.42±0.1	47.5±18.8	91
Dams	5.3±2,9	7.6±0.4	122.0±33.4	49.7±43.8	0.40±0.1	49.3±21.8	68

References: DO=dissolved oxygen, TDS=total dissolved solids, NO3= nitrates, TP= total phosphorus and WQI=water quality index

Regarding to vegetal biodiversity, 61species of herbaceous plants and 25 species of trees associated to grasslands were found. Ten species represent 74% of the soil covering in the reference plots at the beginning of the project, those species were: *Axonopus affinis*, *Cynodon dactylon*, *Piptochaetium montevidense*, *Chevreulia sarmentosa*, *Ciperus sp.*, *Richardia humistrata*, *Panicum sabulorum*, *Dichondra microcalix*, *Paspalum quadrifarium* and *Danthonia rhizomata*. After two year of project implementation, the proportion and the ranking of species changed due to a combination of factors both grazing management and climate, specifically the high levels of rainfall recorded in the past years. There was an increase of summer grasses species, specially *Axonopus affinis* and others with similar functional type while *Ciperus sp., Juncus sp.* and *Mimosa australis* also increased. Is also remarkable the reduction of the presence on *Cynodon dactylon* which is an alien plant considered a weed and the increase of *Coelorhachis selloana,* a high quality forage supplier. Other changes were registered in structure and average forage mass which increased from 1152 to 1718 $kg.ha^{-1}$. Besides of changes in species contributions, there was no evidence of any species disappearance.

Considering bird diversity, 59 birds species were found during the first year (transects method), and after two years 88 species were registered, and reach 100 species considering those registered out of transect. Accumulation curves showed differences in the estimated richness project in four years sampling for natural grasslands (89), and annual pastures (68). Eight species considered as national conservation priority (Soutullo et al, 2013) were recorded: *Cariama cristata*, *Coragyps atratus, Donacospiza albifrons, Gnorimopsar chopi, Lochmias nematura, Nothura maculosa, Picumnus nebulosus, Rhea americana* and *Rynchotus rufescens.* The effect of richness reduction in seeded area is considered to be low impact due to the low fraction of the total farm area dedicated to this used, only 11.3%. Most of the production areas are covered with natural vegetation communities providing birds with rich habitat and a well-preserved structural complexity.

In relation to spiders communities, nine families belonging to seven different gilds and a total of 20 species were registered. In both evaluated situations, natural grasslands and annual pastures, the most frequent gild was the orbicular web builders and *Larinia vivittata* the most frequent species, although in NG the population was three time higher. Irregular web builder and ambush hunters' gilds were found exclusively in NG.

General ecosystem integrity index of whole farm was 4.0, which result from the integration of "good" indexes in the majority of the area and lower values in a relative small zone of more intensive production used. In Fig.1 the distribution of index values for each paddock is shown.

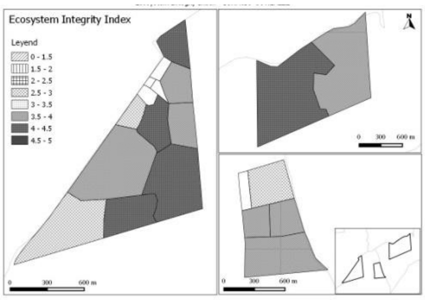

Fig. 1. Map with Ecosystem Integrity Index for each plot of the farm.

4 Conclusions

We found a general well preserved natural ecosystem that support the studied production systems, including biodiversity with a wide range of flora and fauna species. Initial records and in-course samplings showed the stability of wildlife species and favorable changes in the herbaceous species composition and structure.

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Co-design of improved climbing bean technologies for smallholder farmers in Uganda

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1 Introduction

Technologies to improve agricultural production in Africa need to address the needs and objectives of farmers in different bio-physical and socio-economic environments. A participatory process can facilitate the development of such technologies by taking into account farmers' feedback and adaptations. However, participatory processes are time and data demanding, and efficient implementation and out-scaling in large-scale projects remains a challenge. In this study we used a participatory process to co-design a 'basket of options' of improved climbing bean technologies for specific recommendation domains (based on bio-physical factors and farm type), and to develop principles and guidelines for technology development in new areas or similar projects.

2 Materials and Methods

Two sites in the eastern and southwestern highlands of Uganda were selected with similar agro-ecologies but differences in market access, use of inputs and access to trees for staking. We conducted an iterative cycle of co-design, implementation and evaluation: a first set of improved climbing bean technologies was tested in on-farm demonstrations in the first season of 2014 (season A). This first set was based on initial interviews with a random selection of farmers. Staking was reported as main challenge, so improved technologies included alternative, low-cost staking materials: sisal string and banana fibre. We also included tripods, which were expected to enhance yields but were also more labour intensive. Besides, we compared a local and an improved (NABE 26C) variety, with and without manure and TSP fertilizer. Different types of farmers (men and women from low (LRE), medium (MRE) and high (HRE) resource endowed households) evaluated these technologies by pairwise comparison at planting, staking, podding and harvest. Farmers also indicated their reasons for preference of the treatments, feeding into an assessment of farmer criteria for appraisal of the new climbing bean technologies. The evaluations formed the basis for a session where farmers, researchers, extension officers and NGO staff co-designed treatments for new demonstrations in the second season of 2014 (season B). In this second season, the cycle of evaluations and co-design was repeated.

3 Results – Discussion

Among the staking methods, sisal strings and single stakes performed best in terms of yield (Fig. 1a). We hypothesized that LRE and MRE farmers would prefer technology options which maximize returns to labour, and HRE farmers options which maximize returns to land. Remarkably, farmers of all types preferred the more labour intensive tripods (Fig. 1b), which yielded less than single stakes. The most frequently mentioned reason for preference was that tripods were strong and prevented the stakes from falling over (Fig. 1c). LRE farmers preferred the low-cost banana fibre ropes relatively more often than MRE and HRE farmers, and mentioned costs and labour demand more frequently.

b. **c.**

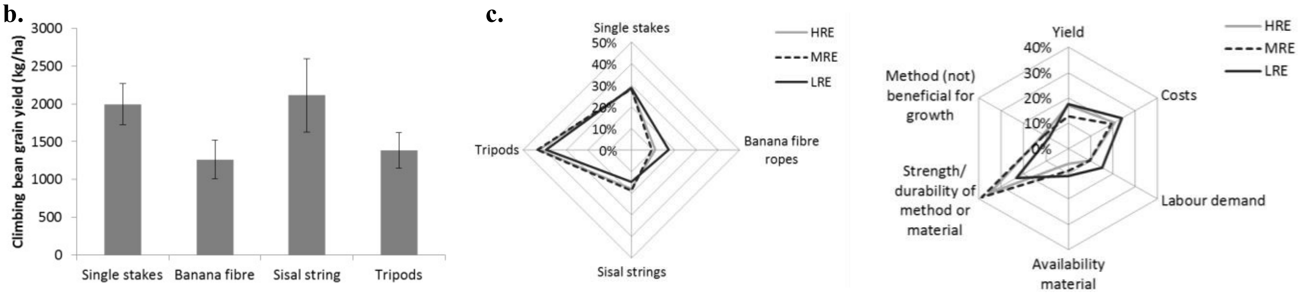

Fig. 1a: Climbing bean grain yield (kg/ha) for alternative staking methods in 2014A (n=7).
Fig. 1b: Pairwise comparison of staking methods by high (HRE), medium (MRE) and low (LRE) resource endowed farmers; % is number of times method was preferred, divided by total number of comparisons.
Fig. 1c: Categories of reasons for preference staking methods; % is number of times the reason was mentioned divided by total number of reasons.

We also hypothesized that female farmers would rank technology options with little capital and labour input higher than male farmers, as we expected female farmers to have less access to capital and labour within the household. Preference for staking methods did not differ between men and women: both ranked tripods highest and mentioned similar reasons (results not shown). But in the comparison of varieties with and without inputs (Fig. 2a), female farmers had a stronger preference for the local variety without inputs, and male farmers for the improved variety with inputs (Fig. 2b). Women more often than men mentioned that they could not afford fertilizer, and valued different characteristics of the varieties than men: both women and men mentioned yield as the most important criterion (27% vs 42%), but women placed relatively more emphasis on characteristics of the leaves (used as vegetable) (19% vs 14%), early maturity (8% vs 4%), performance without fertilizer (5% vs 2%) and taste (4% vs 0%). LRE farmers clearly preferred the treatments without inputs more strongly than MRE and HRE farmers (Fig. 2c). LRE farmers mentioned that they could not afford fertilizer and that they found the yield without fertilizer still acceptable, which is not surprising considering the similar yields of the treatments with and without inputs.

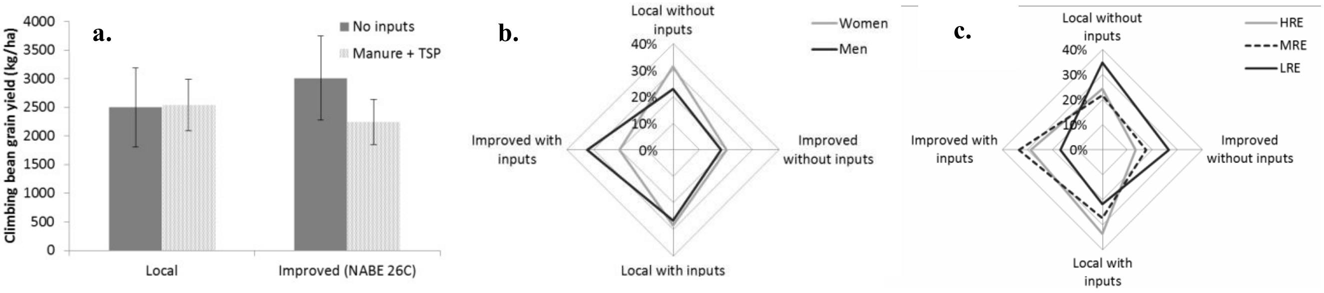

Fig. 2a: Climbing bean grain yield (kg/ha) for local and improved variety with and without inputs in 2014A (n=4). **Fig. 2b&c**: Pairwise comparison of local and improved variety with and without inputs by women and men (**b.**) and high (HRE), medium (MRE) and low (LRE) resource endowed farmers (**c.**); % is number of times treatment was preferred, divided by total number of comparisons.

Results of the evaluations were used to co-design treatments for subsequent seasons. Notable contributions from farmers were refinement of treatments (cost-reduction for sisal string and banana fibre methods, labour and risk reduction by planting two seeds per hole instead of one to avoid gap-filling); solutions for locally identified problems (use of shorter stakes to reduce damage by birds); and new treatments to experiment with ("will cutting the growing tip of beans at a certain height enhance yields?"). Research, extension and NGO staff contributed with knowledge and technologies from elsewhere.

The co-design process resulted in a long list of about 20 promising treatments, including abovementioned suggestions from farmers. This long list can be used by extension agents or other projects to select options for cultivation of climbing beans in similar recommendation domains, and for further testing and tailoring. Offering a range of options rather than narrowing down to best yielding technologies is important considering the diversity of users. However, as it will be impossible to develop 'best-fit' technology packages for every type of farmer in every environment, 'flexible recommendations' that extension officers can pass on to farmers will also help to take into account different objectives and constraints (e.g. what is a good option for 'best yield' 'short maturity time', 'low costs' or 'little labour') (Collinson, 2000).

4 Conclusions

Farmers of different types (wealth, gender) have different preferences and use different criteria to evaluate new technologies. Researchers often focus on 'yield', but farmers use yield next to other criteria. Co-design of technologies helps getting insight in differences between users, but will remain challenging in many large-scale projects. Such projects may benefit from offering farmers a range of (stepwise) options to choose from, and from flexible recommendations that address different objectives and challenges of different types of users.

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Iterative design and *ex ante* assessment of cropping systems including energy crops in the Dijon plain (France)

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1 Introduction

The European Directive on Renewable Energy (2009) defined the reduction of greenhouse gas (GHG) emissions as one of the main criteria that must be fulfilled for biofuels produced from energy crops. As these crops have specific lifespans and short and long-term effects on the following crops of the crop sequence, an assessment at the cropping system (CS) scale is required. Our study aimed at designing and assessing CS including energy crops in the Dijon plain (Bourgogne region, France), where perennial (e.g. *Miscanthus x giganteus,* hereafter referred as *M.giganteus*), pluriannual (e.g. alfalfa) and annual (e.g. triticale) crops have already been grown and could be candidate to produce bioenergy.

2 Materials and Methods

The main target that energy-oriented CS aimed at fulfilling was to decrease GHG net emissions (*i.e.* N_2O and CO_2 emissions minus carbon storage in the soil) by 75% compared to the reference CS (REF) mostly practiced in the study area (*i.e.* characterized by the crop succession "rapeseed-wheat-barley" and an intensive crop management system for each crop). In addition, we also wanted these CS to decrease the Treatment Frequency Index (TFI) by 50%. We developed a four-step approach (Fig. 1), based on an iterative process including design and *ex ante* assessment steps (Meynard *et al.*, 2012): a design workshop, as described by Reau *et al.* (2012), involving scientific and local experts (step 1) was followed by an *ex ante* assessment step (step 2), where a set of tools were used, such as PERSYST (Guichard *et al*, 2010). Eight scenarios combining minimum and maximum inputs prices, crops prices and yields were defined. The results of this first assessment were then presented to the experts, who provided us with modifications on CS1 (step 3). These new CS (CS1' and CS2') were then assessed in step 4.

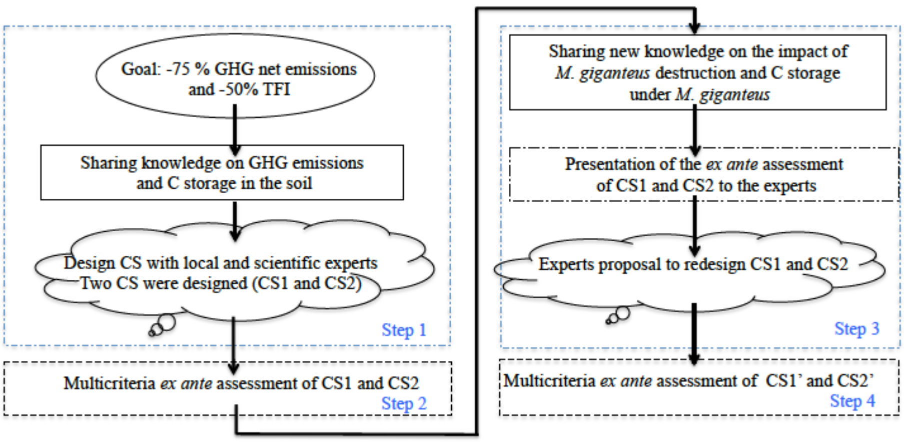

Fig. 1. A four-step approach used to design and assess CS including energy crops

3 Results – Discussion

Two innovative CS (CS1 and CS2) including *M. giganteus* as an energy crop were designed by the experts during the first step. CS1 is presented in Fig. 2 as an example. Its assessment showed that the main target (i.e. decreasing GHG net emissions by 75% compared to REF) has been reached (Fig. 3). This result is mainly due to *M. giganteus*, which uses low quantities of N fertilizer (involving low emissions of N_2O), and stores carbon in the soil: growing *M. giganteus* for 15 years indeed improves carbon storage of 6 t C ha^{-1} +/- 3 t C ha^{-1} (Poeplau

& Don, 2014). Thanks to *M. giganteus* and alfalfa in the CS1, the second target (to decrease the TFI by 50% compared to REF) has been reached too. However, REF was more profitable, mainly because of the low price assigned to *M. giganteus* (Fig. 3).

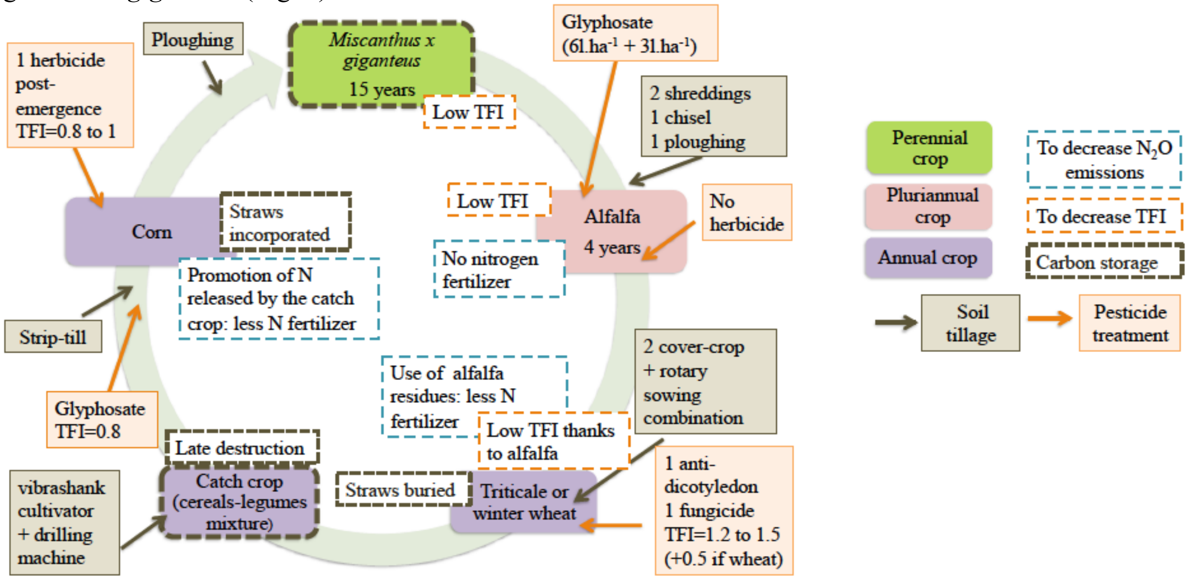

Fig. 2. Description of the cropping system CS1. N= nitrogen fertilizer

During the third step, experts recommended to reduce the lifespan of *M. giganteus* (10 years instead of 15 years) to improve the profitability of the energy-oriented CS while benefiting from the positive effect of *M. giganteus* on soil carbon storage. During the fourth step, CS1' (with the reduction of the lifespan of *M. giganteus* reduced*)* was assessed. Results showed that GHG net emissions of CS1' increased by 29.7% compared to CS1. However the semi-net margin of CS1' was not improved compared to the semi-net margin of CS1 (Fig. 3). Hence, results showed that CS1 and CS1' were beneficial regarding environmental and energy indicators, whereas REF was more profitable regarding semi-net margin in seven out of eight scenarios.

Indicators	Unit	CS1	CS1'	REF
GHG net emissions	kg CO_2 eq. ha^{-1} $year^{-1}$	-128	38	2682
TFI	no unit	0.44	0.44	6.63
Average NO_3^- losses	mg NO_3^- l^{-1} y^{-1}	8.16	10.30	28.33
Semi-net margin	€ ha^{-1}	927	927	1327
Energy efficiency	no unit	77	68	10
Energy cost	GJ ha^{-1} $year^{-1}$	4.42	5.80	12.74
Food capacity	no unit	0.32	0.32	0.97

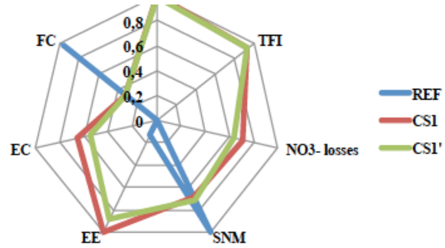

Fig. 3. Overview of the multicriteria assessment of CS1 and CS1' in comparison with REF. GHG = Greenhouse gas net emissions; TFI = treatment frequency index; SNM = semi-net margin; EE = energy efficiency; EC = energy costs; FC = food capacity. This scenario corresponds to maximum crops prices, maximum yield and minimum input prices.

4 Conclusions

We observed in this case study that a tradeoff between (i) environmental and energetical impacts on one hand and (ii) profitability and food capacity on the other hand needs to be found to design mixed CS, i.e. CS including crops dedicated to provide food and bioenergy. Lastly, these prototypes of CS could contribute to feed an integrated assessment in the Dijon plain at the supply area scale.

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Designing agroforestry systems for food production and provision of other ecosystems services: cases in the sub-humid tropics of Nicaragua

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1 Introduction

The provision of food and other key ecosystem services in rural landscapes of the sub-humid tropics of Central America are increasingly at risk as a result of unsustainable management practices, high potential for soil degradation and climate variability (FAO *et al.*, 2012). A promising farming practice to restore ecological processes and the provision of ecosystem services is the use of agroforestry systems (AFS), which combine crops/pastures and trees to improve agro-ecosystem functioning, including biomass production, soil and water retention (Jose, 2009). AFS, however, can be difficult to implement and can generate trade-offs between ecosystem services, as well as between (limiting) resources such as labor, water, light and nutrients at both plot and farm scales (German *et al.*, 2006). Better farming, development and research interactions and approaches are needed to develop AFS and farming systems that account for farmers' objectives, while restoring the provision of ecosystem services in degraded rural landscapes. The objective of this study was to evaluate the effect of AFS in restoring the provisioning of ecosystems services at the plot level, used on-farm experiments established with farmers and other partners in Nicaragua.

2 Materials and Methods

On-farm experiments were established with farmers and others partners at two sites in the sub-humid tropics of Nicaragua. Each site had 8 on-farm experiments comparing two major systems: AFS with maize/beans (i.e. Quesungual), and silvopastoral systems. In each system, different treatments or components were compared: soil cover (burning vs. mulching crop residues), maize/bean varieties (traditional vs. improved) and trees (with vs. without) in the Quesungual system (5 treatments); and grass species (traditional vs. *Brachiaria spp*) and trees (with vs. without) in a silvopastoral system (3 treatments). Different indicators were monitored during 2011 and 2013 to quantify the potential impact of these treatments in soil health, crop and livestock productivity, C sequestration and biodiversity. Non-parametric data analyses (Mann-Whitney Test) were conducted to evaluate potential differences between treatments of key selected indicators, specifically the potential influence of variety/species selection and tree presence in both Quesungual and silvopastoral systems.

3 Results – Discussion

These results indicate that the presence of trees and proper management (e.g. timely pruning, planting density) in croplands and pastures did not have a significant impact on maize and livestock productivity in the on-farm experiments (Fig. 1). In fact, treatments with trees had significantly higher bean productivity, particularly in 2013 (averages 0.9vs. 0.7t ha^{-1}), likely a result of improved water use efficiency. In the case of grasslands, the use of *Brachiaria spp.* and regulated grazing showed higher livestock productivity compared with the traditional pasture management (averages 3.8 vs. 2.8 L cow day^{-1} in 2013), independent of the presence of trees. This indicates that improved pastures and livestock management can be combined with trees to enhance productivity and reduce potential environmental impact.

As expected, the presence of trees increased both tree diversity and above-ground C storage under Quesungual management (Fig. 1B). For tree diversity, the Quesungual system demonstrated similar values as some of the surrounding secondary forests. In terms of above-ground C, Quesungual systems stored 5-20 t ha^{-1}. This reinforces the notion that AFS can bring multiple benefits to rural landscapes in this region, and maintains the soil functioning (Rousseau *et al.*, 2013). A major challenge remains as to how farmers could benefit from ecosystem services that can have a positive impact for a larger population in emerging economies, where successful payment for ecosystems services is rare.

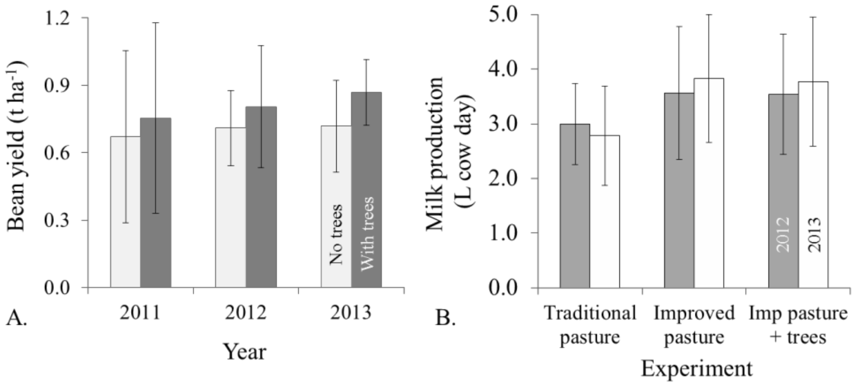

Fig. 1. Comparison of treatments: A. bean productivity in Quesungual across years; B. Livestock productivity in silvopastoral systems across treatments.

These results suggest that the proper combination of a tree component in farming systems of the sub-humid tropics of Central America do not generate major trade-offs with food production. In fact, the combination of trees with other good agronomic practices (e.g. not burning) can enhance the overall provision of ecosystems services at the plot level, thus restoring soils and multiple ecological processes that can benefit farmers and rural communities (e.g. water regulation, C sequestration, biodiversity). However, the implications of these results will depend on the degree of agricultural intensification of the farming systems, which is also related to their ecological context and market integration.

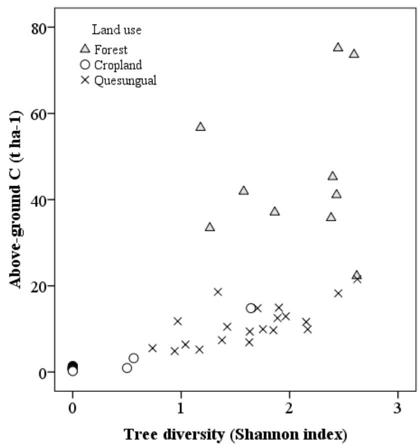

Fig. 2. Comparison of tree diversity and above-ground C for three treatments or land use systems.

4 Conclusions

The development of more sustainable farming and land use systems in rural landscapes of the sub-humidtropics of Central America requires a close interaction with farmers and other partners (i.e., co-design) to build common knowledge on social-ecological systems, as well as to facilitate the adoption and adaptation of technologies relevant to farmers and to the specific contexts associated with rural landscapes.

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Managing pasture-herd interactions in livestock family farm systems based on natural grasslands in Uruguay

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1 Introduction

Livestock production in Uruguay involves the management of C4-species dominated natural grasslands, which cover more than 70% of the country's surface area. Almost 80% of the farms specialized in beef and wool production are family farms, which usually exhibit low sustainability due to low family income and grassland overgrazing. Historically, natural grasslands have been managed with low forage heights (2 to 4 cm), and consequently low leaf area indices, reducing the capacity of the sward to intercept light and photosynthesize, and providing niches for invasion by low productive grass species. As a result, grassland productivity has been low, and risk of erosion and loss of biodiversity high. Experimental evidence suggests that improving management of the pasture-herd interactions by seasonal modulation of animal density could improve natural grassland growth and increase meat production, which would contribute to the design of more resilient systems less vulnerable to droughts. To test this hypothesis at the scale of real family farms, a co-innovation approach was implemented on seven pilot farms in the east of Uruguay with the aim of improving family income and reducing natural resource degradation.

2 Materials and Methods

A co-innovation approach (Dogliotti *et al*., 2014) was implemented during two years in seven pilot farms involving family livestock grazing systems based on natural grasslands, located in the East of Uruguay. The approach involved characterization and diagnosis of the farm system's sustainability, followed by cycles of re-design, implementation, and monitoring of system evolution. Proposals for re-design were based on changes in management practices without adding external inputs and without increasing costs. The relevance of increasing the amount of standing biomass and improving pasture-herd management at farm level was discussed between technicians and farmers. Productivity (meat productivity, stocking rate, sheep to cattle ratio, kg of weaning calf per breeding cow and forage allowance), and economic (net income) indicators were estimated for the three previous years before starting the project from farmers' records, and records were kept during the project. After starting the project also forage mass (Haydock & Shaw, 1975) and forage height (Barthram, 1986) were measured twice per season in all farms.

3 Discussion

During characterization and diagnosis at farm level, we found low physical and economic results and natural resource degradation. Low values of standing biomass (1.183±335 kg of dry matter (DM) ha^{-1}) were found and areas with low soil cover, presence of low productive grass species and problems of forage structure, revealing natural grassland degradations were observed. Low biomass, and as a consequence low leaf area index values reduced the capacity of the sward to intercept light and photosynthesize, affecting pasture growth. Inadequate feed supply resulted in low cattle sale weights and low animal reproductive efficiency, which led to low meat productivity and family income. Those problems were discussed with farmers and agreed. Historically, farmers managed their systems with large numbers of animals and high sheep to cattle ratio. Stocking rate is one of the most important management variables in grassland ecosystems, since it determines the relationship between forage offer and animal demand. Proposals for redesign were done by technicians and discussed with farmers. The main strategy elaborated with and implemented by the farmers was to increase standing biomass and forage production of the grasslands by reducing stocking rate and the sheep-to- cattle ratio, and adjusting allocation of animal categories to paddocks over the course of the year. Also the use of low cost breeding practices, such as allocation of different animal categories to different paddocks according to standing biomass, feed provision according to body condition, temporary weaning, definitive weaning of calves in autumn, and extra attention to feeding female calves and heifers during their first winter (Quintans & Scarsi 2013). After two years of implementation of the redesign proposal, significant improvements were achieved at farm level.

On average, farms decreased total stocking rate by 8% (from 0.92 Livestock Unit (LU) to 0.84 LU ha^{-1}) and decreased the sheep to cattle ratio by 34% (from 2.6 to 1.4). The improved management of the pasture-herd interaction resulted in an increase in standing biomass (Fig. 1). The average forage height at the beginning of the project (summer 2012-2013), the moment in which cows are lactating and should get pregnant again, was half the amount required according to Soca and Orcasberro (1992) (Fig. 2). The next summer (2013-2014) average forage height was already at the recommended level and it was kept above requirements till spring 2014.

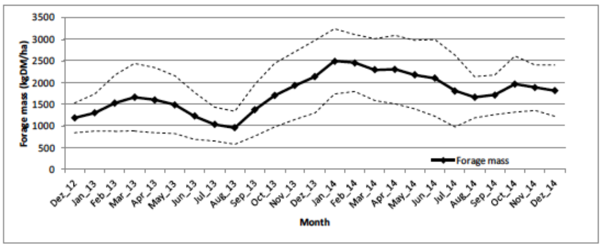

Figure 1. Monthly average forage mass (kg DM ha^{-1}) for 7 pilot farms during the two years of the project. *Dotted lines indicate standard deviation.*

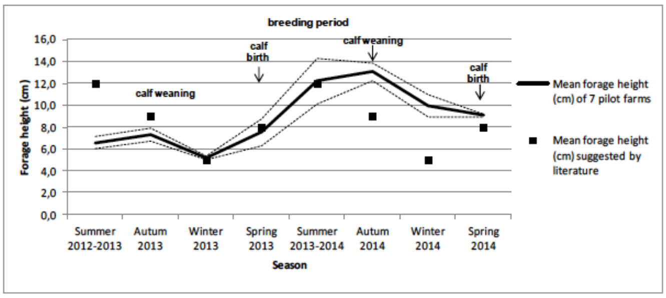

Figure 2. Average forage height (cm) for 7 pilot farms per season and forage height (cm) suggested by Soca and Orcasberro (1992). *Dotted lines indicate standard deviation.*

These increases in forage height and standing biomass resulted in an increase in forage and meat production per ha. Forage allowance, an instantaneous measure of the forage-to-animal relationship, increased on average, after two years of implementation of the project, from 3.5±1.2 to 6.1±2.0 kg of DM per kg Live Weight^{-1}. As a consequence, equivalent meat production (i.e. meat +wool) increased by 24% (from 99 kg ha^{-1} to 123 kg ha^{-1}), and the weight of weaning calf per breeding cow increased by 39% (from 107 kg to 149 kg). Comparing the average of the two years before the beginning of the implementation of the re-design plans with the average of the two years after, the net income increased from 70 to 98 US$ ha^{-1}. We hypothesize that a higher standing biomass also had a beneficial effect in terms of reducing the risk of erosion, climate vulnerability and increasing soil carbon.

4 Conclusions

We presented a successful co-innovation process involving farmers and scientists showing that, even in slow-responding perennial systems, ecologically intensive strategies that better utilized system functionalities without extra inputs resulted in important improvements of system functioning within two years.

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DESIGNING APPROPRIATE AGROFORESTRY SYSTEMS: A SYSTEMATIC UNDERSTANDING OF ADOPTION DECISIONS

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1 Introduction

Many of the silvo-arable and silvopastoral agroforestry systems in Flanders have been abandoned because they are considered to be incompatible with today's agro-economy and intensive farming practices. Nevertheless, modernized agroforestry systems could enhance farm resilience and respond to several challenges in agriculture through diversifying production and supplying a wide range of ecosystem services. Because these opportunities are increasingly recognized by policy makers, consultants, researchers and educators, the Flemish government set up a subsidy program for the installment of agroforestry parcels in 2011. Since 2014 the subsidy covers up to 80% of the plantation costs if some requirements with respect to parcel size, crop type, amount, type and distribution of trees are fulfilled. Despite the existence of this subsidy program and the increasing interest of policy makers and researchers in agroforestry as a sustainable land use system, the adoption rate of agroforestry in Flanders remains very low. The results of a questionnaire distributed to a group of farmers in Flanders in 2012 showed that this low adoption rate is mainly related to farmers' limited knowledge of the practice and negative perceptions towards its' profitability and compatibility within their current farming system (Baeyens, 2012). Although the results of this questionnaire give some indications about how to make agroforestry more attractive to Flemish famers in the short term, it does not give any information about the reasons behind the negative perceptions of farmers towards agroforestry and the processes by which trees have increasingly disappeared from the agricultural landscape from the 1960's onwards. Therefore the overall aim of this paper is to explore the main drivers and processes, in the past and in the present, that make Flemish farmers today reluctant with respect to tree-planting on the farm. The results are intended to aid in the design and study of appropriate agroforestry systems for Flanders. As such we hope to contribute in the long term to an increased uptake of agroforestry and more general to more tree-planting in and around farmers' fields in Flanders and the rest of Europe.

2 Materials and Methods

The framework for this research is a 5-year project in which a system perspective and an interdisciplinary and participatory approach towards agroforestry design, research and development is used. The project builds upon the farming systems research methodology, which comprises a family of approaches for the diagnosis of land management problems and potentials and the design of appropriate agricultural interventions. Although the different approaches under the FSR methodology have a lot of characteristics in common, this research project fits particularly well under the *systeme agraire* approach as used by francophone agronomists and described by Cochet (2012). He explains that the original *systeme agraire* approach was particularly focused on the relation between farmers' technical choices and their social and political context. To be able to understand this relation, different scales of analysis were necessary. This was different in the English literature in which the farming systems research was originally focused on solving technical questions in the short-term by analysing processes at field- or farm level. Furthermore, according to Cochet (2012) the francophone approach of farming systems research payed more attention to social aspects, long-term processes and historical aspects than was usual in the English approach.

With the *systeme agraire* approach in mind information and data are gathered about the social, financial, political and historical drivers behind the disappearance of trees out of the Flemish agricultural landscapes and the current negative perceptions of farmers towards agroforestry and tree-planting on the farm. A first part of the data is gathered through content analysis, a research technique used to make replicable and valid inferences from books, book chapters, essays, interviews, newspaper articles, historical documents, etc. (Krippendorff, 2013). The second part of the data collection exists of two series of in-depth interview with farmers. In a first series of 20 interviews the focus will be on the historical evolution from a natural agroforestry-situation in Flanders to an agricultural landscape that is largely without trees. The respondents will need to describe the historical and current situation with respect to trees on the farm and describe the most important processes and drivers that have contributed to and/or supported this evolution. As such we try to get a picture of trees and hedges in a historical perspective. We take here the methodology of Peterson (2005) as an example, who interviewed 20 farmers about trees as part of their production system during a walk through the farmers' own land. In the second series of 20 in-depth interviews the focus will be on the perceptions of the farmers towards agroforestry and trees on the farm. The questionnaire that was distributed to a group of farmers in 2012 will be used here as a starting point to explore why farmers believe in certain advantages or disadvantages in more detail.

3 Expected and preliminary results

The questionnaire about agroforestry that was distributed to farmers in 2012 already pointed out that the low adoption rate of agroforestry in Flanders is mainly related to farmers' limited knowledge of the practice and negative perceptions towards its' profitability and compatibility within their current farming system. Some test-interviews already showed that farmers associate agroforestry systems mainly with crop production losses and have difficulties to estimate or appraise the benefits of the tree component in the long term. Furthermore farmers consider time restrictions and mechanization difficulties as very important drawbacks of trees on the farm.

A literature review already indicated that the situation was different in the past. Flanders counted before much more agricultural holdings which were much smaller. According to Platteau *et al.* (2013) the number of farm units in 2011 amounted up to 25.982, which is a decrease of 63% in comparison with 1980. At the same time average farm size doubled over the past thirty years to 23.6 ha, which proves the current scaling up practice in Flemish agriculture. This scaling up practice is related to the land consolidation processes that found place from the 1950's onwards with the original goal to improve food productivity. This implied a clustering of the fragmented parcels into large units with an optimal rectangle shape and located adjacent to the farm, resulting in the disappearance of traditional hedges and bocage-elements separating different parcels (Pauwels, 2014). Also the initial EU Common Agricultural Policy (CAP) from the 1960's till the 1980's has influenced negatively the amount of trees and hedges in agricultural fields by focusing on maximization of agricultural production (Howarth, 2008). This is in contrast to the actual CAP, of which 30% is greening payment and depends on the implementation of agricultural policies beneficial for climate and the environment (EU, 2013).

4 Discussion – Conclusion

The overall aim of this study is to explore the main drivers and processes, in the past and in the present, that make Flemish farmers today reluctant with respect to tree-planting on the farm. The preliminary results already indicate inter alia the scaling-up practices and land-consolidation processes in Flemish agriculture from the 1960's onwards, the increasing level of mechanization and the CAP as important drivers of the disappearance of trees and hedges out of agricultural parcels. Previous interviews also pointed out that farmers consider a lack of time, mechanization difficulties and possible crop production losses as important drawbacks to plant trees on their farmland. These findings will be complemented with the results of our interviews that are planned in the near future. As such we hope to give recommendations for the design of appropriate agroforestry systems that address Flemish farmers' needs.

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Participatory design of irrigated landscapes to limit the risk of water crisis

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1 Introduction

In Europe, the recent development of environmental public policies (e.g. European Water Framework Directive) highlighted structural water deficit situations, of which many sub-basins of the Adour-Garonne watershed (France). In these rivers, flows are regularly observed below the regulatory low-water flow levels. These recurring "water crises" are mainly linked to agricultural withdrawals during periods of natural water shortage. The French law on water and aquatic habitats (LEMA 2006) seeks to balance water demand with resources and to promote territorial management through stakeholder involvement. In some basins, this means to significantly lower agricultural withdrawals while irrigation is a key production factor for farming systems. Opportunities for water storage development being limited, the current challenge is to help stakeholders design cropping systems and water management strategies that conciliate both water resources protection and economic viability of agriculture.
Our work aims at developing a generic and participatory design and assessment methodology to identify site-specific pathways to balance the dynamics of agricultural water demand and water resources availability. The methodology allows stakeholders to first model the socio-agro-hydrological system (SASH) based on "hard" and "soft" methods, knowledge and tools, and then to design and assess alternatives (Murgue *et al.*, 2015). This communication presents the implementation of the methodology in a sub-basin of the Adour-Garonne watershed.

2 Materials and Methods

We used as case study a 800 km² irrigated territory: the downstream part of the Aveyron watershed (water deficit is about 5 million m^3 in dry years). We identified and interacted with two stakeholders' collectives: one is representative of the agricultural stakes, the other of the water management and aquatic environments stakes. Our methodology is structured 3 steps: (1) co-construction of a shared, fine and dynamic representation of the current SAHS, (2) co-design of potential options of change for cropping systems and their spatial distributions, (3) simulation and evaluation of alternatives using the MAELIA multi-agent simulation platform (Therond *et al.*, 2014). Both collectives were involved in every steps of the procedure, either separately or jointly, in individual open interviews, collective mapping or designing workshops. Our participatory approach was based on the use of models (representation, simulation and evaluation of the socio-environmental system) as boundary objects to facilitate the flow of information between science and society. To represent the current situation of the SAHS (step 1), in line with the concepts of (Yeager & Steiger, 2013), we enriched quantitative geo-datasets by mapping peoples' spatial, qualitative knowledge on bio-physical features, hydrological dynamics and distribution of cropping practices in the territory. Co-design of options (step 2) was a participatory process where stakeholders were asked to specify changes in cropping systems and their distribution within the irrigated landscape. The facilitator provided a sequential framework to progressively elicit tacit knowledge, allowing to widen the possibility space and then to refocus it on key elements (Fig. 1). Eight options of change were specified each including an acceptability threshold expressed as a percentage on a farm's candidate area.

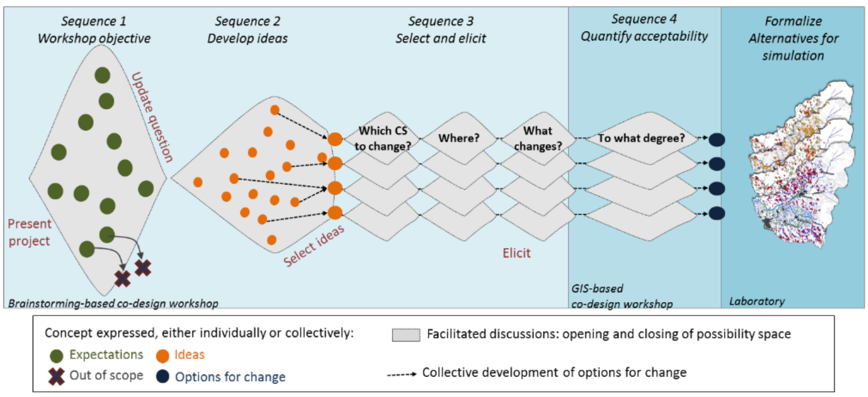

Fig. 1. Organization of the design process.

On the basis of the designed options, two alternatives (a combination of some options) were assessed using MAELIA simulations (step 3): the use of early flowering cultivars for maize planted earlier (AltPrec) and the reduction of monocropping areas using winter cereals (AltRot). For both alternatives, we simulated the proposed acceptability thresholds as well as a range of higher thresholds in order to evaluate their potential to solve the water crisis issue in comparison with the simulation of the current situation (CurSit).

3 Results – Discussion

The modelling step resulted into a dynamic representation of the current SAHS into the MAELIA platform (19.000 parcels, 4 water resources types, flow regulation norms). This model of the irrigated territory is a multi-agent, spatially explicit simulation platform which can reproduce farmers' decisions (sowing date, soil management, irrigation) and water managers operations (dam releases and water use restrictions). The simulation can run day-to-day calculations, using ten years of observed climatic and hydrological data (2002-2012). The formal outcomes of the design process is a set of mapped cropping system distributions (rotation + cropping practices) in all fields of the landscape (Tab. 1).

Table. 1. Example of an option for change after the design workshop

Options	Objectives	Change in practice	Location criteria	Acceptability threshold
1. Adjust planting dates & precocity of grain maize	**1a.** Advance peak water needs (flowering)	Early planting / early varieties	Terraces, except for hydromorphic *boulbène** soil	20% of a farm's annual area of grain maize

The simulation of the formalized alternatives showed that using the proposed acceptability threshold, neither could solve the water crisis issue significantly. However both showed significant impact if applied on all candidate fields. $\text{AltPrec}_{100\%}$ reduces late season irrigation withdrawals but also significantly raises the need for early season dam releases to sustain river flows. $\text{AltRot}_{100\%}$ allows to reduce overall irrigation water volumes (39% of the deficit in a dry year -2009-), but its hydrological impact is variable. In fact as awaited, AltRot tends to raise river flows where irrigation is abstracted directly from the streams. However opposite to what is commonly thought, in situations where water is abstracted from stored water resources (individual dams), AltRot may lower hydrological flows due to less drainage (Fig.2). Our simulations also show that due to more winter cropping of wheat with AltRot, soils are generally drier at the end of summer than with wide spread irrigated maize monocropping system, which induces a longer time period with no or few runoff to rivers and so a longer period with low river flows (Fig. 2).

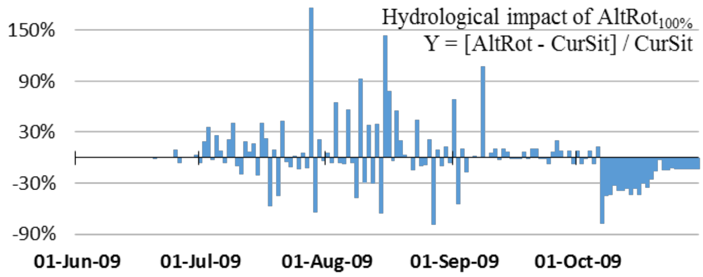

Fig. 2. Hydrological impact of $\text{AltRot}_{100\%}$ in the Lère sub-watershed, 2009

4 Conclusions

The design process required persistent interactions with the collectives. Both tackling water management issue through land use as well as thinking change in cropping systems at the scale of a 800 km² territory were challenging exercises. Participants expressed their views mostly in parametrical space (Shi *et al.* 2009) (i.e. manipulating structural entities of the model to express spatial distribution). The model previously built eased the process by acting as "hub" for knowledge: it gave spatial meaning to formalize participants' parametrical visions.
The integrated model of the socio-agro-hydrological system and the assessed alternatives provides sound, bottom up base material for discussing agricultural land management alternatives through additional iterative design-and assessment cycles.

Acknowledgements. Agence de l'Eau Adour-Garonne, the INRA ACCAF metaprogram, Région Midi-Pyrénées, the MAELIA Project. Experts and stakeholders, interviewees and participants of the workshops: Local farmers, governments agents (Direction départemental des Territoires 82).

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PARTICIPATORY PROTOTYPING FOR COMPLEX RICE BASED ADAPTIVE SYSTEMS DESIGN IN EAST JAVA, INDONESIA

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1 Introduction

Despite the continuous development of improved rice varieties, severe pest outbreaks due to the combined impact of extreme weather conditions and increased use of agro-chemicals, are considered to be the major reason for the current unstable rice production in Indonesia (Sogawa, 2015; Baehaki, 2011; Soemarwoto and Conway, 1992; Khumairoh et al., 2012). The process of designing sustainable rice production systems requires integrated approaches taking into account the existing local natural resources and indigenous knowledge, and allowing step-by-step adaptations. Complex rice-based production systems incorporating azolla, fish, ducks and margin plants enable the promotion of ecosystem services, stabilise yield fluctuations and foster farm viability, whilst minimizing environmental pollution (Khumairoh et al., 2012). However, huge variations in biophysical and socioeconomic conditions challenge the implementation of complex designs due to the wide range of components integrated and the necessity for proper balancing and exact timing. To this end, scientists have developed participatory prototyping approaches to improve traditional crop production methods (Bellec *et al*., 2012). The Farmer Field School (FFS) approach for Integrated Pest Management (IPM) in Indonesia successfully reduced the national pesticide use in the late 1990s. However, IPM practices dropped down due to pesticide subsidies which have been increased more than 30 times since the year 2000 (Sogawa, 2015). In order to find a formula to repeat their initial success, we complemented existing prototype design methods with FFS activities to attain robust complex agro-ecological rice production systems that can easily be adapted to specific locations and vice versa to develop FFSs that are more efficient and effective than before.

2 Materials and Methods

We formulated prototyping method to design complex rice based adaptive systems (Fig.1) by combining farm typology (Blazy et al., 2009) in step 1, simple experimentations on four pilot farms (Vereijken, 1997) by applying the FFS approach in step 2 and adjustment of the proposed design in step 3.

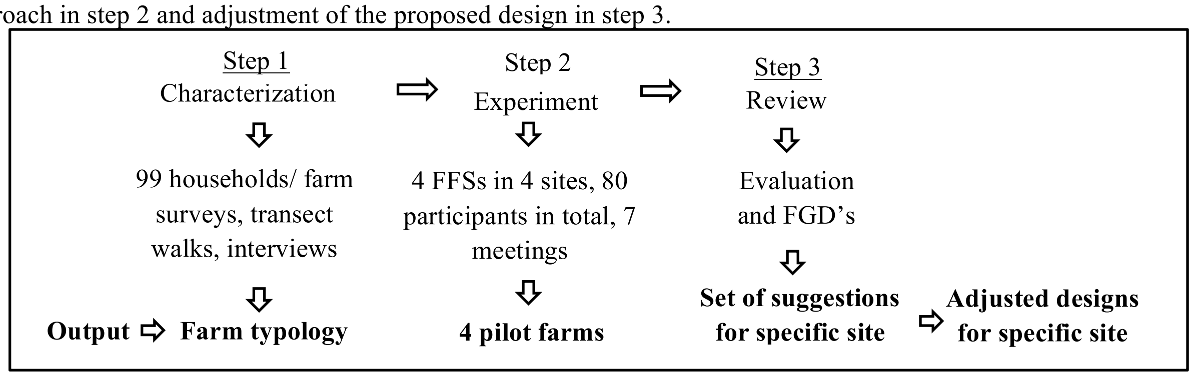

Fig. 1. Prototyping steps for complex rice-based system design. FFS: farming field school; FGD: focus group discussion.

3 Results - Discussion

In **step 1** we sampled 99 farmer households across four districts in East Java from 2014 to 2015. Each in-depth interview lasted approximately 2.5 hours. We live in a farmer household in each district during the survey to understand their daily farming activities. Questionnaires were divided into three categories; farm performance, cultivation methods and farming context. The description of variables to establish a farm typology is provided in Table 1. In **step 2**, we conducted FFSs in four districts. Each FFS contained of seven meetings. The first meeting was started with Rapid Rural Appraisal (RRA), formulized the objectives namely stabilising rice yield, reduction of pollution, external inputs and operational costs and was followed by establishing a learning agreement. In 2nd-5th meetings we conducted a simple experiment in pilot farms consisted of three treatments; conventional, organic and complex rice plots that were replicated two times. Meeting 6 was a cross-visit for 2 FFSs and involved watching agro-ecological movies for another two FFSs. In the final meeting as part of **step 3**, we evaluated FFS processes to develop innovative, efficient and effective FFSs, followed by FGD on the proposed complex rice adaptive systems design to get suggestions for ideal designs to be adjusted to local conditions and to available resources. At the time of writing, rice in experimental plots were harvested in two sites while two other sites are in the ripening stage. However, current plant performance visually shows the difference between treatments. In general, plots treated with complex elements performed better than organic, and similar or even better than conventional plots. Despite a devastating rat attack in one study site in Malang where many farmers failed to harvest their rice grain, the experimental plots were able to avoid high losses. Moreover, the side products from ducks and intercropped plants avert further deterioration. It implies that the proposed design successfully reduces pollution due to zero chemical application while increasing yield stability. FFS can be a useful tool to formalize farmer's roles in prototyping farm designs. However, conventional FFSs with high meeting frequencies, monotonous activities, sticking to only morning time and limited target need to be reformulated to further improve the sustainability, cost efficiency and effectiveness. One simple example is to replace cross visit sessions by watching movies on agricultural innovations which will greatly reduce costs while diverting tedium effects from some flat activities during FFS meetings.

Table 1. Variables used to set a typology of rice production systems in East Java

Variables	Units	Variables	Units	Variables	Units
FARMING CONTEXT		**Economic sources**		Marking	-
Bio-physical		Land ownership	-	Direct/ transplanting	-
Altitude	m.a.s.l	Off-farm income	USD year^{-1}	Planting distance	-
Precipitation	mm	Land fragmentation	#	Seedling age	days
Topography	-	Cash flow	-	Seedling number/hill	#
Soil types	-	Investment capacity	-	Amount of seed	kg ha^{-1} cycle^{-1}
Soil texture	-	**CULTIVATION METHOD**		**PERFORMANCE**	-
Irrigation condition	-	**Inputs**		**Agronomy**	
Polyculture	-	Organic fertilizers	kg ha^{-1} cycle^{-1}	Cultivation number	Units year^{-1}
Rotation	-	Synthetic ferlitizers	kg ha^{-1}cycle^{-1}	Rice yield	t ha^{-1} cycle^{-1}
Rice field size	m^2	Fertilizer applications	#	**Economic**	
Bund size	cm	Herbicides	kg ha^{-1}cycle^{-1}	Input costs	USD ha^{-1} cycle^{-1}
Social		Herbicide applications	#	Labor costs	USD ha^{-1} cycle^{-1}
Contact with extension	-	Pesticides	kg ha^{-1} cycle^{-1}	Rented machinaries	USD ha^{-1} cycle^{-1}
Training	-	Pesticide applications	#	Rice margin	USD ha^{-1} cycle^{-1}
Age	Year	**Planting**		Whole farm margin	USD ha^{-1} year^{-1}
Engagement to farming	-	Pre-weeding	-	B/C	-
% of family involved	%	Weeding types	-	**Social-environmental**	
% of family labor	%	Weeding frequencies	#	Chemical active ingredient	kg ha^{-1}cycle^{-1}
Total work hours	Hours	Weeding equipment	-	M/F labor	-

4 Conclusions

Farmer-participatory prototyping appeared to be a successful approach for redesigning current rice production systems into more complex adaptive systems. However, the process is challenging due to the existing large variation in biophysical, social and cultural conditions. Nevertheless, valuable learning tools to gather information about indigenous knowledge and local natural resources for adjusting the proposed designs to a specific site were provided. In order to achieve multiple objectives the presented three-step participatory prototyping methodology could be considered as a promising tool. However, further developments are needed to increase its efficiency and effectiveness.

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Innovative design of smart farming systems: Some insights from the enhancement of native mycorrhizae in Martinique

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1 Introduction

The consensus in support of agroecological principles gained more and more currency with the exacerbation of global changes (Tomich *et al.*, 2011). The natural capacity of ecological systems to adapt to shocks is being exceeded (IPCC, 2014). It reaffirms the importance of human intervention to promote their viability through innovative methods that activate ecological processes. Mobilizing biodiversity offers new lines of action (Doré *et al.,* 2011) and is likely to lead to *smart agriculture* (FAO, 2010). Unexplored potential of soil biodiversity may enhance crop health and productivity, reducing the use of chemicals. For instance, mycorrhizae (symbioses between more than 80% of plants and some soil fungi) provide multiple input services (provisioning, regulating, supporting) and are of growing interest for the ecologization of agriculture. Valorizing mycorrhizae requires to promote a holistic farming system approach and to develop agroecological engineering strategies based on knowledge-intensive sharing process (Angeon & Chave, 2014). An innovative design strategy based on the KCP® (**Knowledge Concepts Propositions**) methodology (Hatchuel *et al.,* 2009) was experienced with horticulture producers in Martinique.

2 Materials and Methods

A partnership gathered researchers (4), technical advisers (4) and farmers (19) to build and take part in a new thinking area on the valorization of mycorrhizae. Three stages were implemented:

1. A collaborative workshop for sharing **Knowledge** and exploring the mycorrhization **Concept**.

Knowledge available in scientific literature shows deficient information on mycorrhizal networks mobilization in agriculture. From a scientific review two paradoxes were identified: i) Although mycorrhizal fungi are present in most of the soils worldwide, the inoculation of standard propagules (mycorrhized roots fragments or spores) is the most spread technology. In soil, these industrialized products are in competition with native mycorrhizae. ii) Few information on agricultural practices necessary for an efficient development of mycorrhizal networks is provided.
Hence, the partners were involved in exploring the concept of mycorrhizal networks mobilization. Three steps aimed at sharing knowledge on « How to enhance and benefit from mycorrhizal networks?» : i) an experimental design based on native mycorrhizal networks mobilization through chive (*Allium fistulosum*) and tomato (*Lycopersicon esculentum*) intercropping, ii) a pedagogical model -representing soil interactions- to understand how to mobilize latent mycorrhizae, iii) a card game to co-construct mycorrhizal networks friendly practices (limiting tillage, reducing chemical inputs etc.).

2. Surveys to assess **Knowledge** and **Concepts** appropriation

Surveys were conducted on farm to situate each of the 19 farmers in learning loops (Argyris & Schön, 1996). The interviews were run on two items: i) mycorrhizae nature and functions, ii) agricultural practices and farming system design. Farmers' answers were assessed in four levels of learning: 0. no learning; 1. simple knowledge acquisition (which does not result in any action); 2. incremental acquisition of knowledge resulting in action; 3. radical acquisition of knowledge (change of values that allows for redesigning farming systems).

3. A collaborative workshop to combine emerging **Propositions** in a design strategy

Two steps were proposed: i) the results of the experimental design and the survey were debated with farmers. ii) a concept-projector for mycorrhizae mobilization was introduced to orient collective creativity for the future. It consisted of the presentation of a virtual start-up producing local selected mycorrhizae strains.

3 Discussion

The farmers' learning processes were analyzed. Among the 19 farmers, two cohorts significantly differed (Student test $\alpha<0{,}05$ p-value $< 0{,}0003$) regarding learning levels. 7 "best learners" (up to level 2) and 12 "in progress learners" (below level 2) were distinguished.
Experience and agronomic brakes were major constraints identified by both cohorts of learners (Fig. 1A). The agronomic practices and the organizational arrangements (Propositions) suggested by both cohorts of farmers to valorize mycorrhizae were capitalized (Fig. 1B).

"Best learners" identified less brakes than "in progress learners". They were able to overwhelm agronomic brakes and moved more easily from the knowledge-sharing phase (K) to the proposition of levers (P). They stressed the importance of collective arrangements to implement agroecological farming systems.

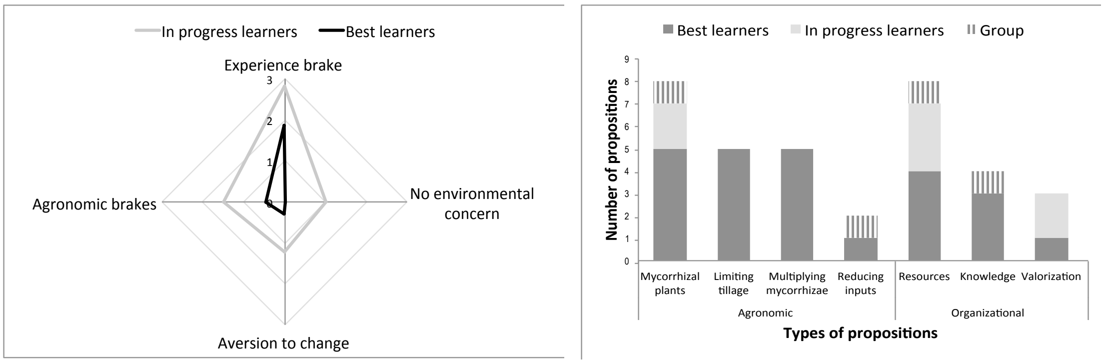

Fig. 1. Brakes (A) and levers (B) identified by farmers exploring the concept of mycorrhizae valorization.
"Best" and "In progress" learners significantly differed regarding learning levels (Student test $\alpha < 0{,}05$ p-value $< 0{,}0003$)

All the partners' propositions were synthetized in a concept tree (Fig. 2) starting from an initial concept "C0: mycorrhizae valorization" which is progressively divided in sub-concepts. Most of the farmers' propositions rely on the concept of mycorrhizal networks mobilization (C1) rather than on the use of propagules. All the farmers rejected the inoculation of standard and local selected strains.
On farm native mycorrhizae amplification (C2) was appropriated. The farmers suggested experimenting native strains production through mycorrhizal crops cultivation in given pedoclimatic areas (C3). Hence, farmers proposed to implement collective arrangements to define the convenient technology. Indeed, on farm native mycorrhizae production is labor-intensive and uncertain (Douds *et al.*, 2005), and the work organization is cost-consuming. It necessitates cooperation between farmers and technical advisers to be developed efficiently.

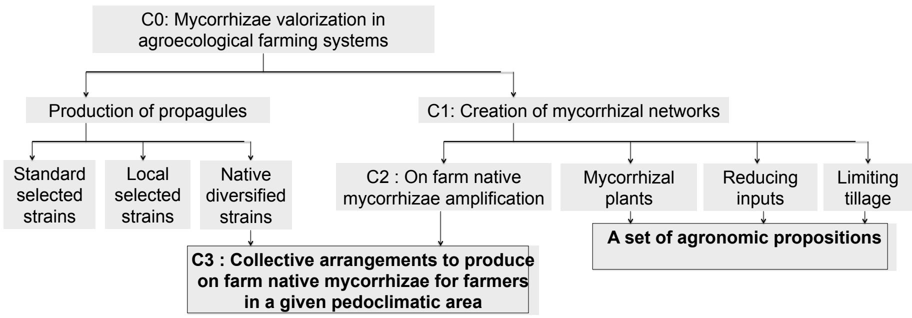

Fig. 2. Concepts tree from C0 to C3. Partners explore the concept of mycorrhizae valorization.
Bold letters indicate farmers' proposals.

The whole KCP® approach resulted in a common research-action project to help farmers to implement C3.

4 Conclusions

The innovative design of smart farming systems based on native mycorrhizae led in Martinique illustrates the pattern of a strong ecologization of agriculture. Further experiences in other contexts will help understand how the mycorrhizae valorization case study supports different agroecological transition pathways.

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Integrated Farming System for Sustainable Rural Livelihood of small and marginal farmers of North Eastern Transitional Zone (Zone-1) and North Eastern Dry Zone (Zone-2) of Hyderabad Karnataka Region

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1 Introduction

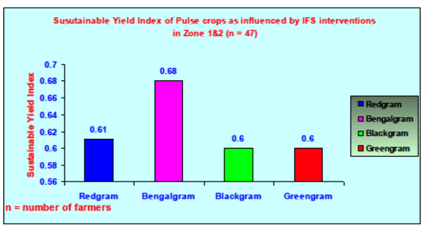
Integrated Farming System (IFS) is a complex interrelated matrix of soil, plants, animals, implements, power, labour, capital and other inputs controlled in part by farming families and influence to varying degree by political, economic, institutional and rest factors that operate at farm level. Under the existing agrarian structure, most of the rural farm families are of small and marginal in nature that are living below the poverty line with the continued threats to their livelihood security characterized by low in food security and income, unemployment, health problems, education etc. Due to this reason, these categories of farmers are poorly adopted to the changed farming scenario especially in rainfed areas (Lal and Miller, 1990). Further, this section of farming community is very much susceptible to the natural vagaries (drought & flood) and resulting in large scale migration to urban areas for seeking livelihood opportunities. Keeping in view of these problems, the innovation on IFS developed by University of Agricultural Sciences, Raichur (UASR) addresses the following major constraints have been demonstrated on farmer's farms in Zone 1&2 of Karnataka state during the year 2010 and 2011. To ensure the consolidation of the natural resource base at farm level and offers better opportunities for adoption of improved technology/ies with the target of enhancement of overall production and productivity of the farm. To provides an opportunity to arrive at appropriate combination of the enterprise through interlinking of different farm enterprises for the effective use of natural resources available at farm level and for recycling of nutrients on the farm. And this technique ensures in the creation of better awareness on the adoption of technology/ies which can lead to sustainable production process with on-farm employment creation to support livelihood of the rural farm families.

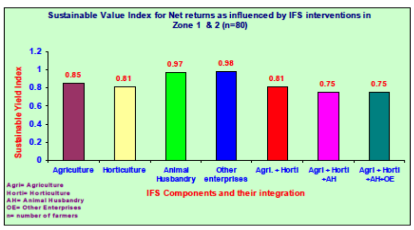
2 Materials and Methods

On farm demonstrations (40 farm families) on integration of different components with crop in Integrated Farming system mode and recycling of resources within the system were organized in Zone 1 and 2 of northern Karnataka during 2010-2011. Villages and Farmers in the zone were randomly selected and rational information from Participatory Rural Appraisal (PRA). This information was used for redesigning the farming activities to develop tailor made IFS modules for different farming situations. The ToT centers under identified agro-climatic zone had selected the farmers having 1 to 2 ha of agriculture land. Based on the PRA analysis suitable action plan was prepared and executed on the farms during 2010-11 and 2011-12. Based on need, choice and resources available on the farm, different allied activities such as horticulture, dairy and vermi compost pits were suitably incorporated into the production system with an aim of generating income and employment for the farm family through economically friendly model to get regular income, employment and livelihood security. The crop and animal residues were recycled for vermi composting for use in the crop field. Budgeting and accounting of all the farm activities were calculated using standard procedures.

3 Discussion

North Eastern Transitional Zone (Zone-1) and North Eastern Dry Zone (Zone-2) of Karnataka cover Bidar and Gulbarga districts with moderate climatic conditions. Looking to the agro-climatic zone 1 & 2 features, to improve the productivity levels of the farm, the farmers were advised to follow the action plan in which the technologies involved laid greater emphasis on the cultivation of pulses followed by cereals, oilseeds and vegetables.





The productivity enhancement after intervention and stability in crop productivity was noticed as indicated by higher sustainable yield index in crops adopted in all farms. In zone 1, 2 among cereals bajra recorded higher (0.60) sustainable yield index (SYI). Bengalgram recorded higher SYI than other pulses. The significant increase in productivity was recorded during the assessment year (2011) over the bench mark year in different food crops, commercial crops and vegetables grown. The increase in yield with different interventions in food grains mainly in bajra, sorghum, wheat was 41, 84, 80 per cent in zone 1 and 2, The change in productivity is variable and in constraint farming situations the interventions have greater impact and brought greater increase in yield (38 to 80 per cent) and stability in yield was noticed. This shows the impact of whole farm demonstration of IFS is significant because of improvement in natural resource base of the farmer and risk reduction. The tangible benefits of introduced vegetables production system were noticed in all the farm families and varied with crops and farming situations. In zone 1 and 2, brinjal, onion and cucumber noticed 36, 26 and 20 per cent higher productivity during 2011-12 as compared to benchmark year 2009-10. Sustainable yield index was higher with technological innovations in different vegetable crops. The new vegetable crops and varieties introduction in to the farms was one of the important interventions which enhanced the income of farm families, increased the cropping intensity, employment generation and nutritional security among farm families and surrounding rural house holds. Gill *et al*., (2009) also opined that, horticultural and vegetable crops can provide 2-3 times more energy production than cereal crops on the same piece of land and will ensure the nutritional security on their inclusion in the existing system. The whole farm analysis was done for different farming situations. The emphasis was given for the incremental changes with seasonal crops and with the other activities, with the introduction of new technologies, forced the farmers to re-organize substantial portions of their activities. Economic analysis was done by recording and the cost and income involved in crop production activities and for other farm enterprises. The monitory values used for comparing the alternatives that includes only those outputs sold for cash are those inputs purchased with cash. The sustainable value index in zone 1 & 2 ranges from 0.75 to 0.97. Higher sustainable value index were observed due to yield stability obtained with IFS interventions. Similar higher sustainable value index due to integrated farming system was also reported by Barik *et al.,* 2010 and Jayanthi *et. al.,* 2010.

Table 1. Productivity and Sustainable Yield Index in field crops as influenced by IFS interventions in Zone 1 & 2

Zone 1 & 2	Before intervention (BI)	After intervention (AI)		% Increase over BI		Standard Deviation	SYI
Food grains	**BI**	**2010**	**2011**	**2010**	**2011**	**SD**	**SYI**
Wheat	5.00	0.00	9.00	-	80.00	1.80	0.32
Bajra	4.60	6.25	6.50	35.87	41.30	1.86	0.60
Sorghum	3.90	7.03	7.19	80.26	84.36	1.82	0.59
Pulses	**BI**	**2010**	**2011**	**2010**	**2011**	**SD**	**SYI**
Redgram	4.90	7.72	8.00	57.55	63.27	1.98	0.61
Bengalgram	7.40	9.44	9.60	27.57	29.73	2.32	0.68
Blackgram	4.70	5.26	5.70	11.91	21.28	1.82	0.60
Greengram	4.30	5.00	5.10	16.28	18.60	1.74	0.60
Oilseeds	**BI**	**2010**	**2011**	-	-	**SD**	**SYI**
Soybean	0	10.06	11.2	-	-	1.537	0.496
Commercial crops	**BI**	**2010**	**2011**	**2010**	**2011**	**SD**	**SYI**
Cotton	17.5	24.5	36	40.00	105.71	3.81	0.62
Sugarcane	99.27	115	23	15.85	-76.83	7.71	0.62

4 Conclusions

The adoption of IFS results in reduction in the expenditure on external inputs namely, chemical fertilizers and plant protection chemicals along with the adoption of Integrated Crop Management Practices. In addition to this with the judicious use of critical inputs, the ill effects due to indiscriminate use of chemicals could be reduced to protect the environment. The IFS therefore refers to the farm as an entity with firm binding of inter departmental farming enterprises combination achieved to attain the overall development of the farm. In this regard IFS creates an opportunity to fine tune the agricultural technologies suiting to the farm situations.

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Structuring data gathering on organic farms: the transdisciplinary development and use of a farm scan within a broader methodological framework

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1 Introduction

In Flanders, organic suckler cow farmers meet at a regular basis to exchange experiences and knowledge. Within this network, an advisory service is involved to give advice on multiple aspects of the farming system. Research has shown that network organisation is rewarding to gain access to knowledge, to facilitate learning processes, and to foster knowledge creation (Van Wijk *et al*., 2003). Although effective management is linked to well-designed monitoring and evaluation (Stem *et al*., 2005), decision making of the farmers in this network is mainly based on practical experiences and perceptions. Comparable data and knowledge gathering by the farmers is lacking due to several reasons. For example, their accountancy systems differ. Furthermore, each farm is characterized by specific conditions. As a result, the farmers themselves are not able to organize efficient data collection to share within their network. However, monitoring and evaluation forms the basis for improved decisions making and improved management. Therefore, this study aims at the development of a monitoring and evaluating approach to improve decision making on organic beef farms. Through the use of a farm scan, we aim at gathering and structuring farm specific data in an efficient way to systemically examine interventions and to share this knowledge within their network. The development of farm scan is part of a broader methodological framework, which focusses on a system based, transdisciplinary approach. The system based approach aims at integrating knowledge on the complex relations within organic farms. The transdisciplinary approach focusses on the involvement of farmers, researchers and advisory services to facilitate the knowledge co-creation between stakeholders and scientists. A mixture of both quantitative and qualitative techniques for data collection is at the basis of this methodological framework and is described in depth by Marchand *et al*. (2015). In this paper, we focus on the iterative farm scan development and use in practice and discuss the experiences within the broader methodological framework.

2 Methodological framework and data collection

The first objective within the broader methodological framework was to reveal some determinative elements for successful organic meat production. As the active role of a stakeholder plays an important role in the success of a development process, participation was ensured from the start (Reed, 2008). Through observations and group discussions with five farmers (qualitative approach), the advisory service, and the network facilitators, main issues perceived as determinative for successful organic farming, were identified. In a second step, which is the focus of this study, a monitoring farm scan was developed to get more insights on the farmers' performance on each of these key aspects. A combination of quantitative and qualitative indicators are structured in a rapid farm scan, which can be considered as a tool to facilitate monitoring and evaluation. For data gathering and processing, researchers and advisors used a simple excel file. Benchmarking of the data was introduced through data from literature or by identifying best performances within the farmer group.

Through an iterative process the scan was validated and improved. This includes an evaluation of the scan data by the advisor followed by an in-depth discussion in a network meeting with the farmers. With this information, the researcher adjusted the farm scan and started with the following round of farm visits to collect new data. The iterative process thus encompasses an initial step of data gathering and structuring by the researcher, followed by a phase of data interpreting by the advisor and a final sharing and discussion step with the farmers.

3 Results - Discussion

We developed a methodology for structured monitoring and evaluation within an existing network of organic beef farmers. In contrast to conventional farms, where Belgian Blue is commonly used, organic holdings use different breeds, often from French origin. Therefore, the first determinative elements for successful farming, indicated by the farmers, were the cows' performances and the potential of the breed with respect to fertility, growth and carcass quality. Through discussions with advisors, relevant indicators were included in the scan and farm data on these key aspects were collected. Within the group of participating farms, animals are slaughtered at varying ages which results in differences with respect to carcass quality. On each of these five farms, a share of grassland is owned by nature

organizations. On this grassland, fertilization and tillage activities are under strict regulations, which limits productivity of the grassland. To reveal to what extent farmers are capable of using this area efficiently in their production system, total meat production/ha utilized agricultural area, which is the area that is cultivated for roughage production without this grassland, was calculated. Despite each farm system has its very specific approach, adjusted to the breed and other farm characteristics, sharing and discussing data was perceived as very valuable. Compared to the potential growth and carcass quality of the breeds used, which was obtained from data in the literature, none of the farms seem to reach this potential. Further insight into the production method and cost, might reveal whether carcass quality might be improved without increasing the production cost. Therefore, as a following step, more insight into the cost structure at each farm, might clarify to what extent optimizing farm management is valuable to positively affect carcass quality.
These examples illustrate how the structure and content of the scan is continuously evolving, dependent on the needs of the participants. This flexibility has been recognized earlier as an integral aspect of participatory monitoring and evaluation processes (Estrella & Gaventa, 2000). Another prospect of successful stakeholder participation is creating confidence between all stakeholders, with a sense of mutual respect between stakeholders involved (Reed et al., 2008). We had the advantage of starting a process within an existing network of farmers that were very open towards each other and towards data shearing and including researchers in this process. However, one of the challenges will be to maintain this trust when they want to extend the existing network towards other farmers. Data gathering has been done by the researchers so far. However, the transdisciplinary approach aims at increasing ownership of the tool both by the advisors and the farmers (Binder *et al*., 2010). As our approach progressed, farmers became more and more confident with the tool for continuing monitoring on the farm. In addition, the advisors became aware of the content and the what's behind the data of the tool. As a result, they are able to interpret the data and use it in their advisory task during the network meetings. However, although discussions on the data might reveal some interactions and trade-offs between different indicators, this knowledge is not structured in the farm scan. Nevertheless, as a system based approach is characterized by considering bio-physical processes within their socio-economic context, other methods can be applied to structure these relationships and trade-offs. This is also acknowledged by Stem *et al*. (2005), emphasizing that monitoring and evaluation approaches cannot solely be based on quantitative information. Additional qualitative data might help to provide a more complete understanding of the processes, which is further described in the framework of Marchand *et al*. (2015).

4 Conclusions

This paper focusses on the transdisciplinary development of a farm scan, as a part of a broader methodological framework. With this farm scan, we aim at structuring monitoring and evaluation on organic farms through involving stakeholders during the development and implementation process. This did not occur as a linear process, however, development and implementation almost occurred at the same time through an iterative transdisciplinary approach. This study illustrates how we succeeded at initiating a process of data gathering on the farm level and using this data within an existing network of organic beef farmers. Furthermore, this process permits farmers to get further insight into strengths and weaknesses and reveals opportunities for potential new farm strategies. However, continuing this process warrants enough discipline and commitment of both advisors and farmers to use this tool as a monitoring tool on the farm level and as a basis for exchanging knowledge in the further network activities. It might evolve towards a database for other farmers and attract new farmers to the network.

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Co-innovation as an effective approach to promote changes in farm management in livestock systems in Uruguay

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1 Introduction

In Uruguay, livestock production involves 65% of the family farmers and more than 70% of the area of the country. Low levels of sustainability were diagnosed in livestock family farming systems based on natural grasslands in Uruguay, being the main causes low meat yield and income. Scientific evidence shows that it is possible to increase production while preserving natural resources and enhancing ecosystem services through changes in management practices of pastures and animals (Nabinger *et al.*, 2011). However, during the last decades low levels of technological innovation has been applied in livestock systems. Lack of improvement by farmers could be explained by the weakness and the traditional approach of the extension service. From a traditional approach, innovations are designed externally to the systems and farmers adopt those innovations by an "extension" process. Extension linearly involves awareness of the problem by the farmer, interest in the solution, evaluation, experimentation and finally adoption (Cramb, 2000). Nevertheless, the active participation of the farmers in the diagnosis and redesign might maximize the impact of the proposals generated, promoting learning processes that support innovation in practices in the long term (Leeuwis & Van der Ban, 2004). The co-innovation approach combines complex systems theory, social learning and dynamic project monitoring and evaluation to stimulate strategic re-orientation of family farm systems (Rossing *et al.*, 2010). We hypothesized that a systemic and participative approach such as this one is necessary for re-designing productive systems in order to improve their sustainability, being the learning process in farmers as important as the bio-physical changes in their production systems.

2 Materials and Methods

The co-innovation approach was implemented in 7 family livestock farms located in eastern Uruguay between 2012 and 2015, in order to generate and evaluate changes in systems sustainability. The approach involved characterization and diagnosis of the farm system's sustainability, re-design, implementation, and monitoring and evaluation of system evolution (Dogliotti *et al.*, 2014). By using the systems approach, an agreed baseline of farms sustainability was generated based on farm information of the three previous years before starting the project. To explore alternatives for re-designing, simple models of farm operation, scientific information and information obtained from other production systems were used. Feeding and financial budgets were performed to assess the impact of re-design. This process was carried out with farmers and their families, letting them choose the final alternative. Monthly visits to the farms were done to implement, support and monitor the process.
This project was based on a multiple case study design in which each farm constituted a case study. The study of multiple cases does not attempt to represent family farmers, rather it is based on replication logic: each case replicates a broader theoretical framework (Yin 2003). The research strongly relies on primary data, which emerges from the combination of different techniques: monthly visits to the farms to monitor and gather data on a series of environmental and economic-productive indicators, and a series of in-depth interviews throughout the project, and a historical analysis of the main milestones that have shaped the life of these farmers to study the main changes and learning processes that have taken place at the micro (family) level.

3 Results – Discussion

After two years of project implementation, significant improvements were achieved at different levels. Adjusted stocking rate and sheep-to-cattle ratio, combined with improved grazing management of the natural grasslands allowed increasing on average 20% the cow´s pregnancy rate and 24% the meat yield per hectare. Farm income increased 40%, as the proposals did not increase productive costs and improved animals' sales strategies. Improved management resulted in an increase in standing biomass of natural grassland, minimizing soil erosion risk and preserving biodiversity.
Changes in farmers' vision and in the way they think and decide on their farms were identified, being a key element for the project approach. The way farmers expressed main changes reflects an understanding and belief in what they are doing, as well as a consciousness about why they have made changes, and its implications (Table 1).

The improvements achieved at farm level, based on farmers learning, were also recognized, being critical for supporting innovation in practices in the long term.
Furthermore, farmers' shared perception is that the project has changed their life at the farm. Their perception regarding the use of time has changed, as well as the type and complexity of the tasks associated to farm management, their future prospects, their goals and their overall approach to the farm.

Table 1. Farmers' perception about the main changes in their farms

Sustainability dimension	Improvement area	Farmers' opinions related to changes in their farms
Bio-physical and Economic	Increased forage and meat production, improved reproductive efficiency. Increased net income.	"We have learned that we should not count how many animals we have, but how much meat we produce, and how many animals we need to produce as many kg of meat per hectare. Because we used to have too many animals per hectare, though with very low production."
Environmental	Soil, natural grasslands and biodiversity conservation.	"We have wasted and wasted the soil so much... now it is so difficult to get it back. Planting a pasture, as green manure. Always trying to leave some residue, not like in the past when we left only the ground and we kept nothing for restoration of the soil." "In pastures, for instance, the appearance of certain species that are indicators of good management of the natural grassland… besides the animals, the birds…"
Social	Use of the time.	"I notice that we are now more organized. And suddenly being more organized means working more comfortable… We are less demanded in winter, it used to be more complicated, but now as we have more forage, we are better prepared… We would have more time to do other things."
	Farm management.	"The pasture management has been very important. I learned a lot of pasture management, about forage height, how to see things I have not seen before. We just used to walk on the grass. We knew it was high or low. But now we can see other indicators in the grassland that are very good and sometimes we didn't realize they were so important."
	Methodological approach.	"The technician is talking about soils but also talks about the body condition of the animals, they cover a broad range of topics. The project has not put money, instead it has been about thinking." "On the technical approach, it has not only been about economics... being in close interaction has been key, and that technicians are so open, so sociable. It is essential that part of knowledge we have of each other… it allows to build confidence"

4 Conclusions

Farms' sustainability increased through a systems re-design. The involvement of farmers and their families in the farm diagnosis, in the development of alternatives for improvement and in monitoring progress was essential in order to promote learning processes to support changes. Changes in the farmers' vision of their own farm, and a new way of facing management decisions were found. The co-innovation approach was an effective tool for promoting changes in farms.

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How to co-build a viable farming model? Guadeloupe and Martinique Cases

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1 Introduction

The implementation of agroecological transition involves the creation of a societal agreement that must be shared with all the stakeholders of a given territory. This implies co-building processes for an effective transition and for perennial effects. To that extent, identifying and analyzing socio-technical conditions for the implementation of agroecological transition is of first importance. Taking as an example the French Caribbean, we wonder about the ability of these areas dominated by the productionist model of farms and facing exacerbated global changes (IPCC, 2014) to invent new futures by implementing agrotechnical and organizational innovations.

We make the hypothesis that agroecological transition comes not only from the ability of stakeholders to build a common paradigm on the viability of farming systems but also from the ability of each stakeholder to transform these production systems. This may involve the establishment of a specific model of territorial governance (both vertical and horizontal) that comes from market and non-market coordination between stakeholders. We then take viability as a « social construct » (Latour, 2010) arisen from collective and individual strategies. The aim of this article is to reveal and draw a map of the actors' understandings of what is necessary to reach viability of farming systems. Our reasoning unfolds in three steps. First, by reviewing the literature, we tackle the scientific context of viability. We identify three key dimensions constituting viability (economic, agroecological, socio-cultural and organisational). Second, we characterize the representations of the stakeholders questioned (Are the three dimensions mentioned? Which variables discriminate them?). Third, we explain in what extent the representations of the different categories of stakeholders diverge and the consequences that may occur on the propensity of the agroecological transition to occur in the studied territories.

2 Material and methods

To tackle how the viability of farming systems is described, our study focuses on two categories of stakeholders: farmers and institutional representatives. Both of them were asked to define viability in terms of objectives and constraints. To quickly collect views of the numerous farmers, we used the focus group method (spring 2013). Only came farmers with the most concerns, they were mainly the small and diversified ones. Using the stakeholders analysis (Mitchell *et al*., 1997) combined with the snowball non-probability sampling method, we conducted 20 comprehensive interviews with institutional stakeholders (local government officers and regional authorities) and non-profit organisations (autumn 2014).

The whole empirical collected material is explored through content analysis. We use qualitative rating scale to illustrate the position of each category of actor. The representations of the farmers from the focus groups (Fig. 1a, b) are presented below as well as those of the institutional stakeholders (Fig. 2a, b).

Fig. 1. a (objectives, *left*) and **1b** (constraints, *right*) Farmers' conception of viability according to agroecological dimension

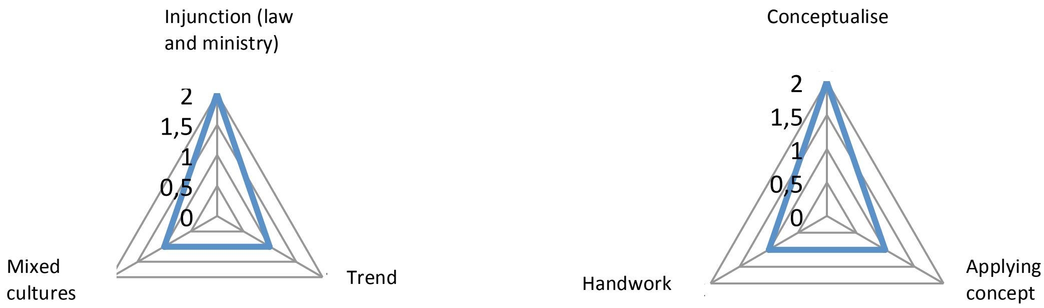

Fig. 2. a (objectives, *left*) and **2b** (constraints, *right*) Institutional representatives' conception of viability according to environmental dimension

3 Discussion

Our results show that: 1/ stakeholders do not have a common view on viability. The three dimensions of viability (economic, agroecological, socio-cultural) are addressed differently. Farmers have a more "holistic" perception of viability. They have no difficulty to fill in the different dimensions. Regarding for example to the agroecological dimension farmers have concerns about improving the environment (identity, pollution, natural capital) while institutions only tend to enforce laws. Then, farmers quickly initiate responses to agroecological practices in concrete terms. As a constraint, they point out that the structures that frame agriculture (rules, skills, training and finances) do not enable to implement traditional practices, still applied on the territory. From their side, institutional stakeholders identify limits to understand cultural and production systems that enable to operate that environmental efficiency of agriculture. Regarding to the other dimensions (economical, socio-cultural), results show the same prominences. Then, 2/ for some stakeholders, farming systems in the French Caribbean are viable while for others the end of an era has been reached. This is a threat to the transition toward agroecology. Finally, 3/ it appears that the viability of farming systems derives from negotiations, tensions and conflicts between agricultural stakeholders, a fact that impede the effectiveness of agroeocological transition. 4/ last but not least, our study makes appear a fourth, and unforeseen, dimension of viability which is the organizational one.

4 Conclusion

Our study shows that agricultural stakeholders have to negotiate new modalities on the ways and means to reach viable farming systems, by creating collective mechanisms to build new rules of actions within their territories: coordination of actors, project implementation, structuring space, creation of regulations (Leloup, 2010). Thus, there are some specific socio-technical conditions for the implementation of agroecological transition leading to a viable farming system in the French Caribbean. In that sense, these stakeholders could participate in the design of a territorial agroecological system (Duru *et al.*, 2014) which would be initiated through collective activities in 2016. This is a major challenge to ensure the resilience of those territories in the context of global changes.

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Agronomic knowledge for cropping system design: characterization and dynamics of mobilization

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1 Introduction

Redesign of cropping systems has been recognized as necessary to implement the agronomic principles required for an agroecological transition (Hill & MacRae, 1995; Meynard *et al.*2012). Namely, the systems targeted are biodiversity based, locally adapted, and more efficient in nutrient use and recycling. To carry out this design, agronomists have mainly worked on a *de-novo* redesign approach (e.g.Vereijken, 1997), and little research concerns *step-by-step* design processes although they seem to better correspond to the reality of the changes implemented by farmers (Chantre *et al.*, 2015). Specificities of *step-by-step* redesign processes are (1) a distant objective (e.g. reducing herbicides use by 50%, or reducing working time), by contrast with a definite target cropping system, (2) a necessary systemic reasoning, (3) numerous uncertainties related to emergent dynamics in natural processes mobilized and feedback loops, and dependency of techniques' results on local environments, (4) a necessary combination of short-term (imminence of the decision) and long-term time scales (e.g. time required for regulation establishment) in reasoning of actions. These specificities require an adaptation of the agronomic knowledge produced and mobilized in agronomic science. Several authors agree on the necessity to mobilize both scientific and local expert knowledge (Doré *et al.*, 2011;Faugère*et al.* 2011). Beyond this legitimation of diverse sources of knowledge, very few theoretical tools exist that make possible an analysis of the specific knowledge content that efficiently equips farmers' action during step-by-step redesign processes. We propose a characterization tool for agronomic knowledge and identify possible attributes of actionable knowledge all along technical changes applied by farmers.

2 Materials and Methods

We first based our analysis of knowledge attributes on a diversity of written documents which concerned three specific techniques (i) diversification strategy with the introduction of a leguminous species into the crop sequence; (ii) implementation of cover crops with diverse objectives (e.g. recycling of nutritive elements, soil structure conservation, weeds regulation); and lastly (iii) functional biodiversity conservation through the establishment of floral strips into the fields or at borders. Seventy-eight documents were analysed, combining scientific articles (15), agricultural press articles (38), and publications of technical institutes (25). A framework of attributes of knowledge was built from this analysis. Then, we applied the framework of attributes to analyse knowledge mobilized by farmers involved in a redesign process. Thirteen semi-directive interviews were held. Interviews were focusing on one or two specific technical changes identified with the farmer as salient in his management evolution and sufficiently recent in order to avoid bias linked with historical reconstruction.

3 Results and Discussion

A framework for knowledge characterization:
The characterization referred to seven main aspects: (1) formatting of evidence, (2) the temporality and dynamics, (3) uncertainties, (4) the objectives explicitly related to knowledge, (5) the elements of agronomic reasoning (explanation), (6) the references to agronomic situations, and (7) the monitoring and assessment of actions. In each of these categories, we identified the diversity of specific attributes (Fig. 1).
Although some attributes were equally abundant in the different types of sources (either present in more than 40% of documents for each type of source, or in less than 25%), some were unequally represented. For instance, descriptions of dynamics were much more common in scientific articles (73%) than in press or technical institutes' articles (24% for both). The same differences were found for factors of sensitivity as form of uncertainty (60%, 21% and 32% for scientific, press and technical articles respectively). By contrast, indicators for monitoring the action were identified in average ratios in press and technical articles (29% and 40% respectively), but never in scientific articles.
The analysis of interviews using the seven main aspects of knowledge previously described showed general trends in dynamics of knowledge mobilization all along technical changes. We could formalize these dynamics in three successive steps, and associate main attributes of knowledge mobilized in each step (Fig. 1). First step corresponds to the choice of a specific technique and the decision to apply it. Second step corresponds to an adaptation of the specific monitoring and management of the technique, toward a relative stabilization of action modalities. The third step

corresponds to the confirmation of the viability of the practice within a system of practices, and according to other technical changes it would require. Evaluation seems to occur at all steps, however in different forms (consistency of the agronomic principle related to the technique, efficiency of a specific actions sequence, viability of a new combination of practices). Surprisingly, quantifications were used only in the second step mainly for adaptation of the practice and its monitoring. Indicators were mainly mobilized in the first and second steps, and very rarely in the third step as evaluation tool of the technique. As a consequence, the value of our work was not to describe unique attributes of actionable knowledge, but rather to reveal necessary dynamics in combinations of different knowledge attributes.

				Steps of technical change		
				1 Choice of the technique Decision to apply it Preparation for implementation	2 One or several tests, Adaptation of specific monitoring of action Stabilization of operational method, Amplification	3 Evaluation of consequences on the system Other related and/or necessary changes
1.	formatting of evidence	1	to measure or validate a mechanism, or its effect		■	
		2	relative quantifications, orders of magnitude			
		3	accurate, absolute quantification		■	
		4	photographs			
		5	narratives	■		
2.	temporality and dynamic	1	dynamic explicitly addressed		■	■
		2	time step of the main concerned object			
		3	larger time scale than concerned object		■	■
3.	Uncertainties	1	limits of a farming practice			
		2	ignorance about the technique			
		3	sensibility		■	■
		4	probabilities of results (losses, failure)			
4.	objectives explicitly related to knowledge	1	numeric objective			
		2	logical objective	■		
		3	elements to (re)define objects concerned			
5.	agronomic reasoning	1	interactions between functions, or mechanisms, or variables	■	■	
		2	mechanisms (ecophysiology, biology, ecology, physics...)	■	■	■
		3	comparisons of technical options	■	■	■
6.	reference to agronomic situations	1	Local agronomic context	■		
		2	specific/limitant characteristics of the situation	■		
		3	type of system and interactions with existing practices	■	■	■
		4	historical and initial situation	■		
		5	homology/analogy of problems and ways to solve them	■		
7.	Monitoring and assesment of actions	1	operating method, decision rule for implementation of action			
		2	indicators to confirm that action performed is the expected one		■	
		3	indicators for adjustment/monitoring of the action		■	
		4	indicators to evaluate the effects of a specific action	■	■	

Figure 1.: Framework for knowledge characterization. The first column corresponds to large categories or themes of distinction. The second column reports more specific modalities within these themes. The three last columns show the knowledge attributes which were mobilized in more than 50% of cases in different steps of technical change.

4 Conclusions

The characterization we proposed for agronomic knowledge in step-by-step redesign processes revealed the necessity to focus on the content of knowledge, beyond the fact that it is an expert or scientific knowledge. The framework built showed a dynamic of mobilization of knowledge in three successive steps when applied to farmers' technical changes.
The framework could be useful for identifying mismatches and hindrances in redesign processes, and to help organizing dynamic advisory support service along time courses of redesign processes. Specific attributes analysed as necessary, for instance concerning references to agronomic situations, also give agronomists guidelines concerning the knowledge that should be produced.

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The need for agronomic indicators to monitor and assess action and to enhance learning loops during cropping system redesign process

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1 Introduction

The re-design of cropping systems towards less dependence on synthetic inputs generates strong uncertainties for the farmers who are confronted to incomplete knowledge on their growing processes (Duru, 2013). The results of actions are highly dependent on local biotic and abiotic conditions (Horlings & Marsden, 2011), which are often unpredictable themselves. In an agroecological paradigm, farmers handle local environment characteristics relying on biological regulations, which are steered thanks to techniques with partial and complementary effects. The farmers need to act within short term of decision making, but with the aim to make the system evolve over the long term, which necessitate to now if the system is evolving in the targeted direction, but also to re-adapt the actions according to the results obtained, to validate new combinations of techniques. However, specific indicators that make possible such monitoring of systems‟ evolutions are seldom described in the scientific literature. In agronomic sciences, we notice a steady progress in analysing and understanding natural processes and dynamics of agroecosystems, and indicators have been formalized to get easy access to information about complex systems. However, these indicators have mostly been used to assess the impacts of existing or simulated practices, according to several dimensions such as agronomic, economic, environmental and social (Bockstaller *et al.*, 2008). As a consequence, their definition and specificities are not dedicated to farmers‟ actions support. Hence, we propose an analysis of indicators actually mobilized during step-by-step redesign processes and compare them to the indicators usually produced by agronomists.

2 Materials and Methods

In order to reach the widest variety of indicators used in redesign actions, we gathered a panel of case studies. First, we interviewed 11 farmers identified as being in a redesign process, located in Ile de France, Pays de la Loire and Centre regions (France). We realised semi-directive interviews focusing on specific technical changes to identify indicators in narratives about recent actions. We then completed by interviews of actors (5 farmers, 2 advisors, and 2 project managers) from a redesign project which lasted from 2003 to 2011. In this case, we could ask farmers about specific indicators that were used for group animation, which gave access to long term related roles of indicators. Finally, we observed meetings of farmers. Most of them were visits of experimental fields with tested cropping systems. We identified the indicators mentioned in their comments about the situations and the states of the observed systems. For each indicator identified in the interviews, we defined on one hand the role(s) it played in the farmer's action and on the other hand the attributes that characterized it.

3 Results and Discussion

We collected 294 statements of indicators from the various case studies. 22 specific roles can be distinguished (Fig. 1), spread along the time course of the technical change, which implies that they are much more diverse than strict evaluative scoring of actions or techniques. Some roles correspond to a classical use of indicators proposed by agronomists (notably from advisory services) as a basis for decision rules and crop management plans specifications: trigger the action, refine a modality of action, identify specific feature of situations to adapt a technical choice. We also found roles corresponding to the classical evaluative use of indicators. Some correspond to the farmers‟ need to evaluate the results of specific technique: verify the viability of a technic, interpret the viability of a strategic choice. But the farmers also need to evaluate the consequences of this choice on the rest of their cropping system. This level of evaluation corresponds to the roles labeled „identify a direction of development of the system‟, „know that the system remains in (situations) states that one knows how to manage‟, „identify a strategic cause-effect link‟. Furthermore, we identified roles related to the learning process that occurs in action thanks to retrospective analysis of actions. Associated to identification of dynamics in the system and intermediary states, they are either observations made without the capacity to interpret directly (identify an intermediary state of the system to reinterpret the effects of action *a posteriori*), or identifications of a known necessary state of the system to obtain certain results („identify an intermediate state of the system necessary to reach a goal‟, „validate that intermediate state of system is reached‟, „ assess a potential to provide a specific function‟).

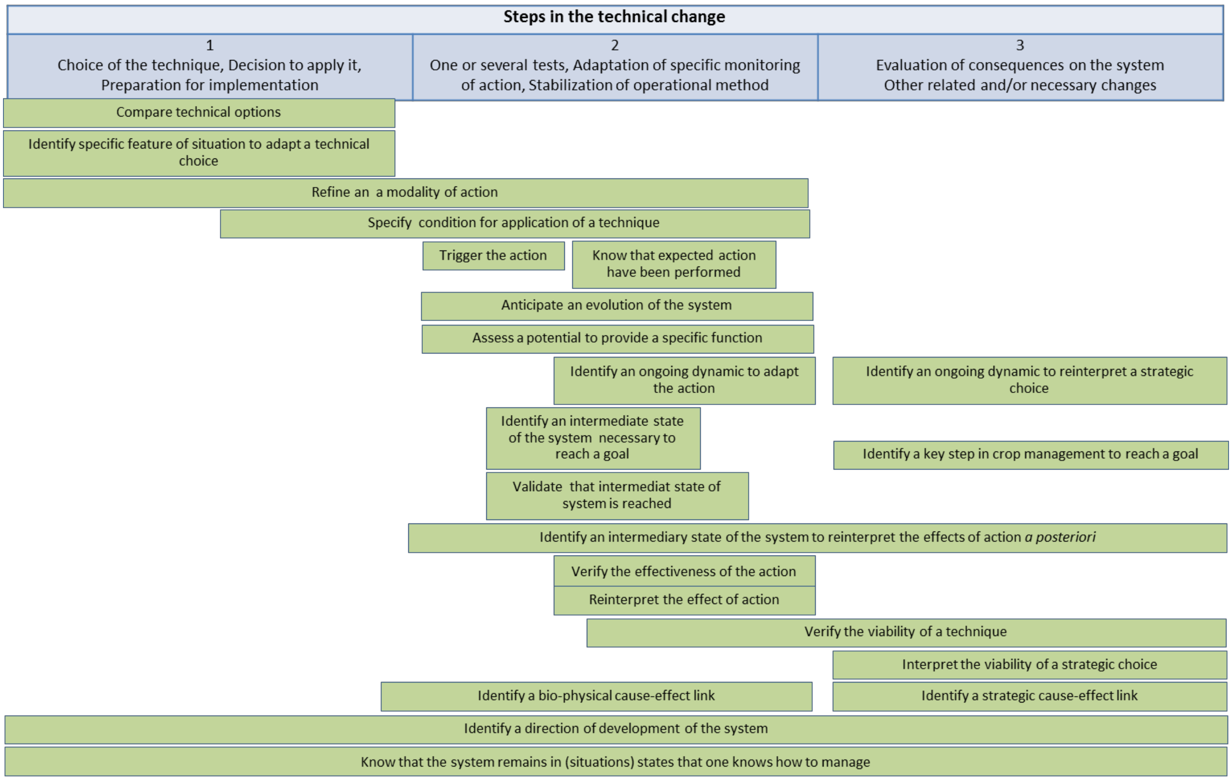

Fig. 1. Roles of indicators for farmers‟ action along the time of technical change

Attributes were specified according to several categories. We distinguished their nature (visual, physico-chemical feature, calculated, measured), form of description (binary, relative, quantified in absolute terms, in reference to an initial situation, or in reference to a value in a group of farmers), their time scale (multi-year, time scale of the object of action, on information acquired subsequently to the object of action, long term evolution), their spatial scale (object of action or plant individual scale, other object than the one targeted through action, field, farm), their mode of acquisition („active‟ meaning that an instrumentation is settled, e.g. the double-density sown strip, by contrast with „passive‟, meaning that spontaneous phenomenon are observed: Fränzle, 2006), and their frequency of assessment (static, repetitive).
We illustrate relations between roles and attributes with two examples. First, whereas indicators for triggering the action are usually related to quantified variables in reference to threshold, or date, this role was associated to very diverse attributes, such as for instance, visual and relative observations of state of the object (e.g. relative height of cereal and legume crop in intercrop), or tendencies deduced from repeated observations. Second, a unique indicator may have distinct roles at different time for a farmer. Yield (quantitative, absolute) was used to validate the viability of a technique, but also to reinterpret the effect of a specific action or identify a key step in crop management, to identify strategic cause-effect links.

4 Conclusions

Rather than propositions to improve the quality and reliability of existent indicators, we bring propositions to explore and develop new types of indicators. Three types of indicator seem to be particularly lacking among those produced by agronomists: the indicators that make possible to monitor an action supposed to produce result mainly over the long term, the indicators that facilitate learning loops required for application of innovative and poorly known techniques, and the indicators that make possible to evaluate the effects of new actions implemented and the adaptation of specific modalities of operational methods. We emphasise that „visual‟, „relative‟, „related to dynamics‟, and „passive‟ attributes should be regarded as contributing to these new roles of indicators.

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De novo design workshop: a method for co-designing innovative cropping systems

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1 Introduction

As agriculture is facing challenges such as environmental degradations, climate change and demographic increase, strong changes in farming systems are needed. Among prototyping and co-design methods useful to prepare system changes, co-design workshop method (Reau *et al*., 2012) aims at *de novo* designing cropping systems (CS) (Meynard *et al*., 2012). Based on its successful implementation in several case studies in France and Spain, we present the method, the goals of each step and examples of results from a Spanish case study.

2 Materials and Methods

The method begins by the definition of the main goal that the CS needs to fulfill (e.g. achieving low Green House Gas emissions): a single goal, and a distant and ambitious target are a way for getting out of a routine and to stimulate the imagination of the participants. This goal could be defined from the negative impacts of the CS mostly practiced in the study area. Then, the design workshop is organized in three steps:
Step 1-Sharing knowledge. Scientific experts specialized in the area covered by the goal provide the other participants (e.g. agronomists working as advisors in extension services, farmers) with generic knowledge about the main processes involved in the goal previously defined (e.g. C and N cycle if the main goal is to achieve low-GHG emissions) and about the way the several elements of the CS (e.g. nature of the crop in the crop sequence, crop techniques of each crop, residues management, etc.) influence them.
Step 2-Expressing technical options or functions (ideas). Participants make single proposals aiming at contributing to the main goal previously defined, and using the located knowledge as well as the generic knowledge shared in step 1.
Step 3-Designing CS prototypes through a collective discussion. Facilitators summarize the individual ideas, and organize a collective discussion aiming at designing one or several CS prototypes. They ensure that each CS is described with enough details to allow its *ex ante* assessment with chosen tools.

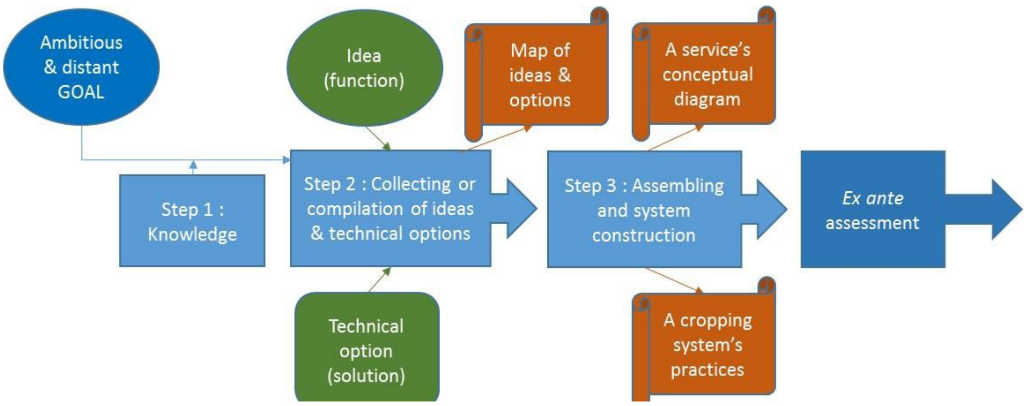

Fig. 1. Main steps, inputs and deliverables of a *de novo* design workshop

3 Results – Discussion

In the province of Caceres (Extremadura, Spain), the main negative impacts of the irrigated arable CS were the high consumption of water and the high use of fossil energy, directly with agricultural mechanical operations, or indirectly with nitrogen fertilizer. As a result, the main goal was to reduce by half the fossil energy consumption and the water consumption (fossil energy consumption less than 15 $GJ.ha^{-1}.year^{-1}$, and irrigation water consumption under 3000 $m^3.ha^{-1}.year^{-1}$), which represents both an ambitious and distant goal.

From the individual ideas proposed by all participants, a facilitator mapped the proposals on a white board, in order to organize them and to link them to the main goal, and to clarify the strategies underlying the choice of a given technical option. A figure linking the aim, the functions targeted and the proposed technical options was built, and could be used as a resource for the following CS design step (Fig. 2).
During the third step, the participants designed one CS prototype. It was first described through a conceptual diagram indicating the main technical options mobilized in order to provide the expected service. Then, a first *ex ante* assessment using two simple indicators (water and energy use) was implemented to check off the main goal was achieved.

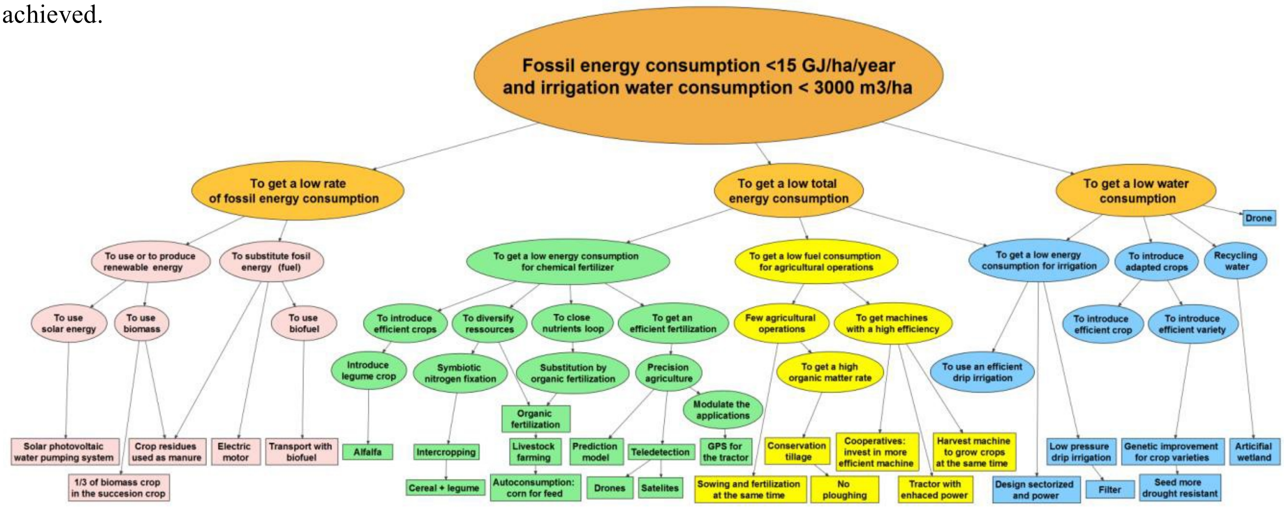

Fig. 2. Concept map summering and organizing individual ideas and technical options gathered during step 2

After the workshop, a facilitator realized the description of the CS practices (Table 1), using bibliography and local experts' knowledge among the participants of the workshop, in order to achieve a wide *ex ante* sustainability assessment.

Table 1. Main practices and yield results of the new cropping system proposed during step 3

Crop practices		Maize	Soya	Wheat	Sorghum	Tomato	Zucchini	Broccoli
Agricultural machine	Ploughing	1	-	1	-	-	-	1
	Other tillage	3	4	2	3	3	4	23
Fertilization (kg/ha)	N	280	15	75	147	220	200	220
	K20	-	76	-	43	73	350	84
	P205	-	23	-	23	-	150	34
Pesticides (passing/ha)	Herbicide	2	-	1	2	3	-	2
	Insecticide, Fungicide	1	-	-	-	-	5	2
Irrigation (m^3/ha)	Irrigation	6 500	-	-	5000	5500	2700	2000
Harvest	1 passing/crop	Machine	Machine	Machine	Machine	Machine	Manual	Manual
Yield (T/ha)	minimum	10	2,7	1,0		60		
	average	14	3,5	2,6	7,8	80	26	22
	maximum	18	6,0	3,0		100		

In addition to the design of new CS, this design workshop delivers useful resources for agronomists and farmers to locally adapt their own CS: a map of ideas and technical options linked to a goal, a conceptual diagram indicating how the proposed CS could fulfill the main goal, and at last, the expected practices and results of the innovative CS.

4 Conclusions

This design workshop approach appeared to be suited to situations where knowledge is poorly synthesized in scientific literature and/or crop models. It was successful to explore new CS, and also to help designing CS before their test through on station experiment (this example in Extremadura, Spain) or directly on farm implementation (non shown example of a case study involving farmers in Burgundy, France). Lastly, in addition to the design of innovative CS, design workshop could also serve as a platform for knowledge exchange and know-how.

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Forages for Reduced Nitrate Leaching – a cross sector approach

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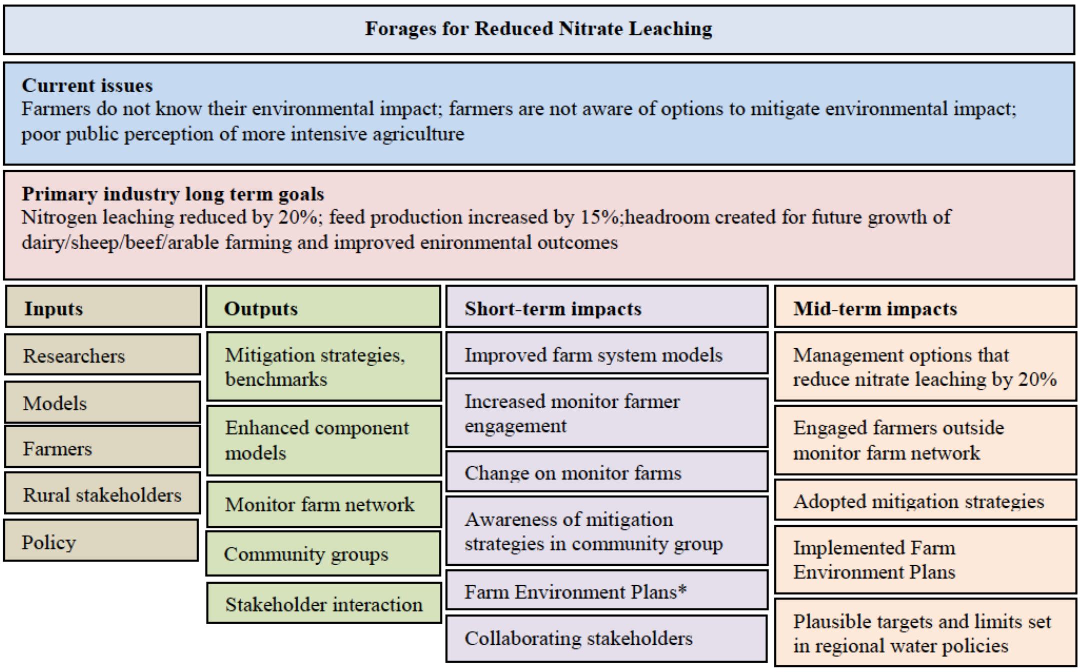
Introduction

In 2013 the New Zealand Government set a target to double agricultural exports by 2025. At the same time, the Government required regional councils to set nutrient discharge limits under the National Policy Statement for Freshwater Management (Ministry for the Environment, 2011). Achieving these dual goals of increased production and mitigating environmental impact will require a substantial effort to achieve on-farm change and will require the input of multiple agricultural sectors. This paper describes how the Forages for Reduced Nitrate Leaching programme (FRNL) aims to support farmers to achieve these demanding objectives through integrated research, development and extension.

FRNL programme logic

Farmer adoption of new technologies and farm systems is the ultimate indicator of the FRNL programme's success. Traditionally, linear information transfer has been less effective at achieving on-farm change for more complex issues, such as increasing production within nutrient limits. The FRNL programme (running from 2014 to 2019) incorporates principles of co-innovation (Klerkx*et al.*, 2012) and participatory modelling (Vanclay*et al.*, 2006), and recognises that a systemic approach to facilitating on-farm practice change is needed. Co-innovation recognises that interactions between stakeholders are as important as integrating different research disciplines.

The FRNL programme logic developed for the programme reflects these principles (Fig. 1). Research will focus on technical issues to reduce nitrate leaching in the context of New Zealand farming systems and developing models to reflect a variety of crops and pasture and impact of management on productivity, profitability and environment. Stakeholders, including farmers, are involved from the beginning of the programme to develop relationships and exchange information to support the research and learning for all involved. An important aspect of FRNL is the involvement of a group of farmers – the monitor farmers – who will guide the development and adoption of sustainable farming systems.



*Farm Environmental plans are action plans developed in a regulatory setting to assess environmental risks on-farm and to define and implement actions to mitigate these risks.

Fig. 1. Diagram of programme logic for Forages for Reduced Nitrate Leaching.

Role of monitor farmers in guiding FRNL programme development

A network of nine monitor farmers is a key feature of the FRNL programme. They represent the arable, dairy and sheep & beef industries in the Canterbury region of New Zealand. The purpose of the network is threefold. First, the monitor farmers will be involved in guiding research direction (co-develop) using their existing knowledge through experiences and innovation on-farm. Second, current practice and practice change will be demonstrated through monitoring and reporting on-farm performance (technical and financial) and modelling nutrient balance and nitrate leaching. Third, whilst demonstrating current practice and change, the monitor farmers will help identify barriers to adoption, in terms of risks, unintended consequences, or whether new skills and resources are required.
With the imposition of targets and limits for nitrogen discharges from farm land, farmers are eager to see commercial scale examples of nutrient management strategies that can be readily incorporated on-farm. Farmers learn more readily from other farmers, therefore it is important to showcase successful colleagues rather than focussing on modelled benchmarks or the average performance of a farmer group (Ondersteijn, 2002). For example, in The Netherlands this approach was successfully adopted in a project involving 17 dairy farms to improve nutrient management. This project supported substantial environmental improvement on-farm and had an additional impact on policy development, which benefitted from reliable data of commercial farms (Oenema, 2014). Another example is an earlier New Zealand project with monitor farmers; the Southern Wintering Systems project which confirmed that farmers feel they learn most from other farmers and prefer to see results from colleagues rather than from modelling or regional benchmarking exercises (Dalley *et al.*, 2014).

Assessing success of the FRNL programme

A meeting with local farm consultants was held to outline the proposed programme logic. Using an interactive voting system, the 33 participants were asked about the expected value of monitor farms in influencing the FRNL research direction. Forty eight percent of the participants agreed that having monitor farmers involved would make solutions practical, with a further 44%saying it would be crucial to achieving relevant results. Similarly, 48% agreed that the monitor farm network would be crucial to achieving adoption of new mitigation options on commercial farms and a further 48% though it would help increase adoption of mitigation options. Forty-one percent wanted to be involved in the network and a further 44% wanted to be updated regularly on the programme. Overall, the survey results suggested that this group believes the FRNL programme is well structured to achieve its goals.
Measures for monitoring and evaluating the impact of the FRNL programme were explored at another meeting involving governance and programme management committee members, key researchers and monitor famers. Several quantifiable measures of the programme's success were identified. These included: the monitor farmers successfully implementing new practices; new mitigation options being included in nutrient budget models; improved awareness and understanding of nutrient cycling and applicability of mitigation options; and level of their adoption as monitored through annual farmer surveys. Other measures included the number of actions in Farm Environmental Plans relating to the programme; an environmental trait being included in the national forage evaluation system; and changes in the ratio of seed of different pasture and crop species being sold by retailers.
With these first two stakeholder meetings the FRNL programme has a clear mandate to involve monitor farmers in guiding research and farmer uptake activities and an agreed approach to assess the success of the programme.

Conclusions

The Forages for Reduced Nitrate Leaching programme (2014-2019) has been established to co-develop solutions to achieve the twin challenge of increasing primary sector productivity, while mitigating environmental impact, through direct engagement between researchers, farmers and other stakeholders. Early engagement with stakeholders has clarified expectations and provided a framework for monitoring and evaluating the impact of the programme.

Acknowledgements. Forages for Reduced Nitrate Leaching is a DairyNZ-led collaborative research programme across the primary sector delivering science for better farming and environmental outcomes. The aim is to reduce nitrate leaching through research into diverse pasture species and crops for dairy, arable and sheep and beef farms. The main funder is the Ministry of Business, Innovation and Employment, with co-funding from research partners DairyNZ, AgResearch, Plant & Food Research, Lincoln University, Foundation for Arable Research and Landcare Research.

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A research trajectory driven by scaling out: from a detailed farm model (SEDIVER) to a participatory board game (Forage Rummy)

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1 Introduction

Under the influence of various factors (climatic, economic, social, etc.), the context of agricultural production is increasingly changing and erratic. Farmers keep trying to adapt their farming systems to this context in order to preserve the sustainability, in particular the production ability, of such systems. Adaptation refers to a process, action or outcome in a system in order for the system to better cope with, manage or adjust to experienced or expected events e.g. climatic. The pace, scale and even the direction of contextual changes being plagued with uncertainties, it is particularly difficult for farmers to make decisions about adaptation measures. To address this adaptation challenge, technology transfer has long been dominant in agricultural research and development. Over recent years, unlike the technology transfer approach, approaches seeking to develop farmers' adaptive capacity have increasingly been developed. They often rely on the modeling of data from physical, chemical, physiological and ecological processes. These approaches are criticized among other things for being unable to cope with different production and management contexts, i.e. for being hard to scale out. In this article, I elaborate on my own research trajectory that has been driven by the scaling out features of the decision support systems I have developed.

2 A first period of detailed simulation modeling

During my PhD, I developed a very detailed dynamic and mechanistic simulation model of grassland-based livestock systems called SEDIVER (Martin et al., 2011b). SEDIVER reproduced the interactions on grassland-based beef-cattle farms between the biophysical and management processes in response to weather conditions. It was intended to be used with farmers in order to design farm management strategies enhancing exploitation of farmland and grassland diversity to promote management flexibility against interannual weather conditions. At that time, in the French community of agricultural scientists, the failure of simulation-based agricultural decision support systems was often related to the poor or even lack of modelling of farmers' decision-making processes leading to too unrealistic simulation outputs to inform practice (Garcia et al., 2005). As a consequence, in SEDIVER, emphasis was put on modelling (i) the heterogeneous nature of the biophysical processes occurring in the system and the subsequent constraints on grassland use, and ii) the farmer's management behaviour on a daily scale to coordinate the work activities that are constrained by this diversity over time and space.

Modelling farmland and grassland diversity and their consequences on biophysical processes required to provide a detailed description of topography (altitude, exposition, etc.), micro-climate (temperatures, rainfall, etc.), soil (water capacity, nutrient status, etc.) and plant types (distribution of grass functional groups, legumes, etc.) for each field as model input parameters. For management-related parameters, the basic modelling unit was an activity. In its simplest form, an activity denoted something to be done (e.g. hay-making) to a particular biophysical object or location, e.g. a field, by an executor, e.g. a worker. It was characterized among other things by local opening and closing conditions, defined by time windows and/or predicates (Boolean functions) and a speed of execution (e.g. number of hectares which can be harvested in a unit of time). Activities were further constrained by using programming constructs enabling specification of temporal ordering, iteration, aggregation and optional execution (e.g. a sequence of two harvests on a field constrained by earliest and latest starting dates). All the activities were connected in a plan. Adjustments to the plan were any change such as the removal or insertion of activities as particular events occur, e.g. a lasting drought event.

To calibrate and validate SEDIVER, we used data from pluriannual surveys on two farms in the French Pyrenees. Simulations accurately reproduced the chronology of farming practices and the resulting production performances (forage production, meat production, self-sufficiency for forage, etc.; see Martin et al., 2011b and 2001c for more details). It also proved informative for farmers in exploring the scope for adaptation of their management practices through enhanced exploitation of farmland and grassland diversity to promote management flexibility against interannual weather conditions. Then, calibration and validation confirmed the capacity of SEDIVER to improve the realism of simulation outputs. Still, SEDIVER was so detailed and it was so hard to get into farmers' mental models that it took 6 months to conduct the calibration and validation work for these two farms (Martin et al., 2011c). It appeared unrealistic to consider scaling out SEDIVER for further projects.

3 A change towards participatory modeling

Following this experience, I started a participatory project to develop a completely different approach called Rami Fourrager® (Forage Rummy, Martin et al., 2011a; Martin, 2015). It is a board game supported by a computer model. It is intended to be used by agricultural consultants and/or researchers with small groups of 2 to 4 farmers during workshops lasting from 2 to 4 hours. Workshops include collectively and iteratively designing (with material objects e.g. cards) and evaluating (with a simulation model) livestock systems able to be adapted to new contextual challenges (e.g. climate change) and new farmers' objectives (e.g. transition to organic farming). Throughout these iterations, it aims at developing farmers' adaptive capacity by stimulating their reflections and discussions.
Forage Rummy has been developed following a participatory approach that resulted in interactions with nearly 200 farmers and agricultural consultants. Modelling choices have been strongly influenced by the outcomes of these interactions. Forage Rummy builds on process-based models that have been selected or developed because (i) they display robustness when being scaled out e.g. the grassland model has been evaluated satisfactorily in a wide number of French regions; and (ii) they require a low number of input parameters to be informed e.g. the management model requires informing about 10 times less parameters than with SEDIVER. Moreover, these parameters are expressed in units used by farmers and agricultural consultants. This way, while management-related parameters were extremely difficult to inform with SEDIVER, they are directly provided by farmers representing their farm on the board game using cards and felt tip with Forage Rummy.
Therefore, scaling out Forage Rummy mostly relies on farmers' and agricultural consultants' experiential knowledge in checking during calibration and validation that the outputs are consistent considering a range of input parameters representing their farm. When a discrepancy is found, the input parameters are modified based on farmers' suggestions until satisfying outputs are obtained. The agreement of farmers and agricultural consultants with the model behaviour is then the key indicator of the validity of the model.

Fig. 1. Overview of a Forage Rummy workshop with farmers.

4 Conclusions

Scaling out turns out to be much quicker (half-a-day for a NUT 3 region) and easier with Forage Rummy than with SEDIVER thanks to the modelling choices made during the development stage. Moreover, involving farmers and agricultural consultants in the calibration and validation process promotes transparency of the whole approach and develops mutual trust and understanding among researchers and farmers. Since 2013, about 30 French agricultural consultants have been trained to using Forage Rummy. They manage its scaling out by themselves.

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Photovoltaic Water Pumping System –Sustainable Water Irrigation for Best Farming System

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1 Introduction

Photovoltaic Systems based Power Plants have emerged as viable power sources for applications such as lighting, water pumping and telecommunications and are being increasingly used for meeting electrical energy needs in un-electrified locations such as remote villages, hamlets, hospitals and households. The country today has the world's largest program for deployment of decentralized PV systems. Photovoltaic-based water pumping system is eco-friendly in nature and pollution free technology can be more appropriate to the needs of the developing countries like India than solar/thermal energy conversion (STEC).

2 Material and Methods

The study was undertaken in the Hisar, Rohtak and Jhajjar districts of Haryana state (India) to know the constraints faced by the farmers in the use of photovoltaic water pumping system. A total number of 282 respondents i.e. 141 beneficiaries and 141 non-beneficiaries were interviewed for the study. To measure the constraints encountered by the farmers in the use of PWPS, a schedule was developed. The responses were obtained on three point continuum i.e. „very serious‟, „serious‟ and „not so serious‟ and the weights of 3, 2 and 1 were assigned, respectively. The scores so obtained on all items were summed up and the rank orders were assigned to each constraint.

3 Results and Discussion

Constraints faced By the Farmers' in the Use of PWPS.

Technical Constraints: The PWPS adopted respondents reported that "This technology only works in less than 8 meters water table" and "It does not works in cold / winter days" consider as major technical constraint, moreover the similar results were also obtained in case of non adopted respondents. Further, "High cost of PWPS" found the most serious financial constraint as observed by both adopted and non-adopted respondents. On the other hand, "Lack of extension literature" and "Lack of package of practices for PWPS irrigation farming system" were percieved as the major extension constraints by the adopted respondents. However, in case of non-adopted farmers, "Lack of attention of mass media" found to be the most serious extension constraint (Table 1). These findings were supported Kaur *et al.* (1998), Prasad and Singh (2000), Hazarika and Palit (2001).

Best farming system recommended by extension functionaries for crop production under PWPS.

Extension functionaries suggested that 16.25, 8.25, 7.58, 5.00, 4.50, 4.16, and 3.66 per cent from area (Table 2) should be covered under vegetable, mushroom, horticulture, floriculture, spices, medicinal plants and fishries, respectively, by PWPS adopted farmers who were having less than 5 acres land holding. The PWPS owning farmers who were having 5 to 15 acres of land holding should covered 12.16, 8.00, 5.50, 4.50, 3.16, 2.25 and 1.82 per cent area under vegetable, horticulture, mushroom, floriculture, fishries, spices and medicinal plants, respectively. The recommended area under different crops the farmers having more than 15 acres was highest (70.65 %) under traditional crops followed by area should be covered under horticulture (9.67%), vegetable (8.16%), mushroom (3.17 %), floriculture (2.75 %), fishries (2.25 %), spices (2.00 %) and medicinal plants (1.33 %).

Best Farming System Recommended by Extension Functionaries for livestocks production under PWPS.

The large majority of the Extension Functionaries recommended 2 to 3 buffaloes / cows, 5 to 10 sheep / goats, 16 to 32 number of layers and 9 to 18 numbers of honey bee boxes for those farmers who are having less than 5 acres land holding for effective management with other farm enterprises. Whereas the study further showed that the significant majority of Extension Functionaries recommended 10 to 15 buffaloes / cows, 10 to 20 sheep / goats, 63 to 106 number of layers and 41 to 57 number of honey bee boxes to those farmers having 5 to 15 acres land holding. More than half of Extension Functionaries recommended 13 to 19 buffaloes / cows to the PWPS owning farmers having more than 15 acres land holding. While more than, two-third of them recommended 20 to 40 sheep / goats to the farmers having more than 15 acres land holding. 100 to 125 numbers of layers for poultry production and 106 to 177 number of honeybee boxes to the farmers having more than 15 acres land holding for effective handling with other enterprises cited in Table 3.

Table 1. Constraints being faced by the farmers' in the use of PWPS

Sr No.	Constraints	Adopted		Non adopted	
		TWFS	R	TWFS	R
A	**Technical constraints**				
1	PWPS spareparts are not available in market	272	III	291	III

2	It does not works in cold/winter days	309	II	311	II
3	This technology only works in less than 8 meters water Table	327	I	333	I
4	Farmers are not aware about the PWPS	245	IV	268	IV
5	The water available through the PWPS is not sufficient for farming	238	V	245	V
B	Financial constraints				
1	Lack of money to buy a PWPS	358	III	342	II
2	Lack of credit facilities	354	IV	289	V
3	Less subsidy on PWPS	347	V	296	IV
4	Less number of PWPS are available on subsidy	380	II	341	III
5	High cost of PWPS	385	I	347	I
C	Extension constraints				
1	Lack of extension literature	327	I	316	IV
2	Lack of attention of mass media	279	VII	343	I
3	Lack of knowledge of extension agencies	298	VI	332	II
4	Lack of adequate manpower from state extension agencies	311	V	316	IV
5	Lack of fellow farmers co-operation	271	VIII	260	VIII
6	Lack of motivational programme for adoption of PWPS	267	IX	278	VI
7	Lack of information after effects of PWPS installation on the farm	232	X	310	V
8	Lack of information regarding the profitability of PWPS on the farm	318	IV	271	VII
9	Lack of package of practices for PWPS irrigation farming systems	326	II	310	V
10	Lack of feedback programme	322	III	321	III

TWFS = Total Weighted Frequency score, R = Rank

Table 2. Best farming system recommended by Extension Functionaries

Sr. No.	Enterprises	Less than 5 acres land holding (N=27)	5 to 15 acres Land holding (N=27)	More than 15 acres land holding (N=27)
1	Horticulture	7.58	8	9.67
2	Vegetable	16.25	12.16	8.16
3	Floriculture	5	4.5	2.75
4	Spices	4.5	2.25	2
5	Medicinal Plant	4.16	1.82	1.33
6	Fishries	3.66	3.16	2.25
7	Mushroom	8.25	5.5	3.17

Table 3. Best farming system recommended by Extension Functionaries for Live stock production under PWPS

Name of Enterprises	Categories	Score Range	land holding	Score Range	land holding	Score Range	land holding
Livestock							
Buffallo/ Cow	Low	Less than 2	Nil (0)	Less than 10	6 (22.22)	Less than13	7 (25.92)
	Middle	2 to 3	25 (92.59)	10 to15	19 (70.37)	13 to 19	16 (59.25)
	High	Above 3	2 (7.40)	Above 15	2 (7.40)	Above 19	4 (14.81)
Sheep / Goat	Low	Less than 5	3 (11.11)	Less than 10	3 (11.11)	Less than 20	3 (11.11)
	Middle	5 to 10	22 (81.48)	10 to 20	20 (74.07)	20 to 40	21 (77.77)
	High	Above 10	2 (7.40)	Above 20	4 (14.81)	Above 40	3 (11.11)
Poultry	Low	Less than 16	3 (11.11)	Less than 63	2 (7.40)	Less than 100	5 (18.51)
	Middle	16 to 32	21 (77.77)	63 to 106	24 (88.88)	100 to 125	18 (66.66)
	High	Above 32	3 (11.11)	Above 106	1 (3.70)	Above 125	4 (14.81)
Bee - Keeping	Low	Less than 9	4 (14.81)	Less than 41	6 (22.22)	Less than 106	1 (3.70)
	Middle	9 to 18	18 (66.66)	41 to 57	18 (66.66)	106 to 177	25 (92.59)
	High	Above 18	5 (18.51)	Above 57	3 (11.21)	Above 177	1 (3.70)
Figure in parentheses indicate percentage							

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Gender and wealth influence how smallholder farmers make on-farm changes: a case study from Uganda

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1 Introduction

Innovation is key to increasing agricultural productivity, however the processes involved in establishing productivity enhancing changes on smallholder farms are poorly understood. In Uganda, the government has recognised the importance of innovation, undertaking significant reforms to extension services in an attempt to promote on-farm innovation (Kjær & Joughin, 2012). However, investment in science and technology alone are not enough to enable innovation (Hall *et al*., 2006) and, in Uganda, there is little evidence that key policies to promote innovation and mainstream gender concerns are being translated into practice. Consequently, a better understanding of the actual processes smallholder farmers engage in to make productivity enhancing on-farm change is required. Given the gendered nature of agriculture and influence of gender and wealth on farmers' access to and control over resources (Moser, 1994; Scoones, 1995), this research expected to find that the gender and wealth of smallholder farmers' influences how they make on-farm changes.

2 Materials and Methods

This case study of seven villages in Nakaseke district, central Uganda, assessed farmers' social networks and the drivers and constraints to agricultural innovation. Initial research focused on crop innovations using participatory methods with farmer focus groups (11 groups with 6-11 participants each). To provide contextual background to innovation activities, agricultural timelines were constructed at three villages by either male, female or mixed groups (Garforth, 2001). At each of the remaining four villages either one male and one female or two mixed groups each completed two innovation histories and a communication map (Douthwaite & Ashby, 2005). These activities provided a more comprehensive analysis of innovation processes anchored in specific examples, as well as a visual representation of linkages within farmers' innovation systems.
Of the seven villages involved in the participatory research, Namasujju village was selected for the questionnaire survey as farmers had identified complex innovation networks and were actively adapting innovations. Four key informants from Namasujju completed a village wealth ranking; dividing farmers into wealthy, medium and poor farmers based on assets, income, education and provision of basic needs (Grandin, 1988). This was used to select a stratified random sample of 99 respondents for a questionnaire which focused on both crop and livestock innovations. Farmers were asked to explain the three key changes they had made in the past ten years and to identify the drivers, constraints and actors involved in making those changes.

3 Results

Smallholder innovation networks were influenced by gender and wealth. Gender analysis indicated that men and women interacted with different types of farmers; women relied on informal interaction with farmers who were in their social network, while men consulted model farmers and engaged with farmers outside the village. Wealth also influenced farmer-farmer interactions, as neighboring farmers' information was considered 'very useful and reliable' by 52% of poorer farmers but only by 23% of wealthy farmers (X^2=14.80, p=0.022). Wealthy farmers instead relied on extension services and NGOs, finding extension staff 'very helpful' in 21% of changes they made, compared to 9% of changes made by poor farmers (X^2=10.93, p=0.012). Gender analysis also indicated that men had more geographically dispersed innovation networks and more ways of accessing information, with men identifying 13 different communication channels and women only 9. In addition, sometimes only one gender received a specific type of information, for example only men said they received information about livestock production. In such cases, if the recipient didn't share the information with their spouse, then the spouse commonly resorted to copying other farmers' practices. Consequently, gender and wealth affect on-farm innovation by influencing which stakeholders farmers engage with, how farmers access information and what information farmers receive.
Gender also influenced the drivers of on-farm change, as men were predominantly driven by income, labor saving and cost reduction and women by food security, taste and market. These differences often persisted even when men and women adopted the same technology. For example, in one village, women adopted a disease resistant banana variety because banana disease was affecting food security, in contrast men adopted the same variety because disease had destroyed their coffee crops and they were endeavoring to replace lost

income. Supporting this example, the importance of income differed with gender, as women considered income 'not important' in 21% of changes they identified compared to only 3% of changes identified by men (X^2=17.34, p=0.001). Wealth also influenced drivers, with food security driving 39% of changes made by poor men but only 23% made by wealthy men (X^2=11.01, p=0.007). In contrast, food security was consistently important for women, as it was considered a 'very important' driver in over 40% of changes made by women across all wealth categories. Therefore, while men and women often respond to different drivers, the interaction between gender and wealth indicated that poor male farmers may respond to the same combination of drivers as female farmers.
Gender and wealth also influenced constraints to on-farm innovation, with key constraints including labour, finance, access to inputs, pests and disease and household support. Gender analysis showed that financial constraints predominantly affected women, as 95% of women were affect by financial constraints compared to 78% of men (X^2=25.185, p=0.007). In addition, women were also more frequently constrained by labour, as it affected 32% of women compared to only 2% of men (X^2=25.185, p<0.001). While women often had better access to information, men commonly controlled the resources to use this information, including income and access to planting material. Wealth also influenced constraints to innovation, with poorer farmers more constrained by finance, labour availability and production risk, which constrained 17% of changes made by poor farmers but only 9% of changes made by wealthy and medium farmers (X^2=12.01, p=0.01). Finally, these constraints are embedded within intra-household interaction, with spousal support able to exacerbate or reduce constraints to innovation.

4 Discussion

The gender and wealth of smallholder farmers' affect their innovation networks and, consequently, how they make on- farm changes. Results indicate that male and wealthy farmers are able to take advantage of consultative relationships with model farmers, extension services and NGOs, while women rely on informal interaction with farmers in their social networks. This suggests that pooling of information within women's networks involves a higher level of reciprocity than in mens' networks and that both gender and wealth influence whether the resources required for innovation are freely available or diffuse through social networks. In addition, intra-household relationships also influence innovation activity, as the disconnect between access and control over information and resources within households and the withholding of information from spouses can significantly constrain on-farm innovation.
Within these innovation networks, the gender and wealth of farmers also influenced the drivers and constraints to on- farm innovation. Men were more frequently driven by income and women by food security, with such differences often persisting even when farmers were adopting the same innovation. Farmers' ability to respond to such drivers was constrained by a range of factors including access to and control of financial resources, land, labour and information. Although both men and women faced constraints to innovation, promotion of household innovation activity requires special consideration of the constraints that women face, such as labour and finance, as on-farm changes that increase household labour may be hampered unless women are able to access some of the benefits.

5 Conclusions

Findings suggest that smallholders farmers' gender and wealth influence their innovation networks and social learning processes. Such differentiation also influences the drivers and constraints to on-farm innovation, resulting in individual technologies being adopted for a range of reasons and adapted to address a range of constraints specific to the farmer's gender and wealth. Consequently, gender and wealth are two vital elements that need to be understood if practitioners in agricultural development wish to promote productivity enhancing on-farm change.

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SCALING UP AGRO-ECOLOGICAL INNOVATION ADOPTION AMONG FARMING SYSTEMS. APPLICATION TO IMPROVED FALLOWS IN MARTINIQUE

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1 Introduction

Agro-ecological innovations face low adoption rates among farmers. Agro-ecological innovations are basically new farming practices whereas agrochemical inputs can be considered as objects. Farming practices are dependent on spatial variables (agro-ecological zoning), the farmer's profile (agronomic expertise), the farming system (mechanized or not, access to labor). Agro-ecological innovations are also dependent on a time frame spanning over several years. Therefore agro-ecological innovations case studies have a poor generic range outside their timeframe, their agro-ecological zoning or even commodity chain in which they have been studied.

The objective of this paper is to suggest a methodology for improving the generic range, and therefore a scaling up, of case studies focusing on agro-ecological innovations. We articulate this methodology around participatory approaches with the key stakeholders, the adaptability of the agro-ecological innovations to the farmer's and farming systems constraints, and the access to census databases.

We tested this methodology with a case study focused on improved fallows in Martinique and the vegetable sector. Martinique is a tropical island of the French West Indies representative of the constraints faced by resource limited and import dependent economies. Martinique faces the challenges of a declining agricultural sector, a large dependence on imports, and environmental degradation (Agreste, 2011, 2013). One alternative to agro-chemical inputs is the promotion of improved fallows. The current practice for fallows in Martinique is to let spontaneous grass and weeds expand on the plots. Improved fallows consist in introducing annual leguminous species to restore the biological and chemical properties of the cultivated soil, respond to local soil borne diseases (nematodes), and compete against weeds (Fernandes *et al.*, 2009). The underlying agronomic principle is to take advantage of the existing and prevalent 2 to 3 months current fallows between the cropping periods to add green manure for a chemical and biological soil improvement.

2 Materials and Methods

A participatory approach hypothesized the adoption potential of improved fallows among farmers and validated the statistical classification of farmers.

A statistical classification from the 2010 agricultural census database was conducted among all farms involved in vegetable production (N= 1382). The participatory approach suggested two variables as potential determinants for the adoption of improved fallows: stable land tenure and total cultivated land area. We conducted a first computation of a Principal Component Analysis (PCA) and an Ascending Hierarchical Classification (AHC) based on those two variables. This first computation excluded farms with unstable land tenure. We conducted a second PCA and AHC computation among farms with stable land tenure for the five following variables related to different crops (in percentage of total farm cultivated area): vegetable, permanent grassland, banana and sugarcane, fallow, orchard. The correlations between these five variables defined the typology of farms.

We surveyed 80 farmers with a quota sampling from the results of the classification of farms. 47 variables were recorded on the profile of the farmers (socio demographic variables, network participation), agronomic practices, farm characteristics (area, mechanization potential of the land, labor supply, etc.).

We used the R 3.1.1. software and the ―glmnet‖ package to establish an econometric model with a set of 47 explanatory variables at farm and farming system level (Tibshirani, 1996). The dependent variable was the (yes/no) willingness to test improved fallows. This package uses a penalized regression method to choose coefficients of the model. A first nmodel using the 47 variables eliminated variables which have no linear link to the dependent variable; this is the Model 1. Then the economic model (Model 2) is obtained by using the variables which are meaningful for the Model 1.The Model 2 confirms each selected variable from the Model 1.

3 Results - Discussion

The two-step statistical classification among the 1382 farms involved in vegetable production resulted in 6 sub-groups of farms: unstable land tenure farms (306 farms), livestock farms (337), banana and sugarcane farms (96), pure vegetable farms (392), fallows farms (162), and orchards farms (89).We interviewed 80 farmers dispatched among 4 subgroups involved in vegetable production: the banana or sugarcane subgroup, livestock, orchards and pure vegetable farms. Farms with unstable land tenure and farms with fallows were not interviewed as they were assumed as non-adopters from the participatory approach. 80% of the farmers interviewed are willing to test improved fallows. Two models display the econometric results. A total of 12 explanatory variables were selected from the 47 initial variables (Model 1).

Table 1. Random-coefficient Logit Parameter Estimates with an elastic net penalization.

	Model 1 including 47 variables	Econometric model : Model 2 including 12 variables
Mean of error rates of prediction	9.45 %	8.65 %
Std. of error rates of prediction	1.65 %	1.56 %
(Intercept)	-3.1149	-3.3150
PRACTICING CURRENTFALLOWS	3.2476	3.3450
MULCHING_INTEREST	1.7563	1.8243
FIELD SUITED FOR MECHANIZ.	1.0992	1.1964
ADITIONAL_WORK	-0.8063	-0.8437
IMPLEMENTATION_COST	-0.7227	-0.8243
N.E._DISTRICTS	-0.7507	-0.7985
TILLAGE_REQUIREMENT	-0.6602	-0.7061
TRAINING_LEVEL	0.5911	0.6545
NEMATICIDE_INTEREST	-0.4166	-0.5219
DEPLETED_FERTILITY	0.3403	0.4353
LABOUR_AVAILABILITY	0.1676	0.1924
FERTILITY_INTEREST	0.0530	0.0839

Notes. Std. is the standard deviation. For the Model 1, the selected parameters are $\alpha = 0.99$ and $\lambda = 0.0345$. For the Model 2, the selected parameters are $\alpha = 0.99$ and $\lambda = 0.0315$.

The explanatory variables for the willingness to test improved fallows show the importance of already practicing current fallows on the farm (FALLOWS) as well as other additional agronomic benefits (MULCHING, TILLAGE, FERTILITY, etc.) and farm characteristics (FIELD SUITED FOR MECHANIZATION for example). Spatial considerations (N.E. DISTRICT) confirm the geographical constraints of agro-ecological innovations. Economic considerations are also confirmed. Fieldwork revealed that the pure vegetable farm group was also interested in improved fallows, in contradiction with an assumption of the participatory approach.

4 Conclusions

Scaling up agro-ecological innovations is possible with the access of an agricultural census and a quota sampling procedure as it reduces the investigation costs and the error margins. Farmer's knowledge of the underlying agronomic principles of agro-ecological innovations is crucial in the willingness to test them. The participatory approaches are necessary but they need to be tested on the field as their assumptions can be contradicted (in our case, the total cultivated land area threshold). The fact that agro-ecological innovations may spread among various farming systems also highlighted the risk of exclusion of farms unsuited to their implementation.

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A participatory approach to design and assess integrated crop-livestock systems at territory level

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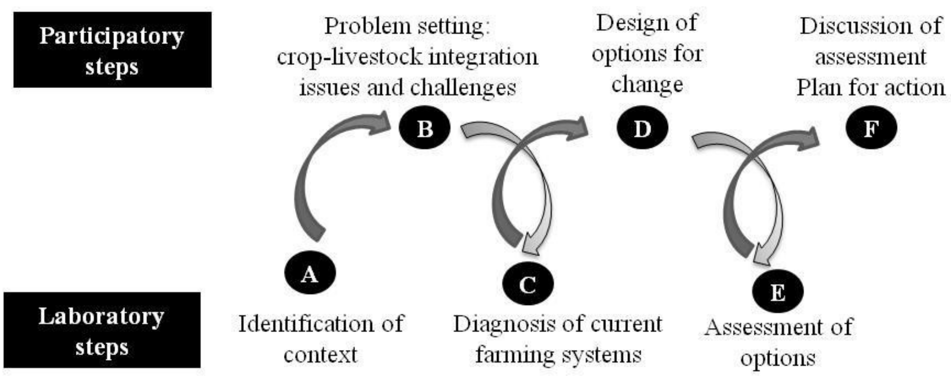
1 Introduction

Due to strong specialization trends in Western Europe, cropping systems and livestock systems are always more simple and more concentrated, resulting in high input levels and sustainability issues. Integrated Crop-Livestock Systems, through interactions between crops, grasslands and animals, can achieve self-sufficiency, high efficiency and sustainable practices (Bonaudo *et al.*, 2013). They are often seen as archetypes of agroecological systems. Given that it will be difficult to reintroduce animals in farms in which they disappeared, crop-livestock interactions could be developed at territory level (Wilkins, 2008). Few studies already exist on such Territorial Crop-Livestock Systems (TCLS). This article presents the methodology used to design and assess TCLS in South-Western France. Designing TCLS raises three methodological issues: (i) its intrinsic "ill-defined" character, (ii) the coordination among local agriculture stakeholders; (iii) the uncertainty regarding interactions between technical practices and key ecosystem services (e.g. biological regulation, soil fertility maintenance). Furthermore, dealing with knowledge management when designing such agroecological systems require methodological engineering and situated research (Francis *et al.*, 2011). To tackle these different issues and challenges, we built a participatory methodology to design and assess TCLS. As in Concept-Knowledge (C-K) theory of innovative design (Hatchuel & Weil, 2009), it is based on the common development of creative ideas and elements of knowledge to assess options of change. It was applied in two case studies for supporting stakeholders' groups in the design of TCLS adapted to their context specificities.

2 Materials and Methods

The two case studies are situated in the Averyon River watershed, in South-West France. The first case study focused on designing cropping systems (CS) in specialized crop farming systems located downstream in the watershed that would answer feed requirements of upstream livestock systems (LS) and local sustainability issues (mainly water deficit due to irrigation). The second case study is a group of organic livestock and crop farmers voluntary to develop direct exchanges. The methodology follows six steps (Fig. 1), adapted for the two case studies. It is supported by two key intermediary objects: (i) a conceptual model of crop-livestock integration structuring analysis of Crops, Animals and Grasslands interactions and associated flows of products and key ecosystem services and (ii) a multicriteria assessment grid (used in step E. Both were built a priori upon a review of literature on TCLS and adapted during the field work. Iterations are made between workshops and laboratory to adapt tools to stakeholders' objectives and local issues (Moraine *et al.*, 2014).

Fig. 1. Generic methodology of territory crop-livestock system design



3 Results – Discussion

Table 1 presents the main outcomes of the two case studies. In the first case study, called "*Territory supply chain*", dealing with large geographical extent implied design of standardized options for change. The current CS are maize monoculture and sunflower – wheat rotations. Stakeholders proposed to introduce alfalfa in rotations for three years. It

would allow reducing N fertilizers (no N fertilization for alfalfa and less during the two following years) and also cutting some pesticide application. Harvest, processing and marketing of alfalfa would be managed by a local cooperative. According to the assessment step (E), the alternative CS show improved efficiency of inputs and surfaces, enhanced ecosystem services and better or at least unchanged socioeconomic performances (work and profitability).
In the second case study, "*Organic farmers exchanges*", options for change are built on the basis of farm diagnosis and collection of ideas and expectations of farmers. Assessment of these options was done at farm level and aggregated at the group level. The exchanges of alfalfa, cereal-legume mixtures, straw and animal manure may improve the self-sufficiency at the group level and also farmers decision autonomy, adaptive capacity and stability of economic performances.

At territory level, the two case studies present different strengths and drawbacks. The *Territory supply chain* allows designing diversified cropping systems on a large scale, through technical changes that were estimated acceptable by farmers and resulting in a significant reduction of irrigation water withdrawals at the watershed level. The limits in this case study are the important dependency on local cooperatives to develop new practices, resulting in low farmers' autonomy. Moreover, the designed TCLS is built on standardized changes in archetypal systems, on-farm adaptation may be necessary to implement adapted changes. The case study *Organic farmers exchanges* produced a TCLS scenario finely adapted to investigated farms, although farmers actually look for developing local trials of new practices (mainly feeding systems) and governance rules for exchanges in order to reduce the perceived risk associated to the options for change. The impact of this TCLS on local sustainability issues would be quite low because it concerns only a small group of farms already with low inputs systems. However the development of local direct exchanges of products between CS and LS could still reinforce those farms and associate other farms in exchanges (possibly supporting the settlement of young farmers) and act as a "sociotechnical niche of innovation" (Geels, 2004).

Table 1. Main outcomes of the methodology (CS: crop farming system, LS: Livestock farming system)

Case study	A	B	C	D	E	F
Territory supply chain	Intensive specialized systems on large scale	Stability of supply of LS Diversification of CS	Typology of CS and LS	Alternative CS with alfalfa Organization of the supply chain	Estimated performances of alternative CS Spatial distribution of alternative CS	Opportunity to develop a new supply chain Investments
Organic farmers exchanges	Network of alternative farms	Self-sufficiency at group level, technical exchanges Local origin of products	Individual diagnosis of farms	Alternative CS with alfalfa and crop- legume mixtures Organization forms of exchanges of products	Estimated performances of options for change on individual CS, LS and at group level	Transition phases to develop structured exchanges and governance

4 Conclusions

We designed TCLS in two contrasted case studies, presenting different objectives, constraints and issues related to crop-livestock integration at territory level. The case study *Territory supply chain* was conducted using local expert knowledge, concerned intensive conventional farming systems and resulted in a scenario of development of standardized but more sustainable cropping systems. The case study "Organic farmers exchanges" was conducted in a small number of farms but takes into account the specific constraints and objectives of each farm. Both are interesting to enhance sustainability of local farming systems. Due the ill-defined character of TCLS and the specificities of investigated case study, methods and tools used to design TCLS were continuously adapted. Accordingly, the two case studies contributed to develop generic tools with outscaling capacities. Furthermore, our work is an original contribution to the development of design methodologies dealing with natural resources management, technical systems analysis and stakeholders' coordination at territory level. It allows producing contextualized knowledge on TCLS and support changes towards more sustainable farming systems.

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Designing a livestock rearing system with stakeholders in Thailand highlands: Companion modelling for integrating knowledge and strengthening the adaptive capacity of herders and foresters

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1 Introduction

Farming systems design with stakeholders is context specific and requests participatory methods to reconcile the field, farm and watershed levels while integrating different knowledge systems. Rapid ecological and socio-economic changes in northern Thailand highlands have created land use conflicts between extensive cattle rearing systems and foresters in "protected forest" and replantation areas following past extended deforestation. Key stakeholders bearing different interest, agro-ecosystem management objectives and strategies, and operating at different scales of the system hierarchy, had conflicting perceptions on the effects of cattle grazing on vegetation dynamics at the field scale.
Suitable communication platforms do not exist for stakeholders to communicate and most of the concerned Hmong herders did not received formal education. A multi-level collaborative modelling and simulation methodology was tested to mitigate the land use conflict between local herders and public foresters.

2 Materials and methods

Main successive phases and their key characteristics
1. Combined on-farm diagnostic surveys were carried out at the field (to understand biomass dynamics), farm (to assess the diversity of types of production systems and their respective importance of the cattle rearing sub-system), and landscape (to assess heterogeneity and recent change in land use) levels. This information was used to initiate a Companion modelling (ComMod) process (Barnaud *et al.* 2008).
2. Interactive diagrammatic conceptual modelling with pictograms to facilitate knowledge integration was used to produce a key vegetation state transition diagram describing vegetation dynamics influenced by human activities. 3.The conceptual model was implemented as a role-playing game (RPG): gaming board conceived as an abstract output of the land use change analysis; two gaming sessions played with stakeholders to enrich and validate the model, calibrate the RPG, and facilitate communication between herders and foresters.
4. Identification of stakeholders preferred land use scenario for both technical improvement of cattle rearing and tree plantation. Implementation of a computer agent-based model (ABM) "playing the game" *in silico* to simulate these proposed management options. Participatory simulations of options by this ABM and results were used to feed the negotiation between the two parties. Integration of new stakeholders and kinds of knowledge (technical expert, administrators) was needed to design a joint action plan and to build trust.
5. Out-scaling of lessons learned by participating herders to the whole village community with the co-designed ABM tool. Participatory use of the ABM for herder to herder training to share lessons learned.
7. Use of a monitoring-evaluation system based on a log book (xls file) to assess (including quantitatively) the process effects on communication, knowledge sharing, stakeholders' creativity and adaptive capacity.

3 Results and discussion

The first phase of the process focusing on co-constructing a representation of the agro-ecosystem facilitated knowledge (empirical, expert and scientific) elicitation and integration about vegetation cover dynamics influenced by cattle grazing: new pictograms of key vegetation states were added to the diagram proposed by the research team (Dumrongrojwatthana *et al.* 2011a) at the request of stakeholders.
The second round of gaming sessions was witnessed by new stakeholders (officials, technical support from the livestock extensionist) to build trust. A new livestock rearing system was designed based on *Brachariaruziziensis* artificial pastures planted on land provided by foresters (figure 1). It included a collective management of grazing cattle (provided by herders) as suggested by the results of participatory ABM simulations used to quantitative lyassess the effects of various options on animal husbandry and economic indicators chosen with the participants.

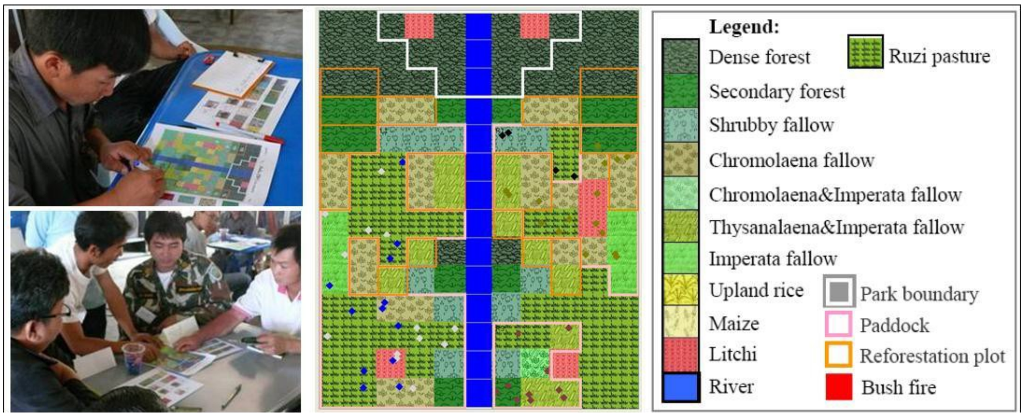

Fig.1. Stakeholders' interaction in the second round of gaming session and example of the ABM interface during a simulation displaying the land use heterogeneity and cattle grazing on *Brachariaruziziensis* pastures.

Herder to herder training supported by the computer ABM was used to out-scale the process, to facilitate the transfer of experience acquired by the participating herders, to promote a shared understanding of the proposed innovation, and to stimulate a collective engagement to respect the agreed-upon experimental protocol for the intensification of cattle rearing at the village scale. Trust building among stakeholders was an important outcome of the process, as well as procedures for out- and up-scaling such processes relying on the ABM tool. Figure 2 shows the intensity of exchanges among the different categories of participating stakeholders in the process. More than 40% of the time was used to elicit and share empirical knowledge (Dumrongrojwatthana *et al.* 2011b).

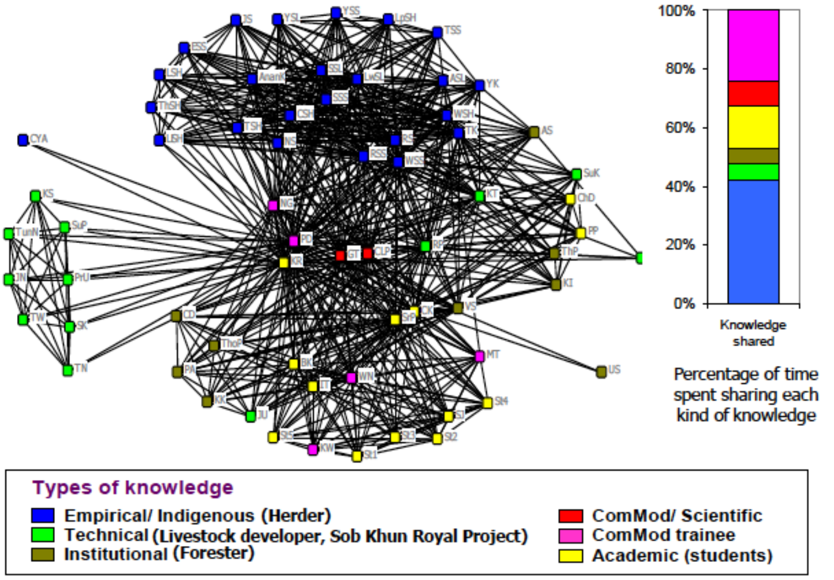

Fig. 2. Social network diagram displaying the communication and the kinds of knowledge shared among the participants during the whole process.

4 Conclusions

The lack of formal education among herders was not an obstacle to their participation because this constraint was well-taken into account when designing the collaborative modelling methodology. For such a process to succeed, a supporting policy environment is crucial to facilitate successful bottom-up design of farming systems and their subsequent experimentation in the field.

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Improving the livelihood of rural communities and natural resource management in the mountains of the Maghreb countries of Algeria, Morocco and Tunisia

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1 Introduction

Mountain regions in the Maghreb countries of Algeria, Morocco and Tunisia cover about 25 million ha and have a significant share of the populations in those countries (20%, 30%, and 10%, respectively) (ICARDA *et al.*, 2003). Yet, despite their social and economic importance, those regions have lagged behind lowland areas, both in terms of appropriate development and research as well. It is only after International Year of the Mountains was celebrated in 2002 that some efforts were deployed by national and international institutions. It was clearly understood that increasing the yields of low-value subsistence crops was not to raise the incomes of small-farmer families sufficiently to lift them out of poverty. Instead, efforts must be deployed to introduce higher-value products in the farming systems, harness local knowledge and product attributes to provide mountain inhabitants with a diversified suite of options and an economic competitive advantage. To address these issues, the national agricultural research systems (NARSs) of Algeria, Morocco, and Tunisia joined hands with ICARDA (International Center for Agricultural Research in the Dry Areas) and SDC (Swiss Agency for Development and Cooperation) to develop and implement a 3-year SDC-Maghreb Mountains (SDC-MM) Project, titled "Improving the Livelihoods of Rural Communities and Natural Resource Management in the Mountains of the Maghreb Countries of Algeria, Morocco, and Tunisia". The Project therefore sought to identify and generate technical, institutional and policy options to improve agricultural production systems in mountainous regions with the ultimate goal of alleviating poverty, while preserving the natural resources in those areas. ICARDA coordinated the Project throughout the 3-year period of 2004-2006 (ICARDA *et al.*, 2007).

2 Materials and Methods

SDC-MM Project adopted a community-based participatory approach where stakeholders are involved in the planning, implementation and monitoring of the project versus a top down, commodity/product approach. While initially conceived based on the 'sustainable intensification' concept, the project was implemented according to the 'sustainable livelihood approach' (SLA), which is centered on people, and on the poor in particular, as promoted by the Department for International Development (DFID,1999) and improved, later on, by international Fund for Agricultural Development (Hamilton-Peach & Townsley, 2005) and other organizations.
During the first year, work teams from the three countries identified 4 pilot mountain sites, one in Algeria at the community of Ighil Ali, near Bejaia in northwestern Algeria, two in Morocco one of which at the community of Anougal in High Atlas in the vicinity of Marrakech and the other at the community of Ait Bazza in the Middle Atlas near Fès, and the forth site at the community of Ouled Helal, near Ain Draham, in northwestern Tunisia. National and regional workshops were held to bring together all stakeholders with involvement or interest in mountain issues and development including communities, government institutions, local institutions, NGOs, national development projects in the target areas, along with research and development (R&D) teams. In addition to informing the communities and other stakeholders of the nature and objectives of the SDC-MM Project, the R&D teams validated the pilot site identification with the communities, and proceeded and completed the diagnosis work, in full participation with the communities and other stakeholders, using SLA tools learned through a training workshop specifically organized for this purpose. A complete database was built that included all required information on the target mountain sites, encompassing geography, natural resources status and use, agricultural systems, and socio-economical features of households and communities. The information was processed, analyzed and discussed with the communities and other stakeholders during the second year of the project, following which an action plan was drafted, restituted to the community and validated for implementation during the third and final year of the project. Although the communities' expectations were broader, only a selected number of options could be tested during that year, leaving the investigations of more complex - yet very important - options to an anticipated second phase of the project. The community-validated

action plan included investigations on policies and household economics, sustainable intensification of mountain agricultural systems, and) promotion of agricultural mountain products.

3 Results - Discussion

Despite the rather short span of the project, significant achievements were to notice that helped identifying diverse potential entry points to livelihood enhancement and diversification. First of all was the huge amount of critical background knowledge and empirical information that was collected relative to natural resources characteristics (soil & water, and medicinal & herbal plants), local genetic resources, farming systems dynamics and potential and limits of conventional agriculture intensification processes.

Practical assessments revealed promising options to improve communities and households productive assets. These options were (i) diversification into high value and labeled products (Moussaoui & El Mourid, 2005) such as fresh vegetables (green peas & beans, potatoes) and special products (Saffron: Crocus), (ii) promoting livestock products processing and transformation (dairy in bee keeping, wool handicrafts) and (iii) adoption of interesting technological innovation packages in micro irrigation systems and in fruit trees production management (nutrition, plant protection, improved trimming techniques).

On the contrary, there were many technical, organizational and institutional constraints to improving local products marketing chains such as highly atomistic productions, lack of farmers organization, poor road infrastructure (in the case of Anougal site) and quasi absence of any significant channel, all of which result in high level of marketing transaction costs and middlemen and retailers market power (Buerli *& al.*, 2006). However, on the social side, the Project underlined existing potential to benefit from the effective role of local enabling organizations and development projects, which requires improvement and capacity building in various aspects: visioning skills, strategic planning and project management capacity, democratic representation and empowerment. Good progress in this instance will help also in implementing identified paths for women economic empowerment (handicrafts; home-based paprika processing). Finally, findings emphasized the critical contribution of deliberate public intervention to reducing context vulnerability (severe destructive floods), improving road infrastructures to reduce currently high transaction costs, enabling effective access to micro-credit and market opportunities and assisting in devising appropriate new technologies.

4 Conclusions

The adoption of SLA proved efficient, as a set of 'high-yielding methodologies', in better integrating and targeting project objectives and in getting higher involvement of local communities as full partners in the design and implementation and evaluation of negotiated R&D action plans.

Project results highlight the contribution of SDC-MM in identifying appropriate entry points to promoting mountain agricultural production systems that alleviate poverty while preserving the limited natural resource base. Yet, the testing and validation of identified technical, institutional, and policy options - some of which have been tested one year but others have not - required more years to enable drawing sound and verifiable conclusions, that would lead to assuring the communities of a comfortable level of self reliance and wellbeing. Fortunately, later on and at present, many of the field work outputs have been introduced into several development projects as was the case of two newer IFAD Projects in Morocco (Royaume du Maroc, 2011, 2014).

Acknowledgements. Authors are willing to thank all team members of the SDC-MM Project as well as associated community farmers in the four study sites of Ighil Ali (Algeria), Ait Bazza and Anougal (Morocco) and Ouled Helal (Tunsia). Efforts deployed by ICARDA scientific committee and SDC contribution are also acknowledged as well as national development agencies high involvement.

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To mulch or to munch? Modelling the benefits and trade offs in the use of crop residues in Kenya

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1 Introduction

In low-income countries from Sub Saharan Africa crop residues are a valuable household resource i.e. livestock feed, energy source, or sold in the market. Quantifying the benefits and trade-offs from these alternative uses has been high in the agenda of those interested in the sustainability and food security of smallholder farming. However, so far the existing diversity in farmers levels of endowment and sources of livelihoods, and the lack of dynamic and integrative analysis tools to quantify benefits and trade-offs from alternative farming systems designs, made answering what practices, tactics and strategies?, suit what situation?, a rather cumbersome exercise. Here we present the results from simulations with a new whole farm model (APSFarm-LivSim) used to quantify the benefits and trade-offs from the alternative uses of crop residues across the diversity of households from eastern and western Kenya. Interfacing the model with a database of a household survey allowed us to parameterise and simulate each of the 600 households in the survey. This is a significant methodological improvement over previous attempts that only modelled single case study farms instead of populations of households and their representativeness across a whole country.

2 Materials and Methods

We used data from an extensive and homogeneous household survey collected by theSIMLESAprogram (http://aciar.gov.au/page/simlesa-program), across two contrasting agro-ecologies in Kenya to (i) describe the diversity of levels of resource endowment among farmers, and (ii) parameterise a newly developed whole farm model to quantify the benefits and trade-offs from alternative managements of crop residues in mixed cropping and livestock smallholder farms. The whole farm model was derived from linking the APSFarm (Rodriguez et al., 2011) and LivSim (Rufino et al., 2009) models. Multivariate statistics were used to classify households into household typologies. Then the APSFarm- LivSim model was used to simulate all 600 households in the household survey (Fig. 1) over 30 years of available climate records. The model was run on a 200-core computer cluster for two simple treatments i.e. present residue management as in the baseline survey, and keeping crop residues as mulch on maize crops. Model outputs included measures of livestock and crop production as well as indicators of environmental impact. Changes from adopting residue retention practices were represented as changes in livestock bodyweight and soil erosion. Modelled results are presented for all the farms in each region, and for different household types.

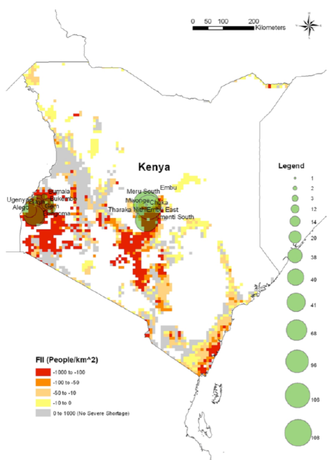

Figure 1. Map of the distribution of the surveyed farms in western and eastern Kenya (n=600), on a map showing a food insecurity index. The size of the circles indicates the number of households surveyed per village.

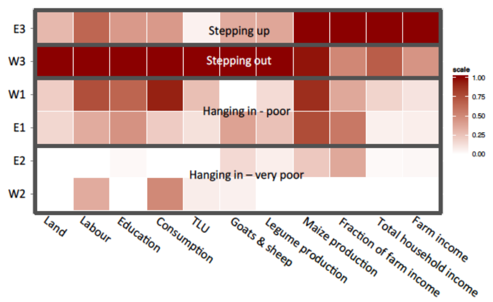

Figure 2. Heat map showing the diversity of household socio-economic characteristics across eastern (clusters E1, E2 and E3) and western (clusters W1, W2 and W3) Kenya. The intensity of red indicates the relative distribution of values for each characteristic. Groups of typologies were named according to their relative concentration of

3 Results – Discussion

Three types of households were identified in each region based on the diversity in levels of endowment and sources of livelihood (Fig. 2). Most of the differences between household types shown in Fig. 2 were statistically significant, indicating large diversity in household levels of endowment and sources of livelihoods. Density plots (Figure 3) showed a large diversity of simulated responses across regions and household types. When all the farms in the survey are plotted together (Figure 3a in Western and Eastern Kenya), keeping crop residues as mulch on maize crops reduced soil erosion by up to -20 and -10%, in Western and Eastern Kenya, respectively. Livestock body weight varied from +10 to -30%, both in Western and Eastern Kenya, respectively. Though most farms i.e. the highest concentration of households in the density plot (green areas), had a -10% and -5% reduction in soil erosion in the wetter (Western) and drier (Eastern) regions, respectively, and no trade-off or bodyweight loss was observed. In the wetter Western Kenya region no trade-offs were observed across the different household types. For the drier Eastern Kenya region, differences were evident between poorly and better endowed households. In the better-endowed households where livestock keeping was an important component of the farming system i.e. TLU>3 (Figure 1c and d in Eastern Africa) showed larger trade-offs between reductions in soil erosion and bodyweight change.

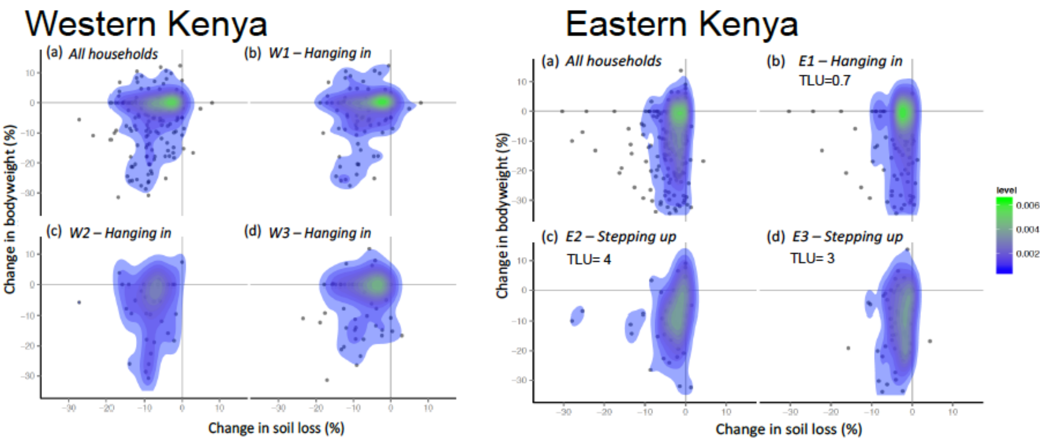

Figure 1. Density plots of simulated trade-offs between livestock bodyweights and soil erosion for each farm from western Kenya and eastern Kenya when crop residues were kept as mulch on maize fields. Simulations are shown for all the farms in each region (a), and when households were grouped according to an analysis of household typologies (b to d). TLU indicates the mean number of tropical livestock units in each household type. The colour scale indicates the density of household i.e. green (blue) showing the highest (lowest) concentration of households.

4 Conclusions

We conclude that (i) due to the large diversity in farmers levels of endowment and sources of livelihoods it is highly unlikely that single interventions will suit the large diversity of constraints and opportunities; (ii) as shown in the example above the use of crop residues as mulches in maize cropping is likely to affect differently households from different agro-ecologies and households having different levels of specialization in livestock keeping; and (iii) that the integration of socio-economic and biophysical approaches provides the opportunity to quantify benefits and trade-offs from alternative interventions and farming systems designs in agriculture development programs.

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VALORIZATION OF SUSTAINABLE MANAGEMENT PRACTICES IN THE FARM BASED SMALL ECONOMY

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1 Introduction

The interplay of market development, sector strategies, local natural conditions, and political frameworks in agriculture has led to farm management practices that in sum exceed the limits of global natural resources capacities (Knudsen *et al.*, 2006; Rockström *et al.,* 2009). Producers and processors in the agriculture and food sectors are increasingly sensitive of these unintended side effects. Approaches for sustainability-led changes in production, however, often fail to appropriate the value created for a long term establishment in the market. Previous studies building on resource based theories suggest that competitive advantage in changing environments is determined by employing dynamic and entrepreneurial capabilities rather than by valuable, rare or inimitable resources (Newbert, 2007; Alvarez & Busenitz, 2001; Porter, 1985). An assessment of resources combinations for responsible innovations in small and medium enterprises shows a need for new business models that source from collaboration in multi-actor networks (Halme & Korpela, 2013). The objective of this study is to compare land conservation and product oriented strategies by analyzing entrepreneurial approaches in two agricultural production systems with distinct elements of production and processing as well as impacts on social and environmental welfare. Based on a literature review and an analysis of stakeholder heuristics we propose a methodology for a resources-based evaluation of production changes for sustainable land management at farm level.

2 Materials and Methods

Two case studies were selected for analysis and case comparison: 1. extensive pasture management, and 2. Dual purpose poultry production. Both case studies were selected for their introduction of changes in agricultural production via innovative management measures. These included the use of biomass from extensive pastures for small-scale thermal production, and the use of traditional breeds for mixed and ethical production of meat and eggs in poultry. For each case study we conducted an on-site inspection with local stakeholders in Brandenburg, Germany. This was followed by a transdisciplinary focus group workshop with experts from practice, and a workshop for reflection with researchers from different fields of sustainability science. Expertise included process and production management, impact assessment, perception analysis, governance, knowledge management, marketing, and business analysis.

In Fig. 1 we propose an analytical frame to link the resources-based perspective with farm performance and impact assessment for an analysis of valorisation strategies for innovative sustainable land management practices. In order to assess farm performance and the underlying factors of competitive advantage we translated a set of theoretical conditions from Alvarez & Busenitz (2001) into practice-oriented aspects that were compared across case studies. An overview is included in table 1 in the results section.

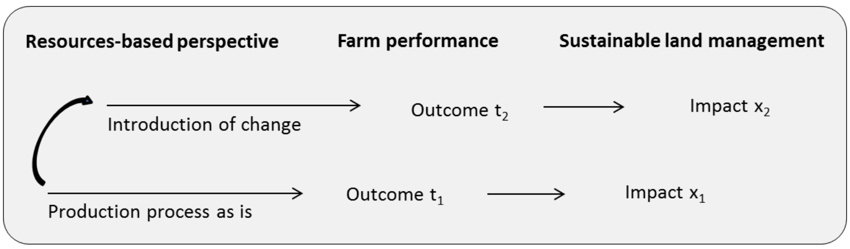

Fig. 1. Analytical frame for assessing valorisation strategies for sustainable land management

3 Results – Discussion

Valorisation of innovative sustainable land management practices was found to be challenged by quantity effects in the implementation of new measures as well as in production and marketing. Positive impacts at a landscape level depend on coordinated and overlapping strategies (e.g. in value creation or marketing), exploitation of existing structures (e.g. value chains or management plans), and interaction between stakeholder groups previously unrelated in production practice. This in turn requires cooperations that's a feguard synergies and intangible assets, as well as access and use rights of bio-physical or other tangible resources. In the case of extensive pasture management, loss of agricultural land area due to trade-offs between sectors posed one main challenge at farm level. In the case of poultry production, quantity effects due to economies of scale in implementation, production and marketing hindered optimal valorisation (« too big to ignore, too small to be »).Table 1 gives an overview of both cases.

Table 1. Comparison of valorisation strategies following a land conservation approach and a product oriented approach

Theoretical condition	Practice-oriented aspect	Extensive pasture management	Dual purpose poultry production
Sustainable business practice	Described change in production management as manifestation of the sustainable product	Use of biomass for on-farm thermal power production	Use of traditional breeds for mixed ethical production
Entrepreneurial recognition	Underlying information, motivation or understanding that triggered the change in production	Site-adequate management is phased out in the absence of profitable utilization of traditional cultivation practices.	An increase of large-scale entities has led to a specialization in meat or egg production. Coupled production considers ethical and breed diversity issues.
Process of combining and organising resources	Activities or knowledge integrated in order to achieve a new combination of resources	Coordination between stakeholders from agriculture, tourism and nature conservation to prevent loss of surface area for sectoral valorization of land use	Coordination between stakeholders along the value chain to prevent failure due to economies of scale
Resource heterogeneity	Type of resources necessary to achieve the change	Coordinated management of land ownership and use rights	Synergies with other existing value chains
Ex post limits to competition	Activities or external factors that achieve competitive advantage as compared to similar products	Achievement of a region-specific unique selling proposition that is recognized by tourists and visitors	Achievement of a sector niche that is recognized by consumers
Imperfect resource mobility	Activities that support safeguarding of resources for the production process	Additional external funding for conservation management based on public regional development strategies	Fixed prices and purchase obligations based on contractual arrangements with a strategic marketing partner
Ex ante limits to competition	Activities or external factors that can sustain competitive advantage	Pooling of land is linked with regional development plans and nature conservation strategies	A set of production criteria that is based on organic farming practices

Previous tools for assessing the sustainability of farming systems have differentiated between farm-focused sustainability and extended sustainability to capture relevant environmental, economic and social aspects of sustainable management practices in agriculture (Terrier *et al.*, 2013; Ghadban *et al.*, 2013). The resources-based perspective applied in this study was tested to incorporate the entrepreneurial perspective of the stakeholders involved.

4 Conclusions

Entrepreneurial stakeholders encounter different challenges in their strategic approaches. Both the land conservation approach and the product-oriented approach, however, required interaction between stakeholders in order to overcome characteristic resources-based limitations to achieving competitive advantage.

Acknowledgements. This study was part of the «Transdisciplinary innovation groups for developing and implementing innovative system solutions for sustainable land management». Financial support was provided by the German Ministry for Education and Research within the programme « Research for Sustainability »(No. 033L145AN). We thank all project partners for the stimulating discussion and for sharing insight from practice.

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Innovation, knowledge management and researchers' postures: exploring their linkages for improving the performance of innovation platforms

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1 Introduction

Multistake holders innovation platforms (IPs) are increasingly used by research and development (R&D) initiatives to actively facilitate social and economic changes in developing countries. In the agricultural innovation systems thinking (Klerkks *et al.* 2012), IPs aim at strengthening the capacity to innovate throughout the agricultural production and marketing system thanks to the creation of spaces where to share and discuss ideas, listen and learn, think and talk, and collaborate. Knowledge and learning issues are central to IPs. However, scientists often wear multiple hats when intervening in IPs, such as facilitators, coordinators, experts or even evaluators. This raises questions about their legitimacy, skills and efficiency in being able to perform such diverse roles and functions, and about the possibility for them to produce generic and useful knowledge for supporting the learning processes that underlie innovation. While much has been discussed on how best to organize IP, choose stakeholders, distribute roles and tasks and plan each step (Kilelu *et al.*, 2013), less is known about how and why learning processes and knowledge should be managed. Hall & Andriani (2003) showed that depending on the nature of innovation, knowledge gaps to be filled differ. And this in turn influences the nature of the knowledge transformation processes to be managed. Lopez-Nicolas & Merono-Cerdán (2011) showed that knowledge management (KM) strategies affect innovation and performance through an increase of stakeholders' innovation capability. But these relationships are not well-understood yet. In this paper, we propose to explore these relationships, between innovation and knowledge management, in order to propose a knowledge-based view of the performance of IPs, with a particular emphasis on the ability of researchers to face KM challenges.

2 Materials and Methods

This paper synthesizes a comparative analysis of six IPs set up at different times between 2000 and nowadays in West Africa (CORAF OID, ABACO, CCV ferti, CARBAP), Meso America (ASOSID) and the Mediterranean area (Aquamed MSHP). The six case studies represent a wide diversity of IPs with regards to their general aim (e.g. improve productivity and competitiveness, transfer and adaptation of agricultural technologies, improve the innovation system itself), the main drivers of innovation (e.g. solution-driven, value chains approach-based, issue-driven), scales of intervention (local, regional, national) and researchers' roles. Each case study was described regarding i) main innovation features and knowledge gaps; ii) types of learning processes that were supported and the knowledge management strategies used to overcome knowledge gaps; iii) researchers' posture and implication in the knowledge management process. We developed a comprehensive framework that integrates three research streams: learning, knowledge management and innovation to test the relationships between IPs functioning, knowledge management and researchers' postures. Data for this analysis included reports, publications and other outputs from IPs, as well as personal experience and reflexive analysis. Analyses were carried out at the aggregate level (not individuals) in order to highlight pervasive features and common issues between case studies.

3 Results – Discussion

We distinguished four roles for KM, associated to different key perspectives of "knowledge" seen either as a process grounded in learning cycles, a tool to structure stakeholders gathering, or a commodity to be transferred (tab.1). The role given to KM and the way researchers involved in the IPs functioning conceptualized the relationships between knowledge system and innovation process appears to be well correlated (fig.1). No links exist however with the features of targeted innovation or knowledge gaps to be filled. Researchers' postures changed overtime, as a consequence of the growing awareness of the role of multiple knowledge sources in innovation processes, the importance of situated learning for the production of useful knowledge and the existence of distributed knowledge systems. In practice it led researchers to ensure a growing responsibility in the support of innovation process and a stronger commitment to stakeholders to achieve the expected results. Nevertheless, the principles of complexity and emergence remained difficult to put into practice, apparently because of increasing tensions due to the multiple hats researchers wear. Different KM strategies co-existed within some innovation platform, reflecting difficulties to effectively switch from a KM perspective (knowledge as commodities) to another (knowledge as a process embedded in organizationnal processes). For instance, decision-support tools are still widely used in the different IPs, reflecting an eagerness to disseminate knowledge possessed by researchers with an epistemology of commodification of knowledge. Some authors suggest that the lack of tools dedicated to the facilitation of learning processes could explain gaps between intention and action in IPs. Our results did not give insights into the influence of KM strategies on innovation. They raised question on the capacity of researchers to operationalise KM concepts for agricultural innovation, so that their approaches and methods become more in line with innovation features, knowledge gaps to be filled in each situation and stakeholders' learning needs.

Table 1. Knowledge management approaches, learning issues and researchers' postures associated to innovation processes in innovation platforms

Role of KM	Key perspective	Learning issues	Researchers 'postures	Drawbacks
Structure stakeholders gathering and strenghthen communication processes that would result into new practices, standards, knowledge	Knowledge sharing between organizations	Create a shared vision and knowledge on innovation issues	**Translator-researcher** Involved in the mobilization and enrolment of stakeholders in order to create a network able to support innovation process	Role of « safeguard », responsible for IP functioning and innovation outcomes Strong commitment to stakeholders
Achieve learning cycles (knowledge explicitation, conceptualization, socialization, practice)	Knowledge process embedded in organizationnal processes People centric and Practice-based Co-learning	Transform stakeholders know-how, routines, or perspectives	**Entrepreneur-researcher** Posture of partner and co-designer of the innovations, which requires capacities to stimulate a demand, make the understanding of innovation issues evolve, influence strategies of the innovation stakeholders	Difficulties to produce generic knowledge due to controversies on legitimate knowledge to be used for action. Risk to produce knowledge to justify the action itself
Knowledge creation and dissemination nowledge dissemination and application	Knowledge as commodities	Produce standard knowledge aiming at minimizing risks and uncertainties	**Expert-researcher** Posture of knowledge producer	Unfocused or useless knowledge due to incomplete vision of the innovation processes and stakeholders' learning needs Risk to produce knowledge to justify the action itself Space for individual values and ideology.

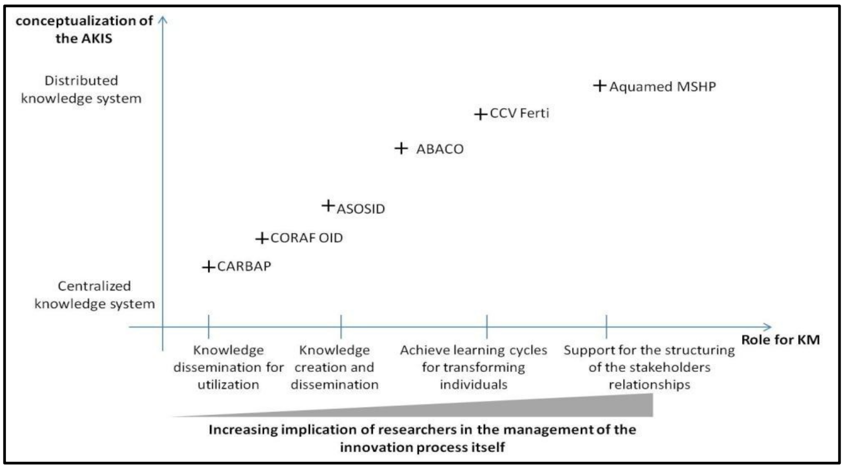

Fig. 1. Correlation between the evolution of the understanding of AKIS (agricultural knowledge and innovation system) and the dominant role given to knowledge management in innovation platforms.

4 Conclusions

While IPs are very diverse in practice with respect to their structure or their objectives, knowledge and learning issues are at the heart of their functioning in multiple ways. Taking into account KM issues associated with innovation could help IP stakeholders to better define research needs and researchers' roles and could contribute to increase the performance of IPs. For this to happen, more attention should be paid to the development of R&D projects which test the efficiency of different KM approaches on innovation processes.

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An innovative approach to simulating household adaptation and investment

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1 Introduction

Facilitating transformational change in agricultural systems in response to high-uncertainty change is difficult. It requires a shift from a 'transfer of knowledge' approach to tools that emphasize collective learning, are co-designed with stakeholders, and are applied flexibly to assist the decision making process.
A small number of process-based simulation models have been developed to address questions at the whole farm scale (e.g. Rodriguez *et al.* 2006, Parsons *et al.* 2011, van Wijk *et al.* 2009, Lisson *et al.* 2010). These models can be used to simulate productivity and natural resource management outcomes, and to evaluate trade-offs between cropping and farming system options that affect profitability and productivity in the short and long term. However, while they provide detailed insights for the farming systems that they are parameterised for, parameterisation for new farming systems and applications is slow and costly. This is a characteristic of their bottom-up design, which represents whole-farm systems as aggregations of often field-scale components.
The current emphasis on detailed bottom-up design creates a niche for simulation models more readily adaptable to new applications at the whole-farm scale. The aim of this research was to develop models readily adaptable to the whole-farm trade-offs involved in intensifying agriculture through an expansion of irrigation in the midlands of Tasmania, Australia.

2 Materials and Methods

For application to agricultural intensification under irrigation we built a prototype model capable of simulating whole-farm trade-offs relating surrounding capital investment in irrigation equipment and the necessary transformational changes in farm management that accompany a shift to irrigation. Initially, a prototype modelling framework was developed as a desktop exercise, to assess whether a model of sufficient flexibility but adequate simulation utility could be built. This prototype modelling framework was then tested and further developed through a participatory process with stakeholders including farmers, agricultural advisors, and extension professionals. Both the desktop and participatory development stages involved identifying and describing model boundaries, decision points, feedbacks, and indicators that define the system.
The model building process focused on development of a simulation model at the whole-farm scale capable of analysing the impact of management options on the biophysical and economic trade-offs. Later stages of model development for new applications are expected to be participatory and iterative processes. For the prototyping process, stakeholders were consulted in order to understand how they perceived the farming system (and sub-sets of the system) to work. The modellers then built the model according to the information from the stakeholders, and presented it back to them for their testing and comment, stimulating further model development. The model was built in Vensim, an icon-based software package using differential equations.

3 Results – Discussion

The function of the model is centred around the consequences of enterprise choice and capital investment (Fig. 1). The model does not attempt to simulate household decision making. Instead, at a set of decision points the user of the model assesses information generated through the evolution of model variables (e.g. economic outputs). The user decides on enterprise and capital investment decisions (bolded in Fig. 1). Decisions interact with the current condition of the land, and with exogenous climatic and economic driving variables (italicised in Fig. 1).
Switches can be used to turn on/off system shocks (e.g. drought or price decline) and other model features (e.g. distributions of exogenous variables).

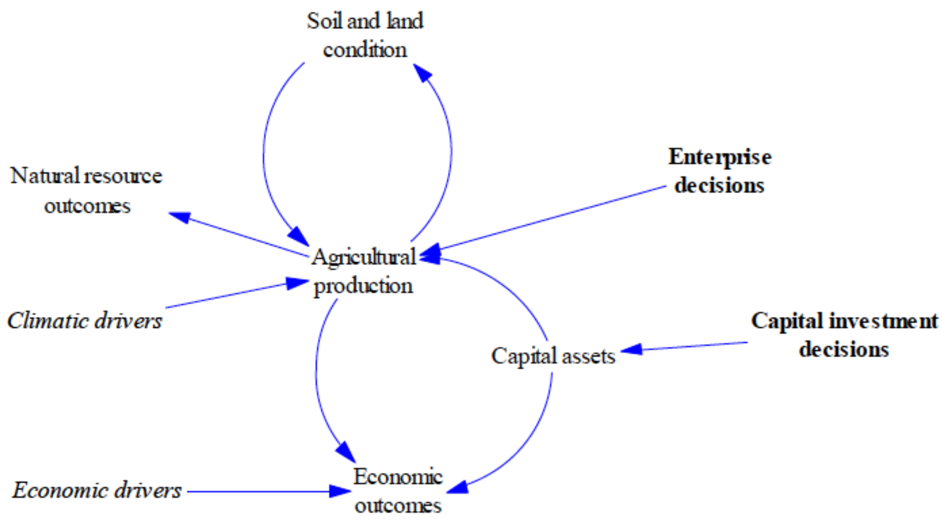

Fig. 1. Model summary diagram

4 Conclusions

The model is designed to be used to facilitate workshops to support discussion by farmers of management strategies for emerging issues. The initial model scenario concerns decision making in irrigated systems in the Tasmanian midlands, amidst potentially competing objectives. Questions will include 'How much additional investment should I make in irrigation, and what are the financial risks?' The focus is on the consequences of strategic decisions (e.g. investing in another pivot irrigator) rather than tactical decisions (e.g. timing of irrigation).

The model is a platform for joint learning among stakeholders and scientists about simulation models as tools for assisting farmers and key stakeholders in adapting to change. The prototype model has been developed and will be further refined through interactions with stakeholders. Through this process, stakeholders will explore the model and allow researchers to better incorporate farmer decision-making context and needs, and understand their capacity to respond to change.

Acknowledgements. Thanks to the stakeholders who contributed their time and understanding to contribute to model development and testing.

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Small farm viability in Central America – can tools for smallholder decision-making play a key role?

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1 Introduction – Can small farm agroecological and business management be improved?

Traditionally small farms have faced complex resource allocation decisions of their scarce land, labor and financial capital to meet home consumption and income aspirations constrained by incomplete information access, including prices, and dependent on ecosystem services. With globalization and climate change, farm households also face stricter quality control and value chain certification, increasing environmental and business regulations, product and input price volatility, declining natural resource quality and increasing frequency of extreme weather events. Research and development organizations primarily address these decision challenges with single factor field-scale solutions – new varieties, agroforestry, crop diversification, IPM packages, value chain linkages, etc. In our own recent work on mixed crop – livestock – tree systems, we developed decision tools for coffee and banana pests, light partitioning in multi-strata systems and dry season feeding (e.g. Staver *et al.* 2014, Guharay *et al.* 2000). Farm households, each with their own array of resources and livelihood goals, face the challenge to evaluate alternatives from us and others and to decide how to reallocate resources to improve their farm enterprise. While diverse aspects of farm decision making have been studied (Kimi and Cameron 2013), whole enterprise management has seldom been the focus for small farm intensification (Alsos *et al.* 2011). When extension services address farmer management skills, they commonly focus on the improvement of input-output relations of specific production systems, a craftsman approach (Lans, Seuneke, Klerkx 2013) rather than on entrepreneurial decision tools for integrated farm intensifiction. Through the CGIAR Consortium Research Program Humid tropics which has a focus on integrated systems intensification, we began an initiative in Central Northern Nicaragua to develop small farm management tools applicable in three land use systems – coffee, cocoa and mixed annual food crops with cattle as a component of all three systems. We hypothesize that farm management and investment decisions can be improved through timely observation, recordkeeping, analysis and learning. This hypothesis is backed by studies from industry suggesting that management is a key element in business performance (Bloom, Sadun and Van Reenen 2012), although Barret, Carter and Timmer (2010) identify numerous external factors which affect farm household resource optimization in a complex and uncertain decision making environment with multiple livelihood goals and Pannell (2006) argues that response curves are relative flat in such an environment making gains from improved decision making minor. We propose that management tools should draw on three perspectives: 1) the farm as agroecosystemic structure and function organized in energy flows, nutrient and water cycles, food webs and biodiversity, 2) the farm as a livelihood system reflecting the interests, resources and social relations of household members and 3) the farm as a competitive enterprise in the market. In this paper we describe the approach and initial progress of a multi-phase effort with research and development partners and farmer organizations to prototype whole farm management tools for smallholders aimed toward integrated intensification.

2 Materials and Methods

Working in three different land use systems in Central Northern Nicaragua oriented towards either cocoa production (Waslala/Rancho Grande), coffee production (Jinotega/El Cua) or a mixed staple food crops and cattle (Esteli), we have initiated the following year by year approach to build a whole farm integrated management toolbox beginning with single field management tools:

1. Through learning alliances of rural development organizations, grower associations and research and education institutes in each land use zone, identify a small working group to assemble from experience and technical publications existing farmer-oriented observation and decision tools with a crop and cropping system approach;
2. With the small group, rework existing tools into a crop phase-based schedule of observation, scouting and monitoring taking into account soil and field conditions, crop density and vigor, presence of pest, disease and natural control mechanisms, labor and input use, involvement of household members in practices and decision-making, soil and weather conditions, etc. For each crop phase, key decisions in crop planning and practices are identified to be addressed with structured observations contributing to decisions to be made. Sampling strategies focusing on only a single aspect of production management such as pest scouting, nutrient status or fruit load were converted into a single sampling routine addressing the diverse aspects of integrated crop, pest and soil management

and costs for input and labor use. Pretesting of the observation routine was completed by the small working group.

3. Testing by farmers and field organizations of the observation and decision-making routine over a full crop cycle with regular meetings among farmers and field technicians to analyze functionality of sampling routines, quality of data and contribution to decision-making and patterns by production system status across multiple fields;

4. Once the field observational routine was underway, design of data entry, storage and access system to make data available in real time both to each farm household and as big data to the participating field organizations;

5. In parallel to field testing, studies to map whole farm agroecosystem structure and related livelihoods of household members to farm and off-farm enterprises, information intended to guide a shift from a field to farm perspective;

6. Evaluation workshop of results of year one and planning for multi-field sampling by each household in year two responding to question whether the observation-for-decisions approach can be applied beyond a single field;

7. Testing by farm household and field organization in year two of proposed observation and decision-making routine with regular meeting to analyze functionality of sampling routines, quality of data and contribution to decision- making and factors in production system status across multiple fields;

8. Evaluation workshop of results of year two and planning for household scale framework combining 3-5 production enterprise formats complemented with data annotation and analysis of food security, income flows, off-farm ecosystem service flows and trade-offs and synergies in decisions on the use of scarce resources;

9. Year three prototyping by farm household and field organization of proposed observation and decision-making routine focusing on whole farm;

10. Based on three years of data from 50 fields by production enterprise, development of scenarios on extreme weather events, pest and disease outbreaks and input and crop price fluctuations and the potential for reduced risk and greater livelihood resilience through modifications in the combinations and management of farm enterprises;

11. Based on farm scale data base with household member livelihoods mapped to farm and off-farm enterprises and follow up studies on hired labor livelihood strategies, analysis of potential for gender transformational alternatives in allocation of farm resources and the impacts of farm intensification on livelihoods of hired farm labor.

3 Results – Discussion

To date in year one with three working groups, the process of assembling dispersed tools into a crop-based observation and decision making routine has been completed for three crop enterprises - coffee, cocoa, maize-bean annual crop rotation - and grazed cattle. For coffee, the integrated tool addresses a mixed multi-strata coffee system intercropped with bananas building on two major sources of tools (Guharay *et al.* 2000; Staver *et al.* 2014). Key decision moments during the annual crop cycle were identified, existing tools were reviewed and diverse scouting approaches were reworked into overlapping and multi-purpose formats. Data are noted onto paper formats, summed in the field and then later entered into a data base. For cocoa, the integrated tool draws on a thematic toolkit which has been converted into six observation moments (http://programs.lwr.org/cocoatoolkit/resources) during the annual crop cycle for an established plantation. Diverse aspects of shade, cocoa phenology and pest and disease status are noted during a single scouting procedure and entered into a hand-carried tablet. Collaborating growers (50 for each crop) and technicians (5 for each crop) from their growers' associations have planned a year-long routine of field visits and meetings to test the tool. A subsample of these same households will be surveyed to characterize the whole farm context as an agroecosystem and map livelihoods to diverse farm and off-farm activities.

4 Conclusions

The process of visioning and assembling an integrated observation and decision-making tool for single field management has provided insights into the potential for small farm intensification. Initial lessons suggest that the process serves as a platform to integrate the experience and perspectives of field organizations, researchers and value chain actors. Challenges in year one are anticipated around the compilation and analysis of data in real time and the documentation of insights into the whole farm context that appear in single field management. A rich exchange is anticipated through the learning alliances based on the parallel experiences generated in the three land use contexts.

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OPENING THE BLACK BOX: INNOVATION PROCESS AND LOGICS OF FONCTIONING OF PEASANT FARMING SYSTEMS

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1 Introduction

Goat milk production and cheese making is an activity typically linked to small family farms of Valles Calchaquíes (NW Argentine). These faming systems operate in isolated territories with a poor infrastructure and they are characterized by a low productivity, difficulties to access to productive resources, environmental fragility and limited bargaining capability (Piccolo *et al*., 2008). Groups of researchers and rural development agents work in the generation, adaptation and diffusion of different technologies aiming at improve goat milk productivity and its quality and in this way to contribute to enhance the sustainability of peasant farming systems. Research questions regarding the impact of innovations arise; that is: is innovation improving poor people wellbeing in a way that it is sustainable and it enhances the environment? The objectives of this study are to understand how the logics of functioning of peasant farming systems contribute in determining innovation processes and to think about the contribution of interdisciplinary research practices used to address this complexity (Boix Mansilla, 2006).

2 Materials and Methods

Information to characterize the diversity of peasant functioning logics of rural systems was collected by a survey to 54 farmers of three communities of Valles Calchaquíes: La Aguadita, Punta de Agua and Amblayo. The survey was structured in five principal axes: characteristics of the family group, characteristics of the production unit, productive process organization, family income composition and local networks insertion (Bravo, 1994). Statistical factorial correspondence analysis (ITCF, 1991) was applied to processed survey data. Interviews to actors (peasant farmers, development agents, researchers) included in the innovation process were made to know how they take part in the construction of this process. Participatory observation was used for understanding the research practices of interdisciplinary group (Beaud and Weber, 1998; Becker, 2011).

3 Results – Discussion

Three principal logics of functioning of peasant rural systems were identified: Type A: young peasant family in domestic phase of expansion, high consumption pressure; the accumulation strategy is based on the growth of the goatish sheepfold and the specialization on dairy production. The strategy of peasant reproduction unit is complemented with family labor outside the farm and/or the receiving of subsidies and pensions. Type B: peasant farmers in middle age and family phase of maturity. To reduce the consumption pressure, some family members emigrate and live outside the rural community. The strategy of peasant reproduction system is based on the dairy production and the family labor outside the farm. This strategy is verified when the family succession perspective is certain and the continuity of peasant production unit is assured (B1). Nonexistence of successor or vague succession process contributes to uncertainty on the family project and on the long term viability of the production unit (B2). Type C: peasant farmers advanced in years and family phase of regression. The size of the domestic group decreases, therefore the consumption pressure on production system is reduced. In case of successor's absence (C1), the prevailing strategy is a gradual leaving of cattle activity, especially for the distressing labor that this activity implies. Great portion of family income becomes from public subsidies and allowances. When succession perspective is confirmed (C2), a dynamic accumulation strategy is observed by the increase of sheepfold size and of dairy production participation in peasant income.

Nutrition goatish sheepfolds practices are based on natural pastures. Pastures provide good grazing in the rainy season (later spring and summer) but by mid to late March production slows to a stop. Consequently these pastures have null capacity to provide animal nutrition in winter season. Peasants attempt supplementary forage using alfalfa hay, barley, oats and corn but this practice is revealed insufficiently to cover nutritional requirements of sheepfolds. In consequence dairy production falls down.

The animal production research team proposes the introduction of corn silage to improve goat nutritional status. The construction of the frame of functioning (Flichy, 1995) of small scale corn silage implied the adjustment of silage corn machine, the experimentation of different silage types and the modification of crop corn management. Researchers are the main actor playing in the technical objet conception and development. They exchange with peasants who act as the first users. This early interaction experiences generate a process of negotiation and the progressive stabilization of the technical artifact: collective management of silage machine, changes in cropping maize system, management of the silage quality and feeding practices of sheepfolds.

At the same time of the construction of the functioning frame of corn silage, the frame of use of this innovation is conformed. Development agents and social local nets catalyze the interesting of potential users (Callon, 1986). The construction of sociotechnical knowledge reveals that the introduction of corn silage generates changes in the organization and functioning of the rural systems: major requirements of family workforce, expanded needs of maize surface, reduction of the sheepfold size and major use of external inputs. The innovation implies an intensification of the milk production process, a specialization in the orientation of the system towards the milk production (minor diversification of cultures) and a major productive risk (minor diversification, increase of dependence of external inputs).

Peasant farmers give different meanings to the innovation according to the diversity of productive situations and family reproduction strategies. Farmers types A adhere to the introduction of corn silage in the production unit. The strategy of accumulation is based on dairy specialization. The innovation needs major employment of workforce and can compete in the cases at which family members are employed out of the farm. Peasants type B have two sociotechnical positions with regards to the innovation. Peasants Type B1 think that the dairy intensification is compatible with the strategy of assuring the continuity of the production system. Peasants B2 want to support without modifications the current way of management and to minimize the risk. They are not ready to intensify the dairy production. Among the peasants in phase of regression, those of the type C1 do not identify the corn silage as a strategic component to incorporate in the production system. They are in stage of slow abandon of the productive activity and do not want to assume a major load of work (gradual reduction of sheepfold size, major participation of the pensions and familiar remittances in the composition of familiar income). Peasants of type C2, where the presence of a successor assures the continuity of the unit of production, have begun to introduce the corn silage and to introduce adjustments in the animal feeding system. They are favorable to the intensification of the dairy production and to introducing improvements in the production process to increase familiar income.

The group of animal production researchers, development agents and social science researchers designed and used the survey to relieve information about peasant rural systems. They integrated social and agronomic perspectives (Dewulf *et al*., 2004; Lungeanu *et al*., 2014; Messer, 2012). Then the group analyzed and interpreted the data looking for the interactions among domestic situations and managing practices of production system. Different positions arose with regard to the relations among peasant logics and innovation design and possibilities of diversification the innovation paths.

4 Conclusions

The different logics of reproduction of the peasant agricultural systems give different meanings to the processes of innovation that are conceived by researchers and development agents. These logics, partly determined by the phase of familiar cycle of the domestic units, define differential insertion in the construction of sociotechnical frame of the innovation. Interdisciplinary research is useful to know how peasant logics influence the innovation path of dairy production.

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Participative design of conservation agriculture cropping systems in organic agriculture

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1 Introduction

New forms of agriculture have emerged aiming at addressing challenges such as improving food production, while minimizing environmental impacts and maintaining economic viability. Among them, organic farming bans the use of synthetic inputs and emphasizes the conservation of soil fertility based on closed farming systems including plants and animals to recycle nutrients. Nevertheless, the number of stockless organic farms specialized in crop production is increasing in Europe. In order to cope with soil fertility problems, some organic farmers are interested in conservation agriculture practices. Conservation agriculture (CA) aims at addressing the problems of soil degradation by improving soil organic matter content, limiting soil erosion, and improving soil structure and fertility. It relies on three principles: minimum or no soil disturbance, permanent soil cover, and diversified crop rotation. Organic farmers are facing technical constraints to combine organic farming and conservation agriculture (e.g. weed infestation that cannot be controlled by herbicides, delay in spring mineralization, or lower yield) and factor-based experimental studies are still insufficient to explore the range of possible solutions and conclude on the possible implementation of conservation agriculture on organic farms (Peigné *et al.*, 2015). Designing organic cropping systems including conservation practices is thus very challenging. Prototyping methods (Vereijken, 1997) have been proved to be efficient to design innovative cropping systems based on limited and dispersed knowledge. Two studies used participative workshops to design organic cropping systems including conservation practices. Lefèvre *et al.* (2013) involved French farmers in a prototyping process to design cropping systems tailored to the local conditions of the participant farms. On the other hand, researchers of the TILMAN-org project (www.tilman.net) designed cropping systems for five pedoclimatic conditions in Europe. The objective of the present study is to analyze the two co-design processes. What are the characteristics of the designed prototypes? What is the impact of the prototyping method and participants on the designed prototypes?

2 Materials and Methods

We compare two methods respectively developed in (i) Lefèvre *et al.* (2013) and (ii) TILMAN-org project that are summarized in Table 1. In case of Lefèvre *et al.* (2013), existing knowledge and data on innovative situations were presented and discussed between step 2 and 3. In case of TILMAN-org project, results from a European farmers' survey (Peigné *et al.*, 2015) were presented during the first workshop to pick the objectives of the prototypes among the ones of the farmers (step 1).

Table 1. Comparison of the two methods

	Lefèvre *et al.* (2013)	**TILMAN-org Project**
Location of the design	France	Europe
	2 pedoclimatic zones	5 pedoclimatic zones[1]
Facilitation	3 researchers	2 researchers
Participants	14 French farmers	17 European researchers
Step 1	**Defining and ranking objectives (collective workshop)**	
Step 2	**Designing prototypes (collective workshop)**	
	7 exploratory prototypes (no constraints)	5 prototypes tailored to the 5 zones
Step 3	**Designing prototypes with constraints (collective and individual workshops)**	-
	14 prototypes tailored to the 14 farms	-
Step 4	**Assessing the prototypes (MASC 2.0.)**	
Step 5	**Redesigning the prototypes**	
	14 prototypes	5 prototypes

[1]Northern, Nordic, Western, Atlantic, and Mediterranean zones.

As the prototypes were designed to follow conservation principles, we compared the characteristics of the prototypes with regard to (i) soil cover, and (ii) soil disturbance (Fig. 1.). Soil cover depends on (i) ley management (1: all cuts are exported, 2: some cuts are exported other are returned to the field, 3: all cuts are returned) and (ii) cover crops (1: occasional or frequent, 2: systematic, 3: permanent). Soil disturbance depends on: (i) soil tillage (1: reduced tillage and occasional ploughing, 2: systematic reduced tillage and no ploughing, 3: 0, 1 or 2 reduced tillage operations (including direct seeding)) and (ii) mechanical weed management (1: systematic, 2: frequent or occasional, 3: no weeding).

3 Results - Discussion

In Lefèvre *et al.* (2013), the method combined collective and individual workshops and led to the design of 14 prototypes, tailored to each farm conditions. In TILMAN-org project, the method, based on the participation of European researchers produced 5 prototypes, adapted to 5 pedoclimatic conditions. In both cases, the overall objective of the prototyping was to preserve and promote soil fertility. In Lefèvre *et al.* (2013), all prototypes were designed with the same objectives and same ranking, combining expectations of the researchers and farmers. In TILMAN-org project, based on the results of a previous farmers' survey (Peigné *et al.*, 2015), for each pedoclimatic zone, the sub-groups of researchers ranked the objectives before designing each prototype. Thus objectives and their ranking were different for each prototype.

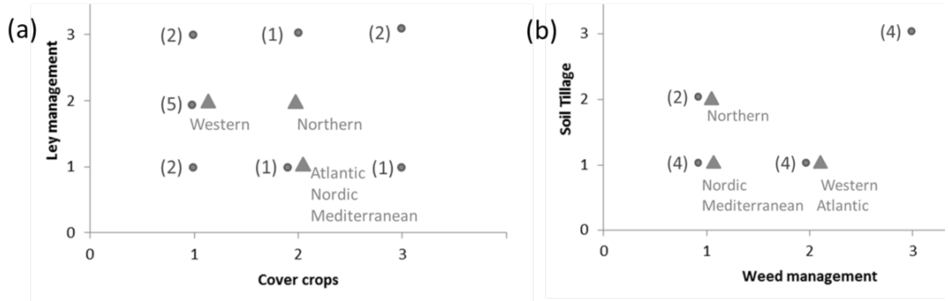

Fig. 1. Distribution of prototypes according to their compliance with (a) soil cover and (b) soil disturbance. Dots refer to the prototypes from Lefèvre *et al.* (2013), and the number in brackets stand for the number of prototypes. Triangles refer to the TILMAN-org prototypes with the corresponding pedoclimatic zones below.

When designed exclusively by researchers (TILMAN-org project), the prototypes of the cropping systems systematically included soil cover (Fig. 1.a.), achieving one of the conservation principle. Nevertheless, ley is often exported and soil is highly disturbed because of mechanical weed management and quite intensive soil tillage (occasional ploughing for 4 prototypes out of 5, Fig. 1.b.). When designed by farmers (Lefèvre *et al.*, 2013), prototypes cover a larger range of situations (Fig 1.), reaching better levels of conservation principles. Indeed, 5 farmers' prototypes return all the ley cuts to the field and 3 farmers' prototypes apply permanent cover crops (Fig. 1.a). Moreover, 4 farmers' prototypes combine no weeding and much reduced tillage (Fig. 1.b.).

The farmers' prototypes (Lefèvre *et al.*, 2013) were more innovative than the researchers ones (TILMAN-org) (Fig. 1). The method of Lefèvre *et al.* (2013) was carried out on a longer period, with more steps (Tab. 1), fostering the creativity of the participants. Ongoing experiments and their scientific knowledge might also have restrained researchers' creativity. The sub-groups of participants (TILMAN-org project) were made of researchers of different countries. They had to find compromise prototypes that were adapted to larger range of conditions (a pedoclimatic zone) compared to the tailored farm prototypes designed by the farmers. In addition, researchers groups included specialists of different disciplines with diverging interests and focus (e.g. soil fertility vs weed control). As researchers aimed at designing prototypes that would be applicable by farmers, they ranked economic objectives among the first objectives of each prototype (even if the farmers of the survey did not rank them uppermost). This lead to prototypes applying quite intensively soil tillage and weed control to avoid risky management (Fig. 1.b.). In case of farmers (Lefèvre *et al.*, 2013), the designed cropping systems detailed the decision-making rules for crop management. This shows that farmers anticipated variable conditions and dealt with risk during the prototyping phase.

4 Conclusions

This comparative paper shows that depending on the objective of the study, the participants and the method should be carefully defined. When looking for innovation and creativity, one would better select farmers and use a long term method with a "no constraints" step. When looking for capitalizing and operationalizing existing knowledge and experiments, involving researchers and/or experts is relevant, but the designed prototypes might lack of creativity. Contrary to conventional thinking, when using adequate method, farmers could put things into perspective and design cropping systems that are very different from their own systems and contribute to address research front issues.

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The institutional innovation in INTA for approaching the territories' complexity of the Argentinean farmland

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1 Introduction

Recently, INTA[1] has started a review of its strategy for approaching the Argentinean rural sector, redirecting its main focus from value chain to territorial complexity. The main novelty of the present projects' portfolio is the Regional Projects with Territorial Focus[2] (geographical basis), which are thematically supported through National Programs, that link and organize the institutional capabilities distributed in the whole country around specific themes. In this framework, in May 2014 the National Program for Development and Sustainability of the Territories[3] was launched.

2 Epistemological framework and strategy of the National Program

This Program is one of the instruments of INTA and integrates9 projects. Its epistemological framework involves the collective construction of knowledge, the paradigm of complexity and integration of thought and action (Fig. 1), considering that to build a complex approach of the territory is unavoidable recognize it and address it as a social construction, as a web of social relations within which conflicts occur. The production of knowledge from the epistemology of complexity and as a tool for transformation, involves strengthening the capabilities for both the production of knowledge and for acting. Therefore, the approach is participatory, interagency and interdisciplinary, promoting technological and organizational innovation from the integration of research and technological development, extension, institutional relations and technological linkages (Fig. 2). The Program identified major problems in Argentina: social and productive imbalances and inequalities; insufficient and/or inadequate policies to promote regional development; weakness in governance for access, use and management of natural resources, common environmental goods and services; asymmetries and fragmentation in the different processes of innovation; improper marketing of goods and services; and lack of systemic and integrated understanding of territorial processes.

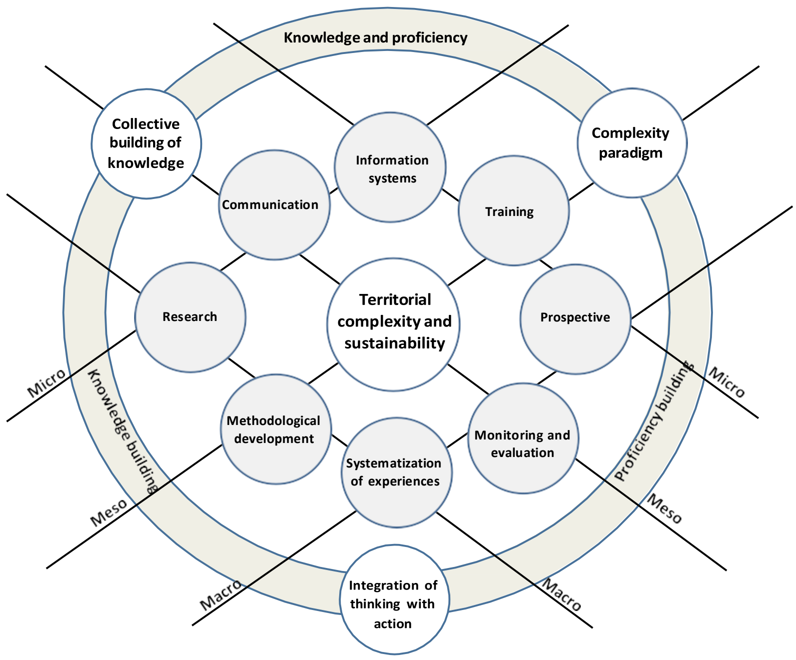

Fig. 1. Epistemological axis, functions and activities based on the objectives of the National Program.

The objective of the program is "to understand the territorial changes and innovation processes and strengthen the skills to manage the development and sustainability of the territory, emphasizing on social subjects and processes". Based on territorial claims, the agenda for research, to prioritize training processes and to develop methodological and conceptual approaches arises. But also, it provides an integrative and multi-scale vision of territorial issues; identification of emerging issues at different scales; development -and analysis of- observatories of territorial practices; and means for generating policies to encourage/facilitate the process of sustainable development of territories.

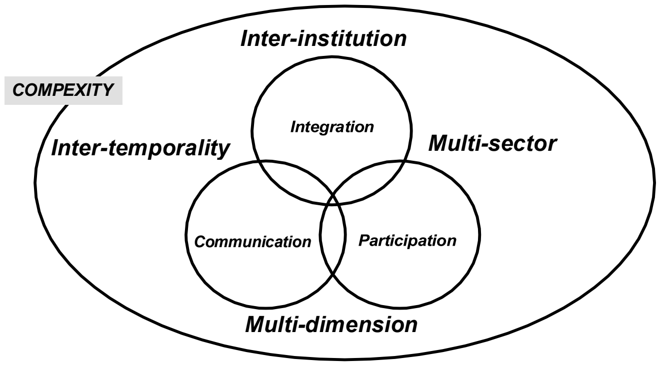

Fig. 2. Schematic representation of complexity as approached by the PNDST.

3 Integrating specific views around strategic themes

The strategy for strengthening an integral approach of the National Program was to link the different (and specific) views from the 9 national projects around main themes. After the first year of implementation, two themes were defined: (1) Observatories of territorial practices (OTP) (Dubois, 2006), as a tool to contribute to sustainable development of territories and performance of production systems. The process of building the OTP started with admission of INTA technicians to France (October2014) and subsequently the organization in Argentina of the First International Seminar/Workshop for Motivation/Sensitization on Observatories (December, 2014). For 2015 a Seminar/Workshop for sharing experiences on Observatories of South America was planned for April, and in May three training workshops on implementing OTP will be organized at regional level of Argentina (North East, North West and Patagonia). (2) The second integrative theme is the "Federal Program for Support of Sustainable Rural Development" (ProFeder)[4]. This program involves a number of institutional instruments (some of them with more than 20 years of implementation) for intervention in the territories and long-term statistics are available. The PNDST will investigate the dynamics of different instruments of ProFeder and its impact in the sustainable development of the territories. Other integrative themes will be defined in participatory workshops during 2015.

4 Main challenges

The agenda of the National Program is built from the local demands expressed by multiple actors of the geographical areas in which the Regional Projects with Territorial Focus (PRET) are acting and from the strategic, prospective and long term visions of senior specialists and policy makers (in both cases through participatory methodologies). The main challenge is to scale-up from local demands (usually very specific) to strategic and broad research lines, and to evolve from disciplinary to inter-disciplinary approaches, with the long-term goal of developing a transdisciplinary perspective for approaching the territorial complexity of the Argentinean rural sector.

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[2] Proyectos Regionales con Enfoque Territorial (PRET).

[3] Programa Nacional para el Desarrollo y la Sustentabilidad de los Territorios (in Spanish;PNDST).

[4] ProFeder (*Programa Federal de Apoyo al Desarrollo Rural Sustentable*). The goal of this program, launched in 2003, is to strength development with social inclusion, to integrate regional and local economies into internal and international markets and to generate working opportunities and income.This Program involves different instruments for specific audiences:*Cambio Rural, Pro-Huerta, Proyectos de Apoyo al Desarrollo Local, Minifundio, Profam* and *Proyectos Integrados*. All of them are based on a strategy of participative action for support of territorial development and the implementation is performed though group projects and plans.

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Adaptation of the Open Innovation Approach for Knowledge and Technology Transfer in an Intensive Agricultural Landscape

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1 Introduction

As a public sector organization, Agriculture and Agri-Food Canada (AAFC) has the mission of producing knowledge and technology (K&T) relevant for various categories of producers and agro-ecological zones. AAFC has to structure, plan and manage research-transfer linkages in order to respond in an effective way to farmers' technical and economic needs while incorporating ecological considerations. The classic linear approach to innovation involves a sequence of phases, for example: research, development, transfer, adoption. Whereas this top-down logic could be operative for the transfer of hard and marketable technologies or products, it appears less adequate for open knowledge, management practices and environmental technologies. Innovation in modern agriculture is rather characterized by a non-linear model, which involves intense communication among stakeholders and interaction and retroaction between each phase of the innovation process. In search for an approach that would make the non-linear model a reality for its transfer mandate, in 2014 AAFC K&T Transfer Office for Quebec region has joined a local partnership called L'Acadie-Lab. L'Acadie-Lab aims to rehabilitate ecosystem functions in an intensive agricultural landscape, namely the L'Acadie river watershed. The initiative relies on a living lab approach, which provides an experiential and learning environment where users and scientists co-create solutions to agricultural, environmental and social issues.

2 L'Acadie River watershed

L'Acadie River flows northerly over 82 km in Montérégie Region, on the south shore of St. Lawrence River, Province of Quebec, Canada. Its source is located near Hemmingford Village (45.038N/73.558W). It runs north through Napierville and L'Acadie to its mouth at Chambly Basin (45.476N/73.287W). It is the main tributary of Richelieu River, which is home to more than fifty species of fish, some of them being considered threatened or endangered as copper redhorse, river redhorse and lake sturgeon. Besides passing through some villages, L'Acadie River flows through agricultural and forest environments (Fig. 1). Its drainage basin covers an area of 41 336 ha, including 30 884 ha (75 %) under cultivation, mainly grain corn, soybean and vegetables. More than 10 000 ha are cropped under the supervision of local agri-environmental advisory clubs. An AAFC experimental farm is also in operation in the watershed. The area features major issues pertaining to surface and subsurface water quality, soil conservation as well as habitat rehabilitation. Considering its land use, its intense anthropic activity and the farmers' commitment toward agricultural beneficial management practices (BMPs), the L'Acadie River watershed offers a suitable frame for the implementation of a living-lab aiming to improve knowledge and technology development and adoption.

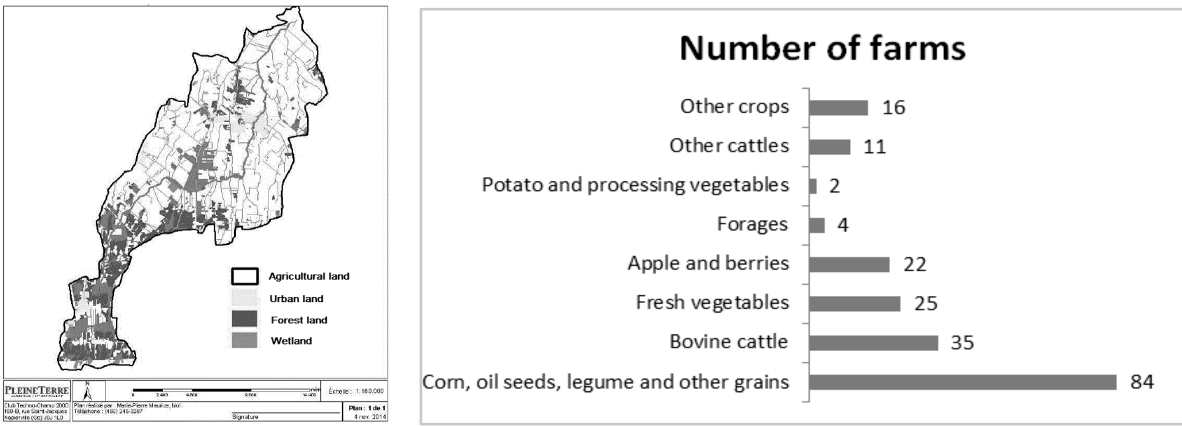

Fig. 1. L'Acadie watershed land use and number of farms per category of production.

3 Living lab concept

The technology and innovation strategy of the Government of Canada (2014) recognises that R&D produces ideas and inventions which, however radical or creative, are not innovation unless they are put in use. The Canadian strategy declares that innovation involves experimenting with different practices, methods and processes, and though it sometimes comes directly from advances in science and technology, innovation can also stem from other sources. The living lab concept takes precisely advantage of pools of creative talent, socio-cultural diversity, and the inventiveness of end-users to enable the development of new useful services and products. First proposed by William J. Mitchell of the MIT Media Lab and School of Architecture and City Planning, the living lab approach represents a user-centric research methodology for sensing, prototyping, validating and refining complex solutions in multiple and evolving real life contexts (Bergvall-Kåreborn *et al.*, 2010). Its process, which integrates both user-centered research and open innovation, relies on four main activities: co-creation, which brings together technology push and application pull; exploration that engages all stakeholders for discovering emerging scenarios, usages and behaviours; experimentation, to experience live scenarios with users; evaluation, to assess new ideas and innovative concepts as well as related technological aspects and to make observations on the potentiality of a viral adoption of new concepts. Some benefits attributed to the approach are (Dubé *et al.*, 2014): from development to adoption cycle reduction; better product and practice uptake by the user; improved knowledge transfer between all stakeholders; enrichment of basic and applied research through new research questions and perspectives.

4 L'Acadie Lab

Veeckman *et al.* (2013) propose a comprehensive framework that links the "building blocks" of a living lab and its effect on outcomes (Fig. 2). According to this model, L'Acadie-Lab's main outcome would be the rehabilitation of ecosystems functions in the L'Acadie River watershed in order to create attractive living environments. With this end in view, the L'Acadie-Lab initiative will provide building blocks both at the living lab environment level (material, immaterial, and contextual elements) and on a project level (i.e., the methodological aspect of the living lab approach).

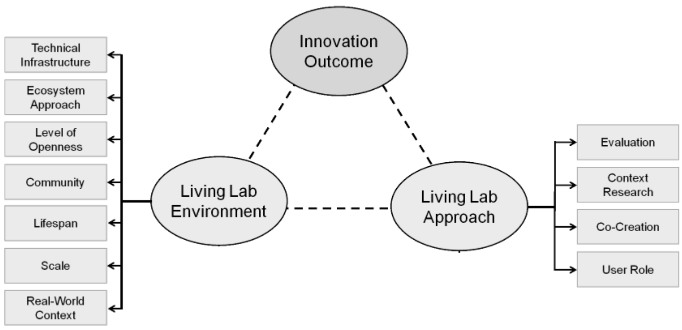

Fig. 2. The triangulation between environment, approach, and outcome in living labs (Veeckman *et al.*, 2013).

The L'Acadie-Lab's overarching element is the founding of an innovation platform that will bring together stakeholders from each part of the agro-environment value-chain. The creation of this platform began in 2014 and will continue in 2015-2016. An important outcome will be the co-creation of models, practices and tools tailored to the environmental and social issues of the watershed and their transfer to the farmers. L'Acadie-Lab will thus provide the real life environment required to identify and build prototypes, and to evaluate multiple solutions. During winter 2014, the lab already identified a set of technologies to be improved or developed, and transferred to end users. Whereas technical support is brought to the lab by agricultural advisors from local and scientists from R&D centres, the knowhow in open innovation methodology and land management comes from experts from the private and academic sector.

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URUGUAY FAMILY FARMING IMPROVEMENT PROJECT

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1 Introduction

While the agricultural sector in Uruguay has achieved a significant growth over the past decade, it has been uneven with a large small farmer sector lagging behind. The Ministry of Livestock, Agriculture and Fisheries (MGAP) estimates that 63% of Uruguayan farms are family farms (FF) occupying 15% of the country's land under agriculture and livestock production but productivity is well below national average. Uruguayan family FF are mainly dedicated to beef and sheep production. The World Bank (2010) considered that "there is considerable scope to improve the long-term profitability and sustainability of family agriculture by improving management of the natural resource base and incorporating technical knowledge alongside increased physical investments".
Evidence of significant differences in productivity reflects the existence of important technological gaps between FF and large-scale producers being one of the principal causes the limited generation and access to technologies suited to address FF needs. The project goal is to improve the profitability and viability of FF without compromising the environment, focusing on three major themes: Profitable and resilient farm systems; Productive and persistent forage systems and Effective rural networks. With the aim of strengthing relationship between organizations and promote local institutions integration as well capacity building, through this combination of themes AgResearch will assist INIA (research organization) and Instituto Plan Agropecuario (IPA: extension organization) in farm systems design and implementation, development and transfer of new technologies, and extension of appropriate farm business practices for the benefit of farming communities. The project period is between 2014 and 2017.

2 Materials and Methods

Activities target at three levels: on farm, farmer organizations and national institutions (research, extension and government). During project first year, 24 Focus Farms (FF) have been selected following criteria agreed by partners involved, either by proposition from local farmers organizations or through regional extension officers. Around each FF, a group between 8 to 15 neighbour farmers (including some rural professionals) has been invited to take part of discussion groups held every season in the FF promoting "farmer to farmer learning". Each FF is monitored monthly by a Facilitator (Technician) whose main tasks are: the completion of a whole farm system diagnostic (social, productive, financial and environmental) in conjunction with the farmer, provide support to Focus farmer to elaborate a Farm Business Plan (FBP) for the project period based on long term goals, prepare and facilitate farmer group meetings and monitor progress. The methodology is based on the coinnovation approach.
The project aims to promote implementation of low cost management practices and technologies which will raise beef production by 100 kg/ha/yr over the current baseline. It has also been designed to meet specific, quantified, targets for uptake and extension by the end of the project (2017) which include: Farmers implementing and validating technologies on MFs (15), Farmers influenced by programme (250), Researchers upskilled for technology development and evaluation (20), Technicians trained for project implementation (100), Networks formed and trained (5). Technologies developed and staff trained within the programme will contribute to INIA and IPA's ongoing initiatives to develop the beef family farming sector and it is anticipated that these advances will be demonstrated on 900 family farms within five years of project end (2022).
In terms on setting up an evironmental baseline and considering 74% of the area occupied by FF is based on native pastures, a Native Grasslands Conservation Index (ICP) evaluation will be carried out in the 24 FF at the beginning and also at the end of project to identify any changes may occur. In order to identify rural networks, surveys to FF farmers and groups will be conducted to set the baseline and discover key influencers, sources of information and also monitor farmer behaviour change.

3 Results – Discussion

Uruguayan family farms growing beef and sheep have received less attention than their large scale counterparts. Under naturally restricted farming conditions and with limited support, farmers have farmed to minimise risk and losses rather than maximise profit. The end result has been low productivity on the family farms, and low family income. During the last decade the small farm sector has come under government attention for development to both alleviate rural

poverty and raise national productivity. Based on this diagnostic, the key problem areas identified for the project to focus on are:
a) Lack of knowledge of productivity and process**:** little research has been carried out within the small farm sector and consequently opportunities for advancement and potential problems are poorly understood. For this reason INIA and IPA are working in a Family Farming programme to address technology, social and environmental issues at the farm level and the project will align to these.
b) Low pasture quantity and quality resulting in low animal performance: much of the limited forage available is used simply to maintain animal body weights rather than contribute to weight gain. Native grassland grazing management practices, regeneration of degraded areas and establishment of new, high-producing pastures appears to be options, but persistence of new pastures is poor in Uruguay and the reasons remain unclear.
c) Lack of access to appropriate technologies and technical assistance**:** there has been a lack of on-farm research and technological support which, in addition to lack of credit, has limited farmer uptake of appropriate technologies. In addition, technical support for system redesign and adjustment of low cost animal and pasture management practices could have a major benefit for small farmers.
d) Lack of farm management business decision making skills: currently farmers are making business decisions based on their experience, their needs and the state of the market. There are a number of implications of which they will be unaware. In this aspect, recording and information analysis as a tool for decision making will be a current practice to be experienced on MF group meetings.
e) Limited connected extension activity and integrated knowledge transfer: the World Bank (2010) report noted that extension services to the family farm sector were limited. However, there is a potentially large source of support available if seed suppliers, meat processors, rural lenders, veterinarians, scientists, extension agents, educational institutes, and industry organisations, are included. At present this support system is fragmented and disjointed. If farmers are to acquire new knowledge and skills through demonstration, training, mentoring, etc., then the knowledge of those to whom they turn for support will also need to be appropriate and connected. The traditional approach of simply up skilling individual extension workers to work with farmers will not be sufficient so that we are initiating the process of capability integration from different organisations (e.g. SUL, MGAP, rural professionals).
f) Balancing profit and environmental outcomes**:** the relationship between the dual outcomes of productivity and reduced environmental footprint are not well articulated as to date there has been little evidence of local community concern about the impact of farming on the environment. A key to increasing productivity will be increasing resource efficiency and this will have environmental co- benefits including less nutrient and GHG emissions to water and air, persistent and resilient natural grassland biodiversity and efficient use of water.
With the objective of setting up a baseline, collecting information for on farm decision making and monitoring progress, electronic tools have been developed: Integral Farm Management tool (GPI), Feed Budget tool (PPF) and an electronic library with national livestock farming research information (Technology Management Guide). During the project these tools will be proved by Facilitators and evaluated as resources to be expanded to MGAP nationwide technicians responsible for designing and monitoriong government Rural Development programmes focused on Family Farming sector.

4 Conclusions

After first year of project implementation, the integration of local organizations with same approach towards the family farming sector it is recognised as a significant achievement. Also, the complementarities of inter-institutional teams for designing, implementing activities, develop tools and review progress strengths the relationship between organizations. The interaction and training from New Zealand expertise to Facilitators and counterpart organizations technical staff is seen as a major capacity building phase at this stage crucial to promote farmer to farmer learning. There is general agreement between the counterparts of the need for aligning the family farming sector approach into the research, extension and government policies strategies. The focus, as it is in this project, is to achieve outcomes on farm, and in industry.

Acknowledgements. This project is moving forward thanks to the support and commitment of Farmers, Facilitators, INIA and IPA teams, AgResearch team, MGAP and MFAT.

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W1. Animal-based systems and crop-livestock interactions at farm and territory level

Chair: Charles-Henri Moulin, Montpellier SupAgro
Co-chair: Amandine Lurette, INRA

USING THE VIABILITY THEORY TO ASSES THE TRADE-OFFS BETWEEN PRODUCTION, ADAPTABILITY AND ROBUSTNESS OF A GRASSLAND AGROECOSYSTEM

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1 Introduction

Negative consequences of the post-WWII conventional model of agriculture has led to renewed interest for grazing-based livestock farming systems (Hassanein and Kloppenburg 1995). However, in such systems farmers have to face high unpredictibility of resource availability and weather uncertainty (Lyon *et al.* 2011). Two contrasting strategies can be followed to cope with this uncertainty: resistance or flexibility (sensu Ten Napel *et al.* 2011). Resistance is the ability of a grazing sequence to remain viable for a wide range of environmental conditions. A farmer using a strategy based on resistance will choose a grazing sequence that makes it possible to feed livestock irrespective of those environmental conditions. Flexibility is the ability of a grazing sequence to be modified (adapted) in response to the environmental conditions encountered. A farmer using a flexible strategy will choose a grazing sequence that can be adapted throughout the year as information on environmental conditions becomes known. Based on a modeling approach, the aim of this study was to quantify both resistence and flexibility of a grazed grassland and to asses the trade-offs between production, flexibility and resistance of different grazing strategies.

2 Materials and Methods

To quantify resistance and flexibility of management strategies, we built a dynamic model of grazed grasslands under the mathematical framework of viability theory (Aubin 1991) as applied to stochastic systems (Doyen and de Lara, 2010). Viability theory makes it possible to look for the set of grazing management strategies that ensure the maintenance of a dynamic system within a defined set of constraints through time. Once viable management strategies are found, we can characterize their properties with respect to production, resistance and flexibility. In this study, management strategies corresponded to grazing sequences and constraints were defined to ensure the sustainability of the system such that the level of performance remained above a minimum threshold and that overgrazing did not occur. In this model, grass growth follows a logistic curve (Voisin 1957) in which the key parameters depend on time so as to reflect the seasonality of grass dynamics and the effects of biomass intake by livestock. The model is parameterized to represent a temperate grassland agroecosystem calibrated on cool-season grasslands of south central Wisconsin, USA. Model calibration was based on datasets from Brink *et al.* (2013) and Oates *et al.* (2011). For full details on model calibration see Sabatier *et al.* (2015).
We ran simulations for a set of 4519 grazing sequences under 500 stochastic climatic scenarios and computed 4 indicators: Production, Resistance, Adaptations and Flexibility. Production from a grazing sequence was defined as the number of animal days livestock could be fed averaged over the 500 stochastic climatic scenarios. Resistance of a grazing sequence was the proportion of climatic scenarios for which the grazing sequence did not lead to overgrazing (i.e. for which it is possible to feed the animals everyday) without modifying this grazing sequence. Adaptation of a grazing sequence was the number of modifications that a farmer had to make to the given sequence to avoid overgrazing. Flexibility of a grazing sequence is a proxy for its potential of adaptation that was a measure of the number of modifications that a farmer could make to a sequence while avoiding overgrazing.

3 Results – Discussion

Resistance and flexibility showed a negative relationship with production (Fig 1.a and 1.b), i.e., the most productive grazing sequences were the least flexible and the least resistant. Conversely, adaptating the grazing sequence showed a positive relationship with production (Fig 1.c.), i.e., the most productive grazing sequences were also the ones for which the farmer had to make the most changes to adapt to climatic uncertainty. Overall, these results show that grazing sequences ranged from resistant and flexible with corresponding low production, to more productive sequences associated with both low flexibility and low resistance that required constant adaptations to cope with environmental variability. The extremes of this gradient of grazing sequences correspond to two major ways of dealing with uncertainty in livestock farming systems as defined by Nozieres *et al.* (2011): overcapacity (pushing the system in sub-optimal situations) and adaptive management (in the sense of Holling (1978)–adjusting management in the face uncertainty).

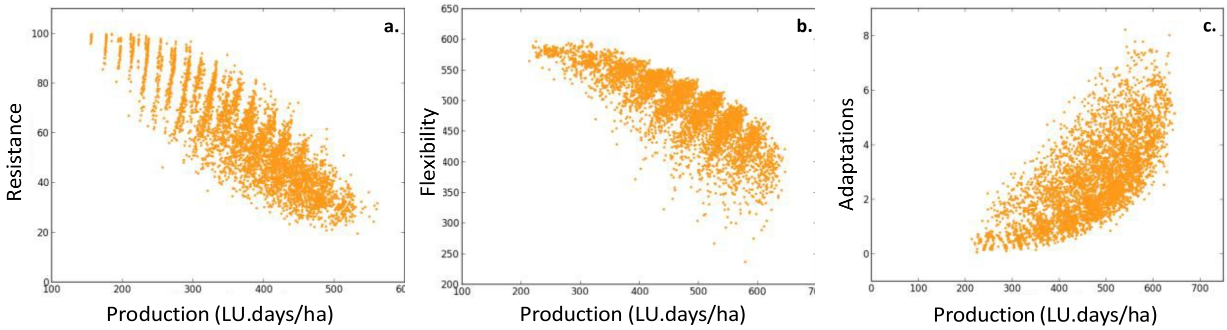

Fig. 1. Trade-offs between production and resistance (a), flexibility (b) or adaptations (c). Each dot corresponds to one grazing sequence

From an applied point of view, these results illustrate strong differences in the way grass-based livestock farming systems relate to uncertainty when compared to controlled confinement systems. The aim of a confinement feeding system is to control environmental unpredictability as much as possible, i.e., minimize environmental variability and the uncertainty of forage availability (although economic unpredictability remains a major issue). By confining the system, farming indoors transforms uncertainty into a known variable. Once variability is known, it can be used to the farmer's advantage with adaptation of farming practices (review in Puillet 2010). Variability is also a characteristic of pasture-based systems from which farmers often benefit (e.g. Andrieu *et al.* 2007; Martin *et al.* 2009a; 2009b). However uncertainty is generally high in these systems and it is generally not possible to adapt *a priori* a management strategy to environmental conditions. To maximize the number of days possible to feed livestock, adaptations need to be made when environmental conditions become known (i.e. when uncertainty has been transformed into variability). Instead of suffering a loss in production, adaptive management (Holling 1978) makes it possible to adjust management to capitalize on unpredictable environmental conditions.

4 Conclusions

These results illustrate the central role played by uncertainty in grassland-based livestock farming systems and the importance for research to focus not only on optimum production in controlled conditions, but also to consider new dimensions of performance such as flexibility and resistance.

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Between social cohesion and rural management: the “Real Employment” calculation as a useful tool of analysis

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1 Introduction

The agricultural activity provides food and organizes a complex socio-economic networking that plays a key role in the social cohesion on rural areas and, at the same time, it encourages regional economy. Reality on the agricultural production processes change over the agrifood chain. Some steps need to outsource several activities and services and it takes an important employment related to the agrifood production chain. Most of the employment is easy to identify and to calculate, for example the labour tied down to the farms or to the material and animals transport and logistic services, but there is another one intangible that is related to the retail distribution sector or the promotion of agricultural products to society. This complex agrifood system and its socio-territorial links requires an in-depth discussion to include new tools and methods to characterize and to manage the new model of agriculture that plays a strategic role in the provision of environmental public goods and services.

The goal of this communication is to provide new knowledge about the variable "labour" within the agrifood system. It is the core of social cohesion of the agricultural economy of the agroforestry mosaic. The idea is to analyse the socio-labour reality around agriculture. For this reason, Agroterritori starts to study “Real Employment” in the pig sector, dairy farming, wine and fruit sector. The results should help to improve the management of labour and to design plans in accordance with social and environmental perspectives.

2 Materials and Methods

To calculate "Real Employment" (total employment: direct, indirect and induced labour and disguised employment) it is defined a transversal methodology in order to estimate with maximum reliability all the tasks carried out by the labour involved along the agrifood value chain. This method requires to study each professional profiles involved in: production, processing, distribution and trade, whatever their origin, participation or function in the agrifood system.

This "Real Employment" methodology has a threefold objective: 1) to characterize and to quantify the socio-labour reality of the different sectors; 2) to develop strategic programmes to improve the employment in agricultural and in other related sectors; and 3) to design a model on employment and professional profiles along agrifood chain. At this point it is essential to identify collaborations between different stakeholders involved. It is also important to have a look on the implementation of dynamic, flexible and resilient soci-labour models. We are aware that of the participative weakness of farmers in the added value of the agrifood chain. So, this study is focus on the analysis of their social and strategic role in the rural territory.

The calculation of "Real Employment" requires an exhaustive fieldwork and a simplified system to collect and manage all the information. It is classified as direct labour (involves the employees that develop daily tasks on farms) and indirect labour (involves individuals who support those processes on farms. They develop punctual or specialized tasks in accordance with its non-agricultural professional profile, for example, animal transport or technical advice or support). The study also aims to bring out the disguised employment, it means, all these activities close to the family unit or to the informal economy that are not accounted in the direct or indirect labour. The sum of these labour typologies embodies a specific methodology that it is easy to export to any agricultural sector. It quantifies and integrates variables such as the number of persons, hours of work on different tasks or the total amount of annual hours worked in agriculture (agricultural work unit, AWU). In a second step, through individual interviews with stakeholders and experts on agriculture, the study contrast the statistical information and existing studies of officials sources. This allows indicators of each type of employment: part-time, full time, eventually, fixed, fixed discontinuous, etc.

3 Results - Discussion

"Real Employment" is a successful methodological tool applied in different regional scale in Catalonia (Spain) to have a picture of pig sector (in the Province of Girona), wine sector (in Alt Penedès region), dairy farming (in the peri-urban area of the city of Girona) and fruit sector (in Empordà region). The results show the dominance of wide-ranging and innovative agro-economy. The relationships across the regional scale, even beyond the national borders. It is visible the deployment of a strong bottom-up organization. It is very interesting the networking between regional and supra-regional companies involved in the manufacture of machinery or equipment and technology. This means that all of them are essential in a complex agrifood system that articulates activities from all economics sectors: agriculture, industry and especially services.

A good example to develop on this communication is the analysis of the dairy farming. In its milk production phase (without taken into consideration the processing or marketing) there are an important range of labour requirements and professional profiles, and also a high amount of annual hours worked. Most of the agricultural and livestock tasks are usually performed in collective work (often as cooperatives): milk collection from farms, livestock waste management or treatment, animal food procurement, animal genetic selection procurement, etc. At the same time, dairy farming unfolds around many jobs in the service sector and in the public administration: essentially on transport, and also on animal health, on animal breeding, on waste recycling, on technical advice, etc. It is extremely difficult to analyse all professional profiles and networking around the dairy sector chain. For this reason, the study does not take into account other activities such as cattle fattening and rearing, rural and agritourism and farm direct selling.

The study is developed on the dairy farming of the peri-urban agricultural area of the south of the city of Girona (northeast Spain) and it takes four case studies clearly representative of the 68 dairy farms: one small size dairy farm (≤500 tonnes of milk quota), two medium size (>500≤1.000 tn of milk quota, both with similar quota but a significant difference in agricultural land) and one big size (>500 tn of milk quota). The analysis reveals that the direct labour (the head of the holding, family labour force and salaried employee) increases proportionately to the milk quota, and agricultural land (Fig. 1). It is a perfect example of an economy of scale to reduce production costs (as is stated in Rémy, 2009). Family labour force works long hours at the farm, around 2825 annual hours, way beyond of 1780 annuals hours that conform 1 AWU (Observatori del boví de llet i de carn, 2013). The graphic shows that direct labour and direct AWU run in parallel with the exception of the big size dairy farm. In this last case, direct AWU are a little higher because these dairy farms have to deal with important amount of work and some eventually employees and external services are needed. In the second graphic, indirect labour is detached from physical parameters of the dairy farm. The tasks and the requirements of labour are almost the same in all case studies.

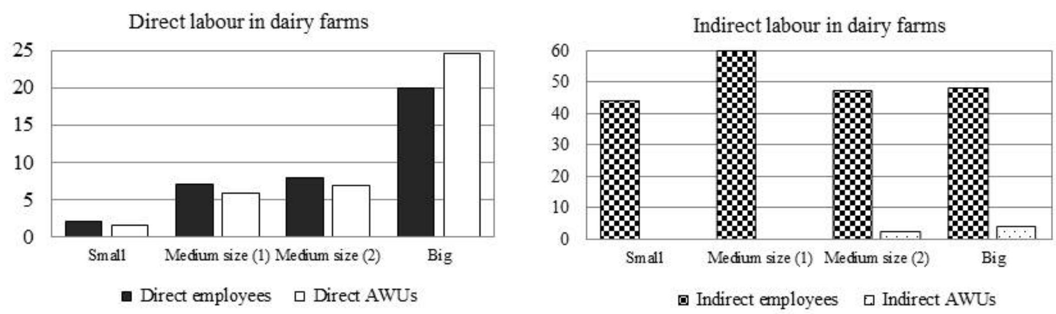

Fig. 1. "Real Employment" in dairy farming, just on milk production stage.

The results of these four case studies are clear, this dairy farms of the peri-urban area close to the city of Girona generates a "Real Employment" (direct and indirect) between 45 and 69 persons and between 1.9 and 28.5 AWU. If these data are extrapolated to the 68 dairy farms of the area it amounts to 442 direct employees and 3949 indirect employees (Roca *et al.*, 2014). These figures underline the importance of the dairy farm in the area and its key role.

4 Conclusions

Agricultural holding mobilizes direct labour and an important indirect labour necessary to develop the activity, which plays a fundamental role in terms of social and territorial cohesion. Therefore it stimulates rural economy and improves the quality of life in rural areas that often turns them back on the agrarian economy. Agriculture increase interdependence between the economics sectors on rural areas. All the employment over the agrifood chain is essential to maintain alive rural areas, in terms of economy and of deep roots of the population in the production areas.

Farmers shares tasks, agricultural machinery, infrastructures and equipment, and they are also organized in associations to reduce costs and labour. The dairy farming sector of the peri-urban area close to Girona is a good example of an organization to work together in innovation projects. It is directly involved in entrepreneurial projects and in research.

The future of agriculture depends on the complicity of all the stakeholders (from farmers to public administration and researchers) to take action and make policy decisions in terms of employment and environmental management. Moreover, the role of the agricultural holdings as managers of the agricultural landscape and natural resources, opens the door to new occupational dynamics (Kroon & Paauwe, 2014) to a society that demands high-quality, local and multifunctional agriculture and the preservation of agricultural and rural landscapes for present and future generations.

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Labour profiles and Electronic Identification (EID) technology: assessing different management approaches on extensive sheep farming systems

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1 Introduction

Extensive sheep farming systems in marginal areas suffer from climatic and production handicaps (Morgan-Davies *et al.*, 2012). These systems play an important role by providing a source of local skilled labour, even if it is very seasonal (Waterhouse, 1996), and they also have a higher labour requirement in proportion to their total gross margin. The farming population in these areas is also an ageing one, with succession problems and not enough attraction to retain the next generation of farm labour (Madelrieux & Dedieu, 2008). Implementing new technologies on such systems could help rationalise labour requirements and improve farm performance (Olaizola *et al.*, 2008). However, labour data at farm-task level are often not measured, or only assessed on a yearly basis (e.g. Nix, 2014), which does not reflect the seasonal variation of the workload. Assessing labour across the whole sheep production year at task level, and taking into account the variation between different farms, is paramount. This paper presents results from research undertaken on an extensive sheep farm in western Scotland, where yearly labour profiles at task level have been measured and compared for two different sheep management systems, one using Electronic Identification (EID) technology, the other following a more conventional approach. Data obtained through questionnaires completed by extensive sheep farmers were also used.

2 Materials and Methods

The research was conducted on a 2200 ha extensive sheep farm in western Scotland. A 900 ewe flock was divided between two systems; with two half-flocks sharing the same pastures, the difference being the use of technology at key handling times to allocate animals to different feeding groups or health treatments. Half of the flock (~450 ewes) was managed using automatic identification, weighing and recording technology (TEC), with each animal identified using Electronic Identification (EID) ear-tags. The other half relied on a more conventional approach (CON), where individuals were identified, weighed and recorded manually. More details of the management systems are available in Umstatter *et al.* (2013) and Morgan-Davies *et al.* (2014). Yearly labour profiles were created by measuring the time spent doing each task within the two systems. Measurements were carried out using a combination of direct recording (stop-watch and hand-held device for continuous recording (The Observer XT, version 9.0, Noldus Information Technology)) and videos. The individual tasks being measured followed the sheep year calendar and encompassed pre-mating (Nov), post-mating (Jan), scanning/pre-lambing (Mar), marking (Jun), shearing (Jul), weaning (Aug), post-weaning (Sep), ewe stock draw (Oct) and lamb selection forsales (Oct). For this particular study, labour recording during lambing was deliberately not included. Additionally, a comparison of labour required to do the tasks involved in more typical extensive low-input sheep management systems, with (Trad-TEC) or without automated technology (Trad-CON) was carried out. These two labour profiles were created using questionnaire answers from 17 extensive farmers who attended a farm open day. The farmers were asked to select which pre-defined tasks they used on their farms. The resulting labour profiles (Trad-CON and Trad-TEC) were quantified by task using the proportion of farmers that selected those different tasks. Results (labour in second/animal for each task) were first compiled and scaled up for 100 breeding ewes and 100 lambs, then for a typical large extensive sheep farm, with 1200 ewes and 1000 lambs.

3 Discussion

The four labour profiles showed differences during the sheep year (Fig. 1). The most time-consuming periods across the four profiles were in June (marking), July (shearing) and October (lamb sales). These periods represented times when all animals were handled (e.g. shearing), or when the tasks needing to be undertaken were numerous (e.g. marking). Selecting lambs for sale was also time-consuming, as animals were handled more than once; generally weighed fortnightly, to check which animals had reached their target weight for sale to an abattoir or market. Conversely, other handling periods, such as October stock draw of the ewes, required minimal handling (just weighing or condition scoring). However, there were differences between the profiles. The labour profiles with technology (TEC and Trad-TEC) were more labour-efficient than those without (CON and Trad-CON). For 100 breeding ewes, yearly labour use was more in CON than TEC by 35 hours 50 minutes. The Trad-TEC profile was also more labour-efficient (12hours 23 minutes) than the Trad-CON one.

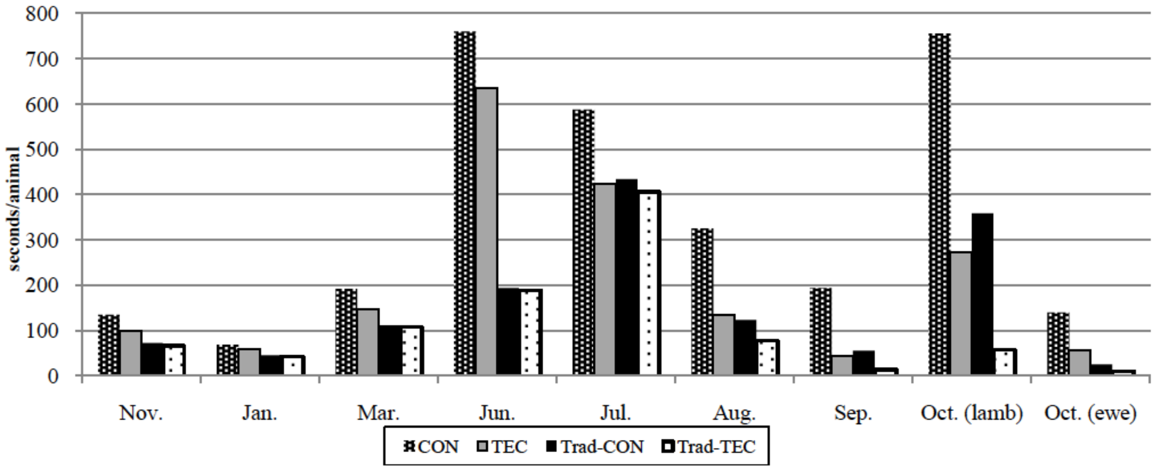

Fig. 1. Yearly labour use (in seconds/animal) for the TEC, CON, Trad-CON and Trad-TEC labour profiles

For a large extensive sheep farm with typically 1200 ewes and 1000 lambs, this equated to labour savings of 15 days (or 46 working days at 8 hours/day) for a TEC over a CON profile, and of 5 days (or 15 working days) for a Trad-TEC over a Trad-CON profile. Both TEC profiles were more labour-efficient due to the automatic weighing, sorting and recording of the animals, compared to the other two profiles where all handlings were done manually. Moreover, the TEC profiles encompassed the selected use of anthelmintic treatment of lambs (Targeted Selective Treatment; Morgan-Davies *et al.*, 2014; Kenyon *et al.*, 2009) in July, August and September. This method, based on individual weight performance of lambs, avoided a blanket treatment approach to anthelmintic use, which, in practice, resulted in less animals being treated, thus saving labour (and anthelmintic costs).

Although the Traditional profiles (Trad-TEC and Trad-CON) were created based on similar individual task measurements, they were less labour-consuming than the CON and TEC profiles. Indeed, farmers in the sample were undertaking fewer tasks at the different time periods. Whilst the CON and TEC profiles were designed to directly compare and benchmark the effect of using technology on an extensive research farm, with a relatively high input management, the Traditional profiles were designed to further represent the inherent variation in husbandry practices within the extensive farmers' population (Morgan-Davies *et al.*, 2012) and to compare the effect of introducing technology on relatively lower input management sheep farms.

4 Conclusions

This research has therefore shown that designing a farming system that incorporates the use of technology could bring potential benefits in terms of labour efficiency, even when the variation in farmers' practices (high input management or low input management) are taken into account. Provided the initial costs of the associated technology can be met, in addition to potential for improved animal welfare and performance, new technology can help make extensive farming systems more labour efficient and resilient.

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Bio-economic assessments of the CAP reform and feed self-sufficiency scenarios on dairy farms in Piedmont, Italy

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1 Introduction

Sustainable intensification is a challenge for specialised dairy farms that must be competitive and respect environmental constraints. A tighter integration of cropping and livestock systems, both in terms of feed and manure flows, can be beneficial for the farm economy and for the environment. In addition, the greening of the direct payments introduced in the European Union's Common Agricultural Policy (CAP) can stimulate the transition towards more sustainable systems. The aim of this study was to quantitatively assess, through indicators, the impacts of CAP-greening policies and scenarios of feed self-sufficiency on three representative dairy farms in Piedmont, Italy.

2 Materials and methods

The Piemonte Region is located in the western Po Plain (NW Italy). As stocking rate is the determining indicator of a farm's intensification level (Gaudino *et al.*, 2014), one farm with a high ('Intensive') and one with a low ('Extensive') stocking rate was selected for this analysis. In addition, an 'Organic' farm was included. Activities provided to the model were those in current situation plus specific alternative crops.
FSSIM (Louhichi *et al.,* 2010; Belhouchette *et al.*, 2011), an optimisation model that maximizes the farm's gross margin subject to relevant resource and policy constraints, was used to evaluate three alternative scenarios. Initially, we optimized the model for gross margin. Then, we simulated three scenarios. Firstly, the feed self-sufficiency scenario (FSS), representative of a tight integration of cropping and livestock systems, evaluated the consequences of minimizing the purchased feed inputs. Secondly, the greening scenario (greening) focused on evaluating the consequences of the greening measures as proposed by the CAP reform 2013-2020. Greening measures include diversification of crop cultivation, maintenance of permanent grassland, and maintenance of an "ecological focus area". The combination of both scenarios represents the third scenario (combi) which explored possible interactions between the effects of the FSS and greening scenarios.
The economic and environmental performance of the three farms under the different scenarios was evaluated and compared to the current situation through eight indicators, related to economic, environmental, and production efficiency aspects. A sensitivity analysis was carried out to explore the sensitivity of the farm gross margin, cropping system organization and ration composition to the degree of farm FSS.

3 Results

In general, silage maize is important in the current systems for animal feeding, results show that on-farm protein production combined with grain maize and hay from mixed grassland are pivotal in offering profitable and environmental friendly solutions.
The number of animals bred in the farm is highly correlated with the farm gross margin. Sensitivity analysis suggests that 90% feed self-sufficiency is difficult to reach without reducing animal numbers and consequently gross margin for farms with a high stocking rate, and/or medium or low cropping system yields.
Indicator results are reported in Table 1. The first two columns represent economic indicators. With the exception of the organic farm, Cropping System Production (CSP*)* was, on average, higher in the different scenarios than in the current situation. Farm management improvements originated mainly from the adoption of alternative crops, or from the substitution of winter cereals with more profitable crops, such as grain maize, soybean, grassland and lucerne. In extensive and organic farms, the FSS scenario limited CSP more than the greening scenario.
With regard to Milk production, as far as the animal number was kept constant, it was also unchanged. Instead the strong limitation to purchase feed for livestock in the FSS scenario, as expected reduced the livestock number with an important consequence for milk production. This occurred most on the intensive farm where it is more difficult to adapt already efficient cropping systems to livestock system requirements.

Table 1. Indicator results of the Extensive, Intensive and Organic farm types.

Farms	Scenarios	Cropping System Production (€ ha^{-1})	Milk production (€ ha^{-1})	Gross N Balance (kg N ha^{-1})	Gross P Balance (kg P ha^{-1})	GHG TOTAL (kg CO_2eq ha^{-1})	NH_3 TOTAL (kg CO_2 eq ha^{-1})	Eco efficiency (kg milk kg N surplus^{-1})	Carbon Credit (kg milk kg GHG^{-1})
Extensive	Current Situation	1708	3937	151	26	7846	91	65	1.25
	Gross Margin	2063	3937	150	19	8082	86	66	1.25
	FSS	1867	3760	124	16	7214	78	76	1.30
	Greening	2174	3937	167	21	8134	89	59	1.21
	Combi	1890	3764	133	16	7380	79	71	1.28
Intensive	Current Situation	1575	8840	275	25	16176	185	80	1.37
	Gross Margin	1701	8840	205	30	15889	173	108	1.39
	FSS	2160	5137	94	7	9575	84	137	1.34
	Greening	1701	8840	205	30	15889	173	108	1.39
	Combi	2145	5110	99	6	9589	95	129	1.33
Organic	Current Situation	4355	8287	164	9	15263	184	107	1.16
	Gross Margin	4090	8287	29	12	15169	177	-	1.16
	FSS	3674	8287	20	16	15403	177	867	1.14
	Greening	4084	8287	12	21	15212	177	-	1.16
	Combi	3759	8287	23	16	15098	177	776	1.17

Environmental indicators (column three to six in Table 1) take advantage from gross margin maximisation compared to current situation, except the P balance for the intensive and organic farm. FSS scenario decreased farm gate N (GNB) and P balances (GPB) due to the reduction in animal numbers, which also caused the emissions indicators (GHG total and NH_3 total) to decrease.

In the greening scenario, N balance and GHG emissions increased marginally. The N surplus was caused by the increased permanent grassland area and the related biologically-fixed N by the legume species. The increased GHG emissions were caused by an increased grain maize surface area that emitted more CO_2 compared to the other crops.

The production efficiency indicators (last two columns in Table 1) represent the amount of milk produced for unit of N surplus or GHG emission. Values were not calculated for the organic farm because extremely low N surpluses. In general N eco-efficiency is affected by total N inputs, while carbon credits are affected only by cropping system management and animal number. The gross margin maximisation scenario increased or maintained efficiency at the current level in all situations. FSS scenario had always a positive effect on N eco-efficiency due to N input reduction while its effect was slightly negative on Carbon Credits both in Intensive and Organic farms due to a larger share of arable crops. Greening scenario had a different effect depending on the farm type.

It is interesting to note that the organic farm reached very high values for N eco-efficiency in all scenarios due to its high milk production and very low N surplus. Low surpluses were justified by a better manure management.

4 Discussion and conclusion

We found that the current situation of the analysed farms could be improved in terms of gross margin. Moreover the application of policies aimed at reducing environmental impact does not necessarily reduce farm profit.

In general there is large possibility to increase gross margin in the analysed farms. The most profitable activity in the farm is milk production, then gross margin maximisation can be obtained reducing or excluding cash crop production and investing all farm area in feed production.

In intensive farm the value obtained for N eco-efficiency indicator equalled 80 kg of milk per kg of N surplus, which was identified as the target for conventional dairy farming systems by De Simone *et al.* (1997).

As to greening policies, it appeared that extensive and organic farms already largely comply with the greening constraints, and therefore the extra subsidy is a bonus, while the intensive farm is likely to sacrifice the subsidy as adapting the farm plan will substantially reduce profit. Introduction of N-fixing crops in Ecological Focus Areas was the easiest greening strategy to adopt for all three farms and led to an increase in the protein feed self-sufficiency.

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Improving the performances of a pastoral system: simulation results against field data

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1 Introduction

The global context of an increasing demand for agricultural products, associated with an increasing concern about the environmental footprint of human activities, triggers changes in agricultural systems. In the perspective of a shift towards agro-ecology, farming systems should rely more on alternative feed resources such as agricultural / agro-industrial by-products or rangelands (Dumont *et al.*, 2013). In Mediterranean areas, rangelands have become a secondary feed resource, often grazed only by animals with low feed requirements in periods of low forage availability (summer or winter) (Jouven *et al.*, 2010). The issue today is to design sustainable rangeland-based farming systems, which display technical, economical and environmental performances equal or higher than traditional systems.
The INRA experimental station of La Fage includes a meat sheep farming system, where prolific *Romane* sheep are reared full outdoors on the rangeland (Molénat *et al.*, 2005). In 2010, a modelling study was undertaken to identify means to reduce inputs and increase the reliance of the feeding system on rangeland vegetation (Jouven *et al.*, 2011). Changes in the management practices were implemented in 2011. The objective of this paper is to analyze the similarities and differences between model predictions and field observations, based on technical and economic indicators. The analysis is based on four campaigns (2011-2014), and puts into perspective both the technical issues associated with rangeland-based feeding and the potential contribution of modelling studies to farming system design.

2 Materials and Methods

The meat sheep flock in the La Fage experimental farm is bred mainly to study the genetic part of animal adaptation to a harsh environment. In order to obtain high animal productivity in a constrained environment, a prolific breed (*Romane* breed, 67.5 kg, prolificacy >240%) is raised full outdoors on the rangeland, with a single lambing period in spring. Biomass production, feeding management and animal performance have been monitored for more than 30 years, thus producing a valuable database to support modelling studies. Though, due to the experimental issues, a number of technical parameters differ from that of a "normal" farm (e.g. high replacement rate, genetic inheritance instead of performance as criteria for selection, experimental animals excluded from pasture during [short] experimental periods, all lambs fattened for carcass analysis, artificial insemination). In 2007-8, an analysis of the feeding system suggested that rangelands could be used more efficiently and provide up to 75% of animal requirements (Jouven *et al.*, 2009).
In 2010, a re-design of the farming system was discussed with the La Fage staff and a modelling study was undertaken to assess the potential performance of the new system. Such study considered a virtual farm, similar to La Fage but free from experimental constraints and thus more representative of the local agricultural context. The virtual farm comprised 13 ha of arable land, 18 ha of fertilized rangeland and 260 ha of poor rangeland. Its flock counted 330 females (adults + young replacement); due to the high prolificacy, only 87.5% of the lambs suckled their mother, the other being fed artificially, indoors. Among the lambs not kept for replacement, 20% were sold just after weaning and the others were fattened. A simple model on an excel file calculating the consumption of grazed forage and supplementation was associated with the OSTRAL model (Benoit, 1998; Benoit *et al.*, 2014) for the simulations. The main changes tested were: a) delaying the 1st lambing at 2 years (=> more unproductive females, but slower growth rate and less concentrate required); b) aligning the lambing period with grass growth on the fertilized rangeland; c) increasing the contribution of rangelands to the diet by specializing paddocks for a given season and type of animal and aiming a total consumption of the available biomass; d) reducing the need to buy concentrate by fattening lambs on grass and e) growing cereals on 2.8 ha. More details on model and simulation parameters are available in Jouven *et al.* (2011).
Given the predicted improvement of multiple system performances (technical: rangeland use and feed self-sufficiency; economic: gross margin and income; environmental: non-renewable energy consumption), the "real" system was re-designed in 2010. In the last four years (2011-2014), the changes simulated were effectively implemented, apart for the fattening of lambs on grass. Compared to the virtual system, the new system still displayed peculiarities due to its experimental activities (see above).

3 Results – Discussion

The climatic conditions in La Fage are typical of the southern Massif Central (alt. 800m): annual precipitations around 900-1000mm with a dryer period in summer and an average daily temperature of 9-10°C with a cold winter. The period considered in our study (2006-2014) was reputed quite favorable in terms of forage availability at pasture.
Strategic indicators of technical and economic performance are presented in Table 1. In line with model predictions, the average prolificacy of the flock increased, although the average values observed were lower than the simulations. Lamb mortality was higher than expected; it increased in 2011-2014 compared to the base situation. A number of factors can explain these two figures: 1) in the former system, female lambs were mated earlier, thus the primiparous females were allowed to suckle only 1 lamb (in the re-designed system: 2 lambs), which made it easier for the mother to care for its offspring. 2) in the former system, lambing took place a fortnight earlier, in a small paddock where sheep were fed conserved forage and concentrate, thus during their first two weeks of life the lambs were protected from predation. In 2014, the paddocks grazed in early spring were fenced with electrified nets, and mortality (assessed based on the number of lambs found dead or not found at all) dropped to 22%. 3) in 2013, due to a great forage availability at pasture (quantity + quality) during the former mating period, prolificacy exploded (272%) and, as a direct (small, fragile lambs) and indirect (more predation) consequence, lamb mortality too (42%). Overall productivity, when expressed per female > 12 months, was thus reduced by almost 30% between 2006-2009 and 2011-2014.

Table 1.A few indicators of performance for the simulations and the real system

	Simulations (virtual farm)		Observations (experimental farm, average ± *s.d.*)	
Indicator	Base situation	Re-designed system	Base situation(2006-9)	New system (2011-14)
Flock size* (nb)	280	280	274 ±*10*	271 ±*10*
Femalesmated (nb)	330	280	334 ±*17*	238 ±*19*
Replacement (nb)	50	50+50 (2 generations)	149±*11*	162±*5* (2 generations)
Prolificacy (%)	242	250	220 ±7	237 ±*27*
Mortality (%)	19.2	19.2	20 ±5	30 ±*8*
Productivity* (%)	196	184	196 ±*28*	138 ±*13*
Concentrate * (kg)	171	86	206±*10*	95±*4*
Feed self-sufficiency (%)	73	93	75 ±*4*	90 ±*2*
Gross product* (€)	152	143	190 ±25	149 ±*13*
Gross margin* (€)	81	97	86 ±*29*	73 ±*15*

figures are expressed per female > 12 months of age

Consistently with simulation results, the re-design of the system enabled to reduce by half concentrate consumption and increase feed self-sufficiency to reach 90% of flock requirements. The number of females mated in the "real" re-designed system was reduced by 29% instead than by 15% in the simulations. As a consequence, with the increase of lamb mortality, the gross product dropped by more than 20% compared to the base situation. Conversely to simulations, the new system displayed a lower gross margin than the former one. The main reasons explaining this counter-performance are the decrease in productivity more pronounced than expected and the perturbations associated with experimental activities, both in terms of costs and in terms of loss of earnings.

4 Conclusions

Consistently with simulation results, re-organizing reproduction and the feeding system has enabled to increase substantially the reliance on grazed forage and feed self-sufficiency. The economic indicators are difficult to analyse per se, due to the costs associated with experimental activities in La Fage. Though, our results suggest that grazing management during the first weeks after lambing and during mating require special attention, in order to control the two main parameters of ewe productivity which are prolificacy and lamb mortality. Delaying the 1st lambing at 2 years also penalizes systems with high numbers of unproductive animals. Our models did not consider predation and feeding effect on reproductive performance, which appear to be determinant for the performance of pastoral systems. Thus, the modelling approach served to identify the strategic component of system management, but overall performance requires the implementation of "precision" day-to-day management based upon a close observation of the local conditions.

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Division of labour in dairy farming – a way to increase income and reduce environmental impact?

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1 Introduction

The efficiency of agricultural production depends on many naturally given factors such as climate, topography, or soil structure, and therefore some regions are considered disadvantaged over others. In Switzerland, this is the case for the mountain region, where the vegetation period is shorter and slopes are steeper, both factors impeding competitive crop production. Even for cattle production, which is performed by most mountain farmers, the disadvantage compared to lowland farmers is large. This is reflected by a lower income of mountain dairy farms (Mouron& Schmid, 2011). It is also observed that mountain farms often have a higher environmental impact per product unit (Alig *et al*., 2011).

In an environmental context, most studies focus on absolute advantages to identify the best region for the production of a given product (Edwards-Jones, 2010), and thus fail to identify products that would be suitable for disadvantaged regions. However, the economic concept of comparative advantage states that a division of labour between two regions can be beneficial for both parties, even if one of the two has an absolute disadvantage in every production activity (Ricardo, 1817). The aim of our study is to test if the concept is applicable in an environmental context by comparing collaborative and non-collaborative dairy production systems.

2 Materials and Methods

Modelled farms and scenarios: Dairy farms from the lowlands and mountains are modelled based on data from the Swiss Farm Accountancy Data Network (FADN, Mouron & Schmid, 2011). The base line (BL) scenario represents typical Swiss dairy production without collaboration. Lowland and mountain BL farms are specialised dairy farms that keep their own young stock of replacement animals. The ratio between farms from the two regions used for calculating average Swiss milk production is based on Swiss dairy statistics (TSM, 2013). In two scenarios a collaboration of mountain and lowland farms is modelled, where milk production is concentrated in the lowlands and mountain farmskeep the young stock. When outsourcing the young stock to a mountain farm, the lowland farmer can either increase the number of dairy cows on his farm, or increase the cropping area. The two options are represented in scenarios C1 and C2, respectively. The ratio between mountain and lowland farms is defined by the lowland farmers' demand of restocking animals.

Socio-Economic assessment: The collaborative systems have an effect on farmers' income as well as on their work load. We consider the marginal return and the associated work load of the changes on farm level based on data from Boessinger *et al*. (2013). The effect of a complete switch from BL to C1 or C2 in Switzerland is estimated based on farm data from Swiss dairy statistics and the ratio between lowland and farmers in the compared scenarios.

Life cycle assessment: The calculation of the life cycle assessment is performed with the method SALCA (Swiss Agricultural Life Cycle Assessment, Nemecek *et al*., 2010). Changes of the dairy production system affect the crop production on the farm, e.g. through changed availability of manure, as well as the amount of crops and the co-product meat produced within the system. To generate systems with the same function, i.e. the same outputs, system expansion is applied. The functional unit (FU) is defined as 1 kg fat and protein corrected milk (FPCM) plus the respective amount of crops and meat. Table 1 shows the composition of the FU for the comparison of BL and C2.

Results are displayed for the total farm as well as for the different farming activities, and for the following impact categories: cumulative non-renewable energy demand, aquatic eutrophication N, and terrestrial ecotoxicity.

Table 1. Composite functional unit (FU) for the comparison of baseline (BL) scenario C2.

	Baseline			Scenario C2			mposition of FU
	Lowland	Mountain	System exp.	Lowland	Mountain	System exp.	
Milk (kg FPCM)	0.680	0.320	-	1	-	-	1.000
Beef (kg LW)	0.026	0.014	-	0.037	0.001	0.002	0.040
Crops (kg DM)	0.030	0.002	0.126	0.157	0.001	-	0.158

FPCM: fat and protein corrected milk; LW: live weight; DM: dry matter; System exp.: System expansion

3 Results and Discussion

Socio-Economic effects of collaborative dairy production: For an average lowland dairy farm the collaboration in C1is cost-neutral, while work load is reduced slightly. Income increases for farms that generate an above-average income per cow, e.g. if they can sell milk for cheese production where higher prices are paid. In C2, lowland farmers' income is reduced. However, as cropping is less labour intensive, 530 working hours per year are saved. If a monetary value based on opportunity costs is attributed to the saved working hours, C2 farmers benefit from collaboration. For mountain farms the financial success depends on the intensity of rearing. With an age of 30 month at first calving a decrease in income is expected, with a younger age an increase is possible.

Currently, the ratio between mountain and lowland dairy farmers is 1:1.2 (TSM, 2013). Based on the demand of heifers by lowland farms, the ratio for the scenarios C1 and C2 would be 1:2.7 and 1:3.3, respectively. If all milk would be produced collaboratively, additional suitable farming systems for mountain farms must be identified to fill the gap.

Environmental benefits of collaboration: Collaboration reduces the environmental impact of dairy farming in both collaborative scenarios, and for all studied impact categories. Results for non-renewable energy demand are illustrated in Fig. 1. Total reduction of non-renewable energy demand of C1 is −9 % and of C2 −7 %. Eutrophication is reduced by−5 % and −8 %, and ecotoxicity by −11 % and −8 % in the collaborative scenarios. The impact of keeping the young stock increases, due to the lower efficiency on mountain farms, but this increase is overcompensated by an impact reduction for milk production (dairy cows), thus resulting in a reduced impact of the total dairy system. In C1, collaboration also has a positive side-effect on cropping activities for energy demand and ecotoxicity, in C2 a positive side-effect for cropping is observed for all three impact categories.

The reduction of the environmental impact in the collaborative systems C1 and C2 is caused by two effects: (1) the comparative advantage effect due to the collaboration, (2) the relocation of production effect, as the ratio between mountain and lowland farms involved in dairy production changes. The comparative advantage effect is responsible for 47 and 33 % of the reduction in non-renewable energy demand in C1 and C2, for 19 and 47 % of the reduction in eutrophication and for 54 and 52 % of the reduction in ecotoxicity, respectively.

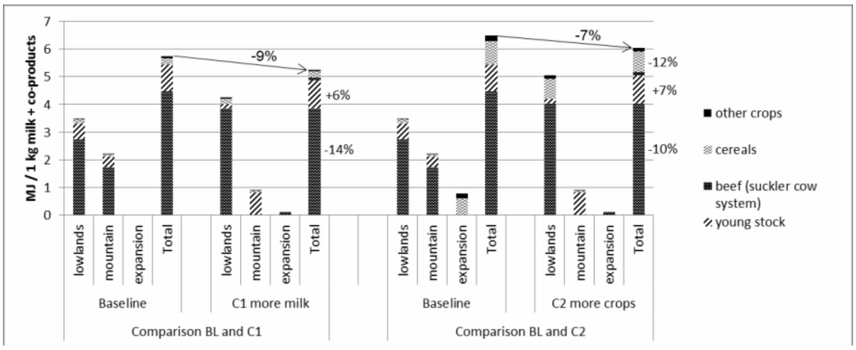

Fig. 1. Differences in non-renewable energy demand between baseline (BL) and collaborative scenarios C1 and C2

4 Conclusions

Division of labour between advantaged lowland and disadvantaged mountain farms in dairy production can help to reduce the environmental impact of milk production compared to non-collaborative dairy production, as mountain farmers have a comparative environmental advantage for keeping young stock while lowland farmers have one for milk production. From the socio-economic perspective, the lowland farmers' benefit from collaboration is higher.

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Improving Nutrient Use Efficiency By Reconnecting Crops And Livestock

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1 Introduction

On a global scale there is an increasing disconnection between crop and livestock production, partly fuelled by human dietary change with increased consumption of animal protein and the associated trade of protein crops (Lassaletta *et al.* 2014). This intensification of agriculture has been accompanied by significant changes in resource use and adverse environmental impacts (Foley *et al.* 2005). Historically in the UK, livestock production was part of an integrated system where a large proportion of the feed and bedding was homegrown and manure returned nutrients directly to crops on-farm. The reasons for increased specialisation in agriculture are complex but one of the possible reasons is that cheap resources lead to specialisation where restricted ones lead to mixed crop and livestock enterprises. The total area of agricultural land in Scotland has remained relatively stable over the last century but there have been some major changes, for example, barley now accounts for ~75% of the grain growing area compared with a high production of oats in the 1950s, the decline in the oat crop coincides with a reduction in horses for agricultural purposes. Declining reliance on manures in arable systems to provide the nutrients may help to explain the reported declines in soil fertility in arable farming systems (Heikkinen *et al.* 2013).

A large scale return to traditional mixed farming is perhaps unlikely but there are interesting questions around the appropriate geographical scale at which the reintegration of crops and livestock might be most useful from a resource perspective. Some argue that the farm is the appropriate scale e.g. Wilson (2009) but others that ecosystem services are produced at the landscape scale (Smith, 2010). There are a range of possibilities for reintegration including an "expanded" nutrient cycle where byproducts from crops harvested and processed for human consumption are returned to livestock farms as feed and manures are reapplied to arable land. Here we explore some of the crop area and farm structural changes which are a precursor to developing nutrient budgets for Scottish regions illustrating how specialized and integrated crop livestock systems could change nutrient use efficiency.

2 Materials and Methods

National changes in cropping areas were assessed from the June census data for Scotland (http://www.gov.scot/Topics/Statistics/Browse/Agriculture-Fisheries/PubFinalResultsJuneCensus). To understand regional change in cropping patterns, ten geographical areas were selected which cover the main farming areas in Eastern Scotland from Berwick in the south-east to the Black-Isle in the north-east. June census data for each of the ten geographical areas for the 24 years from 1982 to 2005 inclusive were obtained from the Scottish Executive. The parish data was aggregated and delivered as summed totals for each geographical area (Parish group). The average size of a geographical area was 11,300 ha with 165 holdings. Data on the total number of dairy cows in Scotland for the period was extracted also extracted from the June census data and data on number of dairy holdings and average herd size was obtained from DairyCo (http://www.dairyco.org.uk/). Nationally available data on nitrogen fertiliser applications and excreta produced per animal type (IPCC, 2006) has been extracted to assess the balance between manure available N and crop requirements.

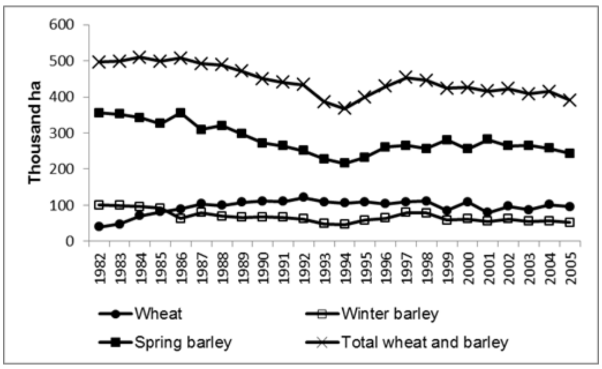

Fig. 1. Change in areas of wheat and barley production in Scotland 1982-2005

3 Results - Discussion

There was an overall decline in the total area of wheat and barley grown in Scotland between 1982 and 2005 (Fig. 1) with a slight increase in wheat and a decline in both spring and winter barley. Concomitantly the area of oilseed rape grown increased from 1600 ha to 35, 591 ha. However, these national statistics mask regional level changes in cropping area. Fig. 2 shows that in Area A there was a much smaller shift from Spring barley to wheat that in Area B. Area A is close to the traditional centre of the whisky industry in the North East and Area B closer to the English market in the South East. In relation to dairy farming in Scotland, the total dairy herd declined from 282000 to 197000 in the period 1982-2005. More recent data shows that there are major changes in farm structure as DairyCo report that average dairy herd size in Scotland grew from 125 cows in 2003 to 153 in 2013. Over the same period (2003-2103) the number of holdings with dairy cows fell from 1590 to 894. The inability of currently estimated available nitrogen in animal excreta to match the required N for Scottish crop production at recommended levels is shown in Fig. 3.

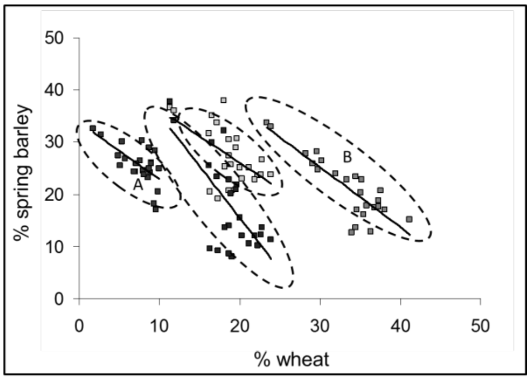

Fig. 2. Change in percentage of the agricultural land area sown to spring barley and wheat in 4 separate Parish groups (1982-2005). Each line represents one Parish group. The ellipse shapes are indicative of the data points for each group.

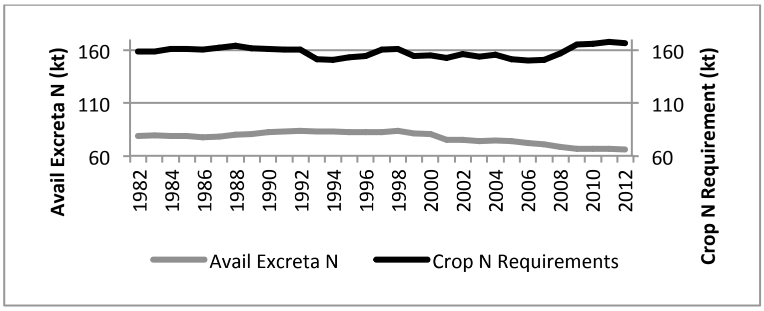

Fig. 3. Available N from excreta N (Avail N) and Fertiliser (Fert) N requirements

4 Conclusions

While reintegrating crops and livestock may bring benfits from a resource use perspective they will only be taken up in practice if they are economically viable. It is important to understand how resource use, and other ecosystem services would be influenced at the farm level but also in the context of the wider farmed landscape and hence take into account the linkages between farms and farming systems. We also need to consider what lessons we can take from the past success of mixed crop and livestock systems and aply to future farming.

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Co-innovation of family farm systems: developing sustainable livestock production systems based on natural grasslands

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1 Introduction

In Uruguay, during the last decades the number of farms has decreased significantly being the family farms the most affected ones. Between 2000 and 2011, 21% of the farms disappeared. However, Uruguay has 26.480 livestock farms in 11.7 million of hectares, most of them family farming systems based on natural grasslands. In those systems, the level of technology applied is low, which in turn, determines low productive efficiency and high output variability across time. Although several technological alternatives have been generated by research, farmers didn´t use them, so significant improvement in sustainability of livestock farmers was not obtained. The technology transfer approach was not successful to promote learning and changes leading to innovation. We proposed that at the farm level there are opportunities to improve the productive and economic results through an adequate selection and orientation of the productive activities and applying the adequate technologies, but in a modality in which researchers and farmers are closely involved in that co-design process. A co-innovation approach implemented in the horticulture systems in Uruguay successfully contributed to improve their sustainability. Proposals for improvement were discussed between farms and scientists considering farmer's objectives and resources (Dogliotti *et al.*, 2014). At the regional level there are opportunities to coordinate activities to enhance family's quality of life. The objective of the project was to evaluate the impact of strategic changes (re-design) in the sustainability of farming systems and to scale up the results to a regional level, using the "co-innovation" approach in the east region of Uruguay.

2 Materials and Methods

The research was conducted in Rocha-Uruguay, between 2012 and 2015. We applied a participative learning and action research approach known as co-innovation (Rossing *et. al.*, 2010). The work was carried out at two scales, the farm and the regional level, with interconnected activities at specific instances, where results were exchanged and discussed. At the farm level the project involved 7 livestock family farms based on natural grasslands that were monthly visited, following three steps (Dogliotti *et al.*, 2014): (i) characterization and diagnosis, (ii) re-design and (iii) implementation, monitoring and evaluation. At the regional level the project has emphasized the strengthening of an inter-institutional network with regular workshops involving the participation of farmers, researchers, technicians and other local actors. In order to evaluate the processes, we used an Indicator-based Framework for Evaluating the Sustainability of Natural Resource Management Systems (Masera *et al.*, 2000) at the farm level, and the framework for planning, monitoring and evaluation called Participatory Impact Pathways Analysis (Alvarez *et al.*, 2010) served at the regional level.

3 Results – Discussion

Results from the initial situation are presented in Table 1. We found that the weakest point of the farms was associated with low physical and economic productivity and with natural resources degradation. The main point to be addressed to improve farm sustainability was an imbalance between animal requirements and nutrient offer. Historically farmers managed their farms with high stocking rate and high sheep to cattle ratio, resulting in other problems such as low reproductive efficiency, low cattle sale weights and low productivity of natural grasslands.

The main strategy of the redesign process was working with more grass. The first step was the adjustment (reduce) in stocking rate and sheep to cattle ratio, and pasture allocation according biomass height and animal category; which was complemented by low cost breeding practices.

The proposals elaborated with farmers have two years of implementation and have led to significant improvements in farm sustainability (Table 1). Compared to the initial situation, meat production increased by 24% and net income increased by 40%, explained by an increase in gross income while maintaining the same costs. . The amount of standing spring biomass of natural grassland increased in 60%. All farmers mentioned a better organization of labor with "*less workload and task simplification*". They learnt and started to use adequate techniques. Also they started to plan in the medium and long term which has enabled them "*to make better decisions, visualize and anticipate future problems*".

At the regional level the implementation of six workshops allowed the development of an inter-institutional network related to the project that also addressed issues linked to rural development. It included an extension institute, local government, Ministry of Agriculture, Livestock and Fisheries, University of the Republic, national and local farmers´ organizations, farmers involved in the project, researchers and other new actors that were invited as the project advanced. During the first workshop the impact pathways of the project were identified and summarized in the following idea: “There is a considerable improvement in the sustainability of the farms and in the region with the application of adequate technologies, which have resulted in higher incomes, conservation of natural resources and improvement at the social level”. Based on that, the actors proposed a set of activities to achieve the vision. In the next workshops, participants reflected on the results and progresses achieved so far using participatory methods and suggested changes for better results and impact. The project´s strategies and activities had been changed to some extent, based on the lessons learnt.

Considering the impact pathways, members of the network elaborated an annual communication plan to effective disseminate the knowledge generated along the project, based on the work at the farm level and taking into account the aims of the different groups (farmers, technicians and institutions). During the last two years several activities, took place, according to the designed plan. Farm´s meeting and field days were organized supported by the inter-institutional network. In November 2014, a field day was done in a farm with the objective of showing main results of the project. Almost 160 people had the possibility to listen about the changes implemented by a farmer in the field, the reasons for doing that and the results obtained. The evaluation showed that participants gained new ideas for their farms.

Table 1: After two years of implementation of redesign proposed, results at farm level.

ATRIBUTE	DIAGNOSTIC CRITERIA	CRITICAL POINT	INDICATOR	UNIT / SCALE	Initial situation (av. 7 farms)	Intermediate situation (av.7 farms)
Productivity	Productive efficiency	Low or upgradable production yields	Equivalent meat production (i.e. meat + wool)	kg ha^{-1}	99	123
	Economic efficiency	Low or upgradable economic income	Net income	U$S ha^{-1}	70	98
Stability	Quality of life	High level of satisfaction with quality of life	Family satisfaction with quality of life	5 to 1 (*^{1})	4,6	4,6
		Inadequate labor organization	N° of families that mention an improvement in labor organization during interviews/ 7 farms involved in the project (^{*2})	%	—	100
	Productive stability	Low use of adequate production techniques	% implementation of an adequate technology set proposed (*^{3})	%	39	98
	Natural Resources conservation	Degraded natural grassland	Spring biomass of natural grassland	kg DMha^{-1}	1183	1868
		Good level of biodiversity	Richness and diversity of birds	N° (Shannon index)	129 (3.71)	132 (3,86)
Reliability/ Adaptability/ Resiliency	System fragility	Availability of family labor	Proportion of labor input provided by family	%	93	93
	Diversification	Diversification of income sources	Number of income sources	N° (*^{4})	2.7	2.6
Self-reliance	Financial dependence	Low level of debt	Relation debt / patrimony	5 to 1 (*^{5})	5	5
	Decision-making	Lack of medium and long term planification	Family worth and use of medium and long term planification	5 to 1 (*^{6})	2.1	3.9

(*^{1}) 5: very satisfied, 4: moderately satisfied, 3: satisfied, 2: little satisfied, 1: not satisfied (*^{2}) Emerged as critical point during monitoring interviews. Farmers mention less workload and task simplification (*^{3}) Adequate technology set proposed: adjustment in stocking rate and sheep to cattle ratio, pasture allocation according biomass height and animal category; adjustment of the mating season, management according to body condition, ovarian activity diagnosis, pregnancy diagnosis, control of breastfeeding, fall weaning, preferential handling of the rearing, mate of heifers at 2 years and use of records.(*^{4}) Sources: cattle, sheep, other animal productions, vegetable production, off-farm work (*^{5}) 5: <0.05, 4:0.05- 0.1, 3: 0.1-0.15, 2: 0.15-0.2, 1: >0.2 (*^{6}) 5:worth planification and use long-term plans, 4: worth planification and use medium-term plans, 3:worth planification and some areas planned, 2: worths planification and don´t use plans, 1: not worth and don´t use plans.

4 Conclusions

The methodological approach is being effective in improving sustainability at farm level and contributing to regional development, where farmers, local institutions and researchers jointly define activities based on the results of the project.

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Production gaps in livestock grazing systems in Sierras del Este, Uruguay: magnitude, causes and strategies to reduce them.

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1 Introduction

In Uruguay beef cattle production is the main source of income in 24848 farms, covering an area of 11.5 million hectares, being 55% of those farms classified as family. The main productive orientation in family farming is cattle breeding, based on natural grasslands. Those systems have very low productivity: 70-80 kg of meat ha^{-1} (Berreta, 2003), calving rate of 62%, and only 50% of the heifers get pregnant with 2 years (DIEA, 2002). Natural grasslands are the main forage resource available in those systems, representing at least 60%. It has been reported that grassland productivity has been low, exists risk of erosion, loss of biodiversity and high presence of weeds (Boggiano, 2003).
Most of the studies in yield gaps analysis have been developed in cropping systems. In these studies the current levels of production are analyzed, potential and achievable yields are determined, considering defining, limiting and reducing factors (van Ittersum *et al*., 2013). In animal production this approach has been rarely used (Cortez-Arriola *et al*., 2014). However, it would be very adequate for studying livestock production systems, especially in the analysis of resource use efficiency. In livestock grazing systems the production gaps may be caused by an inadequate management of the forage (without considering time and space) and the herd. Consequently, forage production and utilization are affected (Carvalho *et al*., 2004). Based on this approach we want to answer which is the magnitude and which are the causes of the production gaps in livestock grazing systems in the region of Sierras del Este, Uruguay. This information is of great relevance to think the re-design of production systems, but looking for a diagnosis for action, since our purpose is to intervene on the causes that limit or reduce production levels.
This work is part of the extension and development project "Improving the sustainability of family farming", carried out by the National Institute of Agriculture Research and Plan Agropecuario of Uruguay with AgResearch of New Zealand, between 2014 and 2017. The aim of this project is to increase the productivity and quality of natural resources in family cattle farms.

2 Materials and methods

We are working in 22 focus farms throughout Uruguay, around each of which it has been formed a group of 8-12 farmers. A co-innovation approach (Dogliotti *et al*., 2014) is being followed. The approach involved characterization and diagnosis of the farm system's sustainability, followed by cycles of re-design, implementation, and monitoring of system evolution. In this paper we present the farm diagnosis and discuss the production gap of four focus farms located in the region Sierras del Este, Uruguay.
The four focus farms were selected with the support of local farmers organizations and extensionist. The main criteria for choosing the focus farms were: being family farmers, being livestock grazing systems with at least 60% of the area with natural grasslands, and showing interest in making changes in their farms. The characterization and diagnosis of the farms was done during 2014, while farm re-design and it implementation started during 2015 (to be developed until 2017).
Monthly visits during the first year were done to evaluate farm resource availability and productive results in addition to farmers objectives. To analyze the magnitude of the production gap, we compared the meat production levels of the four focus farms with those obtained in the seven case studies reported by a Co-innovation project in Rocha-Uruguay (Ruggia *et al*., 2014). The average gap was estimated as: [(average production obtained in the 4 focus farms - average production obtained in the Co-innovation project in Rocha after three years of work) / average production of Co-innovation project in Rocha after three years of work] * 100. We also compared other important indicators for cattle breeders systems: the forage allowance, cow´s pregnancy rate and kg of weaning calf per breeding cow.

3 Results and discussion

The focus farms are representative of the predominant family livestock farms in the region. They have small land area, predominance of family labor, the main forage source is natural grassland and the production orientation is breeding. On average, productivity levels were low: meat production of 84 kg equivalent meat (meat + wool) ha^{-1}, cow`s pregnancy rate of 77%, and 98 kg of weaning calf per breeding cow (Table 1). This diagnosed situation was similar to the baseline reported by the 7 pilots farms of the Co-innovation project of INIA for the same region. These farms after three years of working with a co-innovation process achieved an increase in productive results reaching the following results: meat production of 122 kg equivalent meat per year ha^{-1}, a pregnancy rate of 90% and 149 kg of weaning calf per breeding cow Considering those production levels as achievable, the production gaps in our focus farms was estimated in 31%.

Table 1. Farm characteristics and productive results of each of the four focus farms, its average, and the average for the seven pilot farms of the CoInnovation project in Rocha, at the beggining and after three years of changing implementation.

Farm	Total area (ha)	Stocking rate (LU)	Natural grassland area/ Total area (%)	Sheep-to-cattle ratio	Cow´s pregnancy rate (%)	Meat yield (kg ha^{-1})	Weaning calf per breeding cow	Number of cows mated per year	Forage allowance (kg DM per kg LW)
1	179	0.89	53	0.14	80	86	97	105	3.0
2	517	0.83	90	1.5	79	99	110	202	2.8
3	520	0.62	60	0.5	63	65	79	171	3.8
4	189	1.10	100	2.0	85	86	105	92	3.9
MSGF Este 2014[1]	351	0.86	76	1.0	77	84	98	143	3.4
CoInn Rocha 2014[2]	240	0.84	84	1.4	90	123	149	101	6.1
CoInn Rocha 2012[2]	240	0.92	87	2.6	76	99	107	95	3.5

LU: livestock units. DM: dry matter. LW: live weight.
[1]Average Project "Improving the sustainability of family farming" year 2014.
[2]Average Co-innovation project in Rocha (Ruggia *et al*., 2014) years 2012 and 2014.

Which are the causes of current production levels and the production gaps?. There is lack of planning in the production systems and an imbalance between forage production and animal requirements. Forage allowance, an instantaneous measure of the forage-to-animal relationship, was on average low in the 4 focus farms (3.4 kg dry matter kg live $weight^{-1}$). Consequently, exist low levels of consumption, higher energy costs on grazing, leading to breeding cows to be at many times of the year in negative energy balance (Carvalho *et al*., 2004). Moreover no management practices for breeding were used in the cattle herd, such as: differential feeding management according to body condition and physiological state, mating period setting, suckling control, final weaning in March and diagnosis of ovarian activity and pregnancy, differential feeding management of the female calves in the first winter.

A successful co-innovation process involving farmers in the same region and with the same problems, resulted in important improvements of system functioning within three years, providing specific technical information to re-design the farm systems and elements to think about the possible trajectories for change, inspiring to apply this knowledge to reduce production gaps in other farmers. In this sense, although the current gap is around 31%, there are alternatives to reduce it. These requires re-thinking the systems globally working together extensionists and farmers, redesigning them based on a different organization of the resources that are available.

4 Conclusions

There is an important production gap in family livestock farms under study. They are reaching lower results than the possibles ones to achieve with the available resources. As reported by national research this gap can be reduced. The callenge is to generate changes in management practices without adding external inputs based on systems approach and with active participation of farmers

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Herbage allowance a management tool for re-design livestock grazing systems: four cases of studies

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1 Introduction

Native grasslands represent the largest agro-ecosystem in the Campos biome region, and provide valuable economic and ecosystem services, but they are critically threatened by changes in land use (Overbeck *et al.* 2007). Animal production limitations in these ecosystems are mainly related to grazing management and its interaction with climatic variability. Low income and degradation of natural grassland by over stocking rate is the major problem of the livestock farmers in Uruguay. Traditional management is not quantitative and over or under stocking, has limited both pasture and animal production. Under experimental conditions, management of herbage allowance (HA) has proved to be an effective tool to increase animal performance without increase in cost of production. Stocking rate is a poor indicator of grazing intensity, in contrast to HA, because it gives no information of feed availability. Herbage allowance measured as kg of forage dry matter (DM) per kg of animal live weight (LW) integrates both animal demand and feed availability (Sollenberger *et al.,* 2005). For Campos grasslands, with the management of herbage allowance it is possible to control herbage growth, individual and per ha animal productivity (Do Carmo *et al.,* 2013; Soca *et al.,* 2013; Nabinger *et al.,* 2000). At farm level the use of HA to manage the grazing pressure in each paddock should improve both animal and pasture production. Optimization of stocking rate to maximize animal production should combine pasture resources and animal demand of each type for each season. The objective of this work was to test HA control on 4 commercial grazing systems evaluating the impact on animal production by changing stocking rate management in time and space. To implement the changes in each farm, we working with a participatory approach that considers the particularities of each producer, co-innovation approach (Dogliotti *et al.*, 2014).

2 Materials and Methods

The study was conducted in 4 farms in Uruguay, each one in a different region (Farm 1: 31º38'53'' S 56º31'10'' W, Farm 2: 32º35'46'' S 56º07'10'' W Farm 3: 32º38'47'' S 54º42'38'' W, Farm 4: 33º42'42'' S 55º26'46'' W) from November 2012 to current days. The sizes of these farms are between 465 to 2200 ha and the proportion of improved grasslands is less than 5%, the native grassland is the main feed resource. Three of them combine cattle and sheep mixed grazing. Farm 1 is an open system that has cow-calf system and sale fattened steers but part of them was bought out of the system, also sale cows and growing steers. Farm 2, is a closed system that sale fattened steers but does not bought out of the system, thus has all the sub systems inside the farm. Farm 3, has a cow-calf systems and also sale \`pastoral services\` to livestock owners. Farm 4, has all systems combined with a strong commercial approach looking for the buy and sell price difference in livestock to make the best price difference, this strategy difficult our main \`technical\` approach to be implemented. In each farm, we identified the area of technical problem, and with the constraints of each farmer we worked together to try to solve them. The main problems detected were: low herbage production in Farm 1, low general stocking rate in Farm 2, low cow-calf productivity in Farm 3 and relatively low animal production ha^{-1} in Farm 4. Adjustment of herbage allowance was a major target to solve these problems, and do that monthly was the center of the work due to the high environment variability (Wheeler *et al.,* 1973) in Campos grassland. Due to different farms sizes we controlled closely only part of the systems, from 18% in farm 2 to 50% in farm 1, but working with the most demanding process, like fattening and cow\`s pregnancy. Herbage mass was measured by "comparative yield method" (Haydock & Shaw, 1975) and stocking rate by monthly or seasonal weight of animals, both used to reach our HA reference value for each season and animal category. Uruguayan rainfall average is around 1200 mm y^{-1} distributed equally around the year, but with high variability between years. The rainfall was above the average in 2012 and 2014 when rainfall average was 1466 and 1800 respectively; in 2013 was an average year, but spring and summer rainfalls were above the average. Animal performance was measured as pregnancy rate and calf weight at weaning for cow-calf systems and meat production ha^{-1} for growing and fattening systems.

3 Discussion

Farm 1, changed the spatio-temporal management of cows and fattening steers, by changing paddocks assigned to each one in each season and by management of seasonal HA, this system implies that during the grassland growing season the fattening steers are in the best paddocks for this season at HA of 6 kg DM kg LW^{-1}or more and growing steers and

cows assigned to other paddocks. However lactating cows are also with 5 kg DM kg LW^{-1} and suckling restriction (Quintans *et al.,* 2010) was applied to enhance pregnancy probability. In winter season when the herbage growth is minimum pregnant cows (at HA of 3,0 kg DM kg LW^{-1}) were allocated to the best paddock of the previous growing season that accumulated herbage during the fattening period. Although the spring-summer rainfall was above the average in the last three years, we measured an increment of the animal production from 90 to 110 kg ha^{-1}, and from 110 to 120 kg ha^{-1} comparing year 2012/13 with 2013/14 and 2014/15.
Farm 2, changed both spatio-temporal use of paddocks and HA by cows and fattening steers to enhance the resource use efficiency. This process involved “cultural” change because by tradition some paddocks were paired to animal category, e.g. paddocks for cows and paddock for fattening all around the year. At these paddocks the stocking rate was increased based on herbage mass measurements, relative to the "traditional management" of the farmer. Live weight production ha^{-1} increased from 111 to 196 kg ha^{-1}, without reducing individual animal performance. HA was managed between 3 to 5 in spring to 7 or 8 in winter, and taking into account the herbage mass also to define HA value due to its influence on herbage intake (Wales *et al.,* 1999). However because general stocking rate of the farm was not increased immediately, net income was not increased, and live weight gain per animal was already high, nevertheless 800 ha from the 2200 ha of the farm were remained ungrazed in the last summer, showing the potential to increase general stocking rate without increase in economic risk or food outside the farm, with a close control of HA only in 18% of the farm.
In Farm 3, initially the stocking rate was relatively high to the herbage mass present, (HA was 4.5 kg DM kg LW^{-1} with herbage mass of 950 kg DM ha^{-1}) and we cannot diminish due to financial constraints. Changing the spatial allocation of the most (lactating cows) and less (cows non-pregnant non-lactating, growing females, recently pregnant cows) food demanding animals we modified the HA for lactating cows during the first breeding season (reaching HA of 6.2 kg DM kg LW^{-1}) and also we added suckling restriction to increase pregnancy probability (Quintans *et al.,* 2010). Compared with the previous years pregnancy rate increased from an average of 70% during 2012 to 88% and 90% for year 2013 and 2014, and calf weight measured in May 2013 was 155 kg and 188 kg in May 2014. Comparing pregnancy rate with the average of the farmers of his region, that report pregnancy rate by themselves, the increment was 7% and 18% for 2013 and 2014 respectively.
In Farm 4, the management focus were the growing steers, similar to Farm 2, however the commercial strategy of the farm, and the constraint to management of livestock, limit the potential increase, anyway HA was adjusted in late autumn to 6.0 kg DM kg LW^{-1} and was 4.4 kg DM kg LW^{-1} in average along the year. Live weight production was increased 20% from 100 to 120 kg ha^{-1} for 2013/14.

4 Conclusions

Along two years of the project, in most cases, HA use has been widespread from paddocks to almost of the systems. The improvement of reproductive and productive results showed how this tool could be useful to sustainably systems re-design, as long as the manager (or farmer) incorporates the tool in his decisions. This tool and the approach (co-innovation) to work with farmers contributed to assess the impact of herbage allowance to adjustments on stocking rate. The increase of livestock productivity was based on native grasslands without additional needs of inputs, specifically by managing the plant-animal interactions at different spatio-temporal levels. Nevertheless, we should confirm these results in different climatic years, and we need to develop predictive tools to reduce the too time-consuming herbage mass measurements in order to simplify the incorporation of HA management technologies in farms.

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Participatory Design of Livestock Systems: Explore, Experiment, Innovate (case study in Burkina Faso)

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1 Introduction

In mixed farming systems in western Burkina Faso, more than 80 % of the farmers have in mind a familial breeding project (animal traction, fattening cattle or sheep, milking production, poultry, pigs, etc.). However, more than half of the projects miscarried before starting due to a lack of preparation. Moreover, significant technical weaknesses mainly related to food management are observed in the project implemented (main expenditure item). This lack of control affects the profitability and the sustainability of the projects. Strengthening the capacity of farmers in the development and implementation of aviable breeding project viable is an important research and development issue. The objective of this study is to present a Participatory Design of Livestock Systems (PDLS) approach tested in Burkina Faso. The main hypothesis is that the PDLS approach allows farmers to strengthen their capacity to formulate more realistic projects and change their way of thinking and planning the feeding of the livestock.

2 Materials and Methods

The study involved six farmers carrying breeding projects (2 animal traction (AT), 2 fattening production units (FP), 2 milk production units (MP)). The PDLS approach is inspired by the work on action research in partnership (Vall and Chia, 2014) and design of innovative agricultural systems (Meynard *et al.*, 2012). It aims to help the farmer to make a successful breeding project by adjusting it gradually, at the same time as he learns how to control it, is convinced of its interest, and gradually reorganized the work and the resources of production. This is a participatory and progressive approach including 4 phases: (i) diagnosis by analyzing the initial project of the farmer (P0: identification of goals, strengths and weaknesses, etc.); (ii) research of improvement options (during which the farmer and the adviser identify possible solutions to the causes of the weak points of the project, and then choose the options that best suit to the objective and situation of the farmer; P1: project in phase of design); (iii) implementation and adjustment, where the farmer and the adviser follow the implementation of the project and if necessary adjust it to optimize the effects required by the farmer (PF: project carried out) and (iv) participatory assessment of the project and its consequences on the future of the farm(Fig 1).

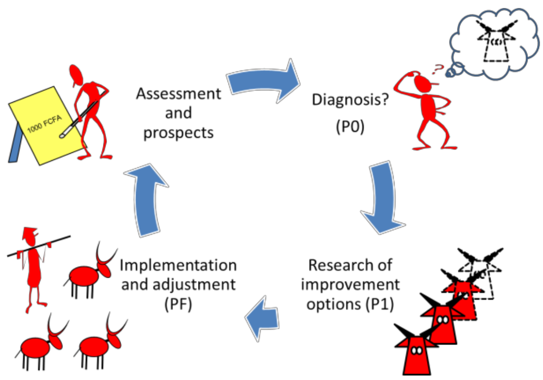

Fig. 1. Participatory Design of Livestock Systems (PDLS)

In this paper, we will focus ourselves on two points: i) improving the control of herd feeding and, ii) learning that underlie this control.

3 Discussion

The results obtained (fig 2) show that the PDLS method allowed in some cases (AT1, AT2 and MP2) to reduce deficits in fodder unit (FU) and digestible crude proteins (DCP), and in other cases (FP1 and MP1) to reduce food waste (in case of diet including cotton seedcake often distributed in large quantities). However in the case FP2, PDLS has reduced waste in DCP, but at the expense of covering in fodder unit (FU). However in the FP2 cases, PDLS has reduced waste in DCP, but at the cost of inadequacy in FU.

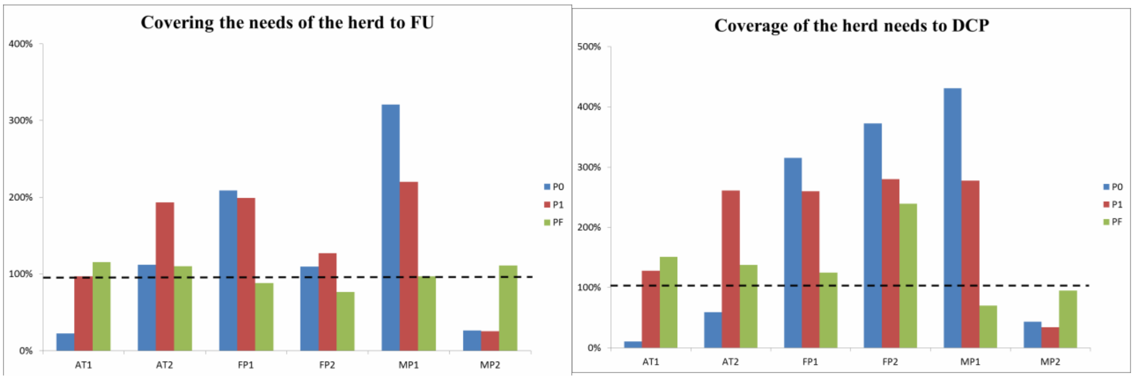

Fig. 2. Evolution of the coverage of the herd needs (FU and DCP) over the phases of the project breeding (P0: initial project; P1: project in phase of design; PF: project carried out) for the three types of breeding projects (TA: Animal traction; FP: fattening production unit; MP: milk production unit)

We can explain these improvements of the control of the animal feeding by learning induced by the PDLS approach. At this stage of the study, and subject to validation (in progress), we assume that these learnings are of different nature according to the phase of the PDLS approach:

- Diagnosis and Co-design Phase (P0 and P1): learning in terms of feasibility (technical, economic) and planning (forecasting forage crops, food stocks ...);
- Implementation Phase (P1): innovative practices (forage crops, storage fodder and food techniques...), feeding management (adjusting supply to needs), technical and economic management of the project (recording of expenses and revenue), monitoring of the project (farmer involvement);
- Assessment phase: for some of the farmers a better ability to projected themselves into the future and to develop more ambitious projects (increase of herd size and forage crops), to change their breeding model(complete stabling of cows for the milk production unit).

In the PDLS, partnership and permanent dialogue between the farmer and the advisor stimulate learning and help the farmer to design a more realistic project technically and economically as well (Meynard *et al.*, 2012;Vall and Chia, 2014). It leads the farmer to question his breeding project to identify the points of weaknesses and to reflect on possible solutions. Finally, it develops technical and operational skills (concerning animals breeding and management) and strategic skills (ability to formulate more realistic project, and to change the production model)(Kolb, 1984; Argyris and Schön, 2002).

4 Conclusions

In the PDLS approach, the permanent interaction between the farmer and the adviser stimulates critical reflexion on breeding projects during the phase of diagnosis and co-design. This improves the viability of the project (reduction of food waste, optimizing costs, reducing losses of working time). Moreover, the heuristic nature of the approach increases the chances of the success of the project and the understanding of the practices and strategies of farmers as well. PDLS can be used as an advice tool for breeding. It enables the design and implementation of more realistic and better adapted breeding projects to the needs of animal production.

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Integrating empirical and scientific knowledge to evaluate the transition to a once-a-day milking in dairy ewe farms

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1 Introduction

As for the whole French ovine sector, the Rayon de Roquefort sector is largely constrained by a conjoncture which combined an explosion of the production costs, a climatic variability which affects forage quality and an increase in the work load and drudgery. The once-a-day milking is an interesting technique in response to the breeders' expectations of finding livestock systems both economically and socially viable. It can lighten the routine work load in dairy flocks. The Lacaune ewe appears to be well adapted to the once-a-day milking situation (Vanbergue *et al.* 2013). However, the resort to this new technique in dairy ewe farms arises questions, both at the individual (balance between income and work load) and at the collective (collection and milking distribution) levels. In this study, we aim at presenting how an approach combining both empirical and scientific knowledges, and their consequential produced scenarios, are likely to stress the technical levers which could accompany the transition to the once-a-day milking in French dairy ewe flocks. The local stakeholders' (breeders, advisors and farms network) mobilisation was regularly held during the four years of the study to discuss on the modelling hypothesis, the scenarios to test and the validity of the results.

2 Materials and Methods

The model BOUSSOLE was developed to represent dairy ewe farms situated on the Rayon de Roquefort area. Its development is based on the use of virtual farm types. A virtual ideal farm type is the optimized economic and technical design of a farming system performed from a farm network. By providing a common language, the farm-types facilitate discussions between all the participants of the project. Seven virtual ideal farms were modelled to represent the diversity of production systems in the Rayon de Roquefort area. This diversity includes soil and climate conditions, farm dimensions, productions combinations in farms, and production periods. BOUSSOLE consists in three interactive modules representing: (1) the flock and its diet, (2) the forage system and (3) the farm's economy.
From the baseline scenario of the twice-a-day milking H0, BOUSSOLE renders it possible to design different configurations of the system. We modelled technical levers which aim at compensating the losses in both milk production and household income due to the transition of one milking per day. The selection of levers was based on (1) experimental results obtained through other parts of the Roquefort'In project in which this work is included; they take place in the Domaine de La Fage (Roquefort-sur-Soulzon, France) and in the agricultural secondary school of Saint-Affrique (Aveyron, France); (2) expertise of advisors in charge of technical support of dairy ewes farms in the Rayon de Roquefort area and (3) scientific experts from INRA and Livestock Institute. The management adaptations associated to these levers are simulated under several conditions of a once-a-day milking implementation: H1, where the transition to the once-a-day milking occurs at the lamb weaning (after about 30 days of lactation), at the first day of the milking period and H2, where the transition to the once-a-day milking occurs after the lamb weaning, and around the turnout date of the flock (around 8 and 10 weeks after the first day of the lactation period.
Finally, a 1250 farm sample under technical support is distributed into the seven farm-types according to their date of first day of milking. This distribution draws the 'virtual dairy area' from which the impact of collective scenarios of once-a-day milking implementation is explored.

3 Results – Discussion

For H1, the loss in milk production slightly varies according to the milking period duration of the farm-types analyzed (Table 1). Farm-types with short milking period are penalised far more than the others: e.g. 19 points of loss for ROQ05 (with 193 days of milking) and 17 points of loss for ROQ06 (with 273 days). A later transition to the once-a-day milking (H2) allows returning to the household income and milk production close to the baseline scenario values, but divides by two the gain in the routine work load obtained under the H1 scenario (Table 1).

Table 1. Impact of scenarios involving the transition to the once-a-day milking on the milk production of the flock (MP), Household Income (HI) and Routine Workload (RW) for the seven farm-types modelled (with an indice 100 = initial situation under twice-a-day milking H0).

	Scenarios H1 with management adaptations			Scenarios H2 with management adaptations		
	MP	**HI**	**RW**	**MP**	**HI**	**RW**
ROQ01	89	97	91	98	100	94
ROQ02	89	99	91	101	103	96
ROQ03	86	97	92	97	101	95
ROQ04	88	97	92	98	101	95
ROQ05	87	94	94	97	98	96
ROQ06	89	86	93	100	101	96
ROQ07	91	97	95	102	100	97
Mean	**88**	**95**	**92**	**99**	**101**	**95**

H0 : initial twice-a-day milking scenario / H1 : once-a-day milking at weaning / H2 : once-a-day milking around the turnout date

Assuming that the once-a-day milking would be accepted in the specification of the PDO Roquefort, the twelve breeders interviewed would applied it in their farm; certainly for nine on the twelve breedersof them, but under certain conditions for the others. Most of them considered that the once-a-day milking could occur in the middle of the milking period, around the turnout date. However one issue was noted. The transition to the once-a-day milking could present a social lock-in: «*one is going to say that we will do nothing further*» (*On va s'entendre dire qu'on ne fait plus rien*). Half of the breeders interviewed did not plan to associate any other technical levers with the implementation of the once-a-day milking (except the adjustment of the concentrates distributed). They also want to keep the flock size and to preserve some quiet time. For the other breeders, several ways of adaptations are possible such as to increase the duration of the milking period and/or a better use of pasture. The breeders questioned seem to be shifting towards a transition around the turnout date. For them, this option reduces the length of the working day and provides flexibility in the work day organisation during spring season.
If all farms use the once-a-day milking at weaning (H1), the amount of milk collected decreases of 18 points compared with the H0 situation (Table 2). The part of milk produced between January and April is slightly reduced. If all farms implemented the transition around the turnout date, the decrease in milk collected is lower (-8 points). With only 41% of the milk collected from the twice-a-day milking, mainly produced between December and February. At the dairy area level, the total amount of milk collected in H0 is almost reached the baseline secnario with the combination of 50% of farms transited around turnout date to a once-a-day milking production and 50 % of farms remainging in twice-a-day milking situation. However, it does not allow to reach volumes of milk from twice-a-day milking system required for the production of Roquefort under the specifications of the PDO.

Table 2. Impact of the implementation of several scenarios of the implementation of the once-a-day milking in farms on the milk collection of the 'virtual dairy area'

Scenarios	**H0**	**Basis scenarios**		**H2 with adaptations**
		H1	**H2**	
Total amount of milk (millions of liters)	170	139 -18%	156 -8%	169 -1%
Total amount of milk from the twice-a-day milking (%)	100	0	41	69

H0 : initial twice-a-day milking scenario / H1 : once-a-day milking at weaning / H2 : once-a-day milking around the turnout date

In addition to the key assumptions associated to the system representation, the partners allow us to determine relevant indicators among the 72 output variables. The appropriate indicators facilitate the discussion within a large range of actors. Moreover, the actors embraced the notion of virtual dairy area. The outputs at both the farm and the dairy area collection levels elicited very relevant debates. As a consequence, discussion derived from the presentations of the simulated results to the actors (breeders, industrials...) allows us to complete the evaluation perfomed by modelling.

4 Conclusions

Based on current scientific knowledge on zootechnical response of Lacaune ewes and simulated results, an increase in the milking duration combined with a better use of pasture can limit losses in milk production and in household income due to the transition to the once-a-day milking. At the dairy area level, the scenarios tested show that the adoption of the once-a-day milking cannot be envisaged without modifications of the Roquefort PDO specifications.

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PATUCHEV and REDCap: two additional research and development schemes for high performance and sustainable goat farming

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1 Introduction

The western France concentrates over half of the country's capacity in terms of dairy goat production (64% of national collecte-Agreste, 2013). Between years 2000 and 2010, goat farms have gradually turned into intensive farming, thereby significantly increasing their need for purchased input. To increase productivity, the grazing has been stopped and the indoor breeding has been developed. Now, the consequences are that goat systems are self-sufficient only to 55% (Bossis *et al.*, 2014) unlike dairy cow systems to 88% (Brunschwig *et al.*, 2012). However, in a context of higher input costs, these systems become now unsustainable. Moreover, these intensive systems do not correspond to the social representation of goat breeding by the consumers. It is therefore important to find techniques of management which are efficient, which correspond to the product picture but also which preserve, the goat health and welfare, and maintain their performances, the income of farmers and the sustainability of farms. It is in this context that the French Institute for Agricultural Research (Inra), professionals of goat sector of Poitou-Charentes Region and structures of development have created two additional research and development schemes for high performances and sustainable goat farming.

2 PATUCHEV: an experimental device to assess high-performances and sustainable goat breeding systems

The experimental platform PATUCHEV is an experimental unit of the division "Animal physiology and livestock systems" of INRA. This device is located near Poitiers in the main area of dairy goat industry in France (Poitou-Charentes). In 2013, the French Institute for Agricultural Research has built especially an experimental goat shed with a solar-heated air hay dryer. This device is aimed at assessing and proposing innovative goat farming systems in order to lead to low input and sustainable goat farms and to answer research question: "what kind of systems would a better self-sufficiency in inputs under a production constraint?" This approach associates the research of economic, environment and social performances in trying to apply the principles of agroecology.
The experimental device is based on conception and long-term evaluation of three kind of systems with 60 goats each: two grazing herds, one kidding at the end of the winter and the other one in autumn, and the last one fed hay indoors all year round and kidding in autumn.10 hectares divided between cultivated grassland and a cereal-protein crops mixture are allocated to each system (Fig. 1). To maximize the feed intake and to limit the use of concentrates, multi-specific cultivated grassland and solar-heated air dried hay are the key points of the forage system (Huyghe *et al.*, 2008; Delaby *et al.*, 2008). To limit the use of inputs, crops are fertilized with composted manure from the herd.

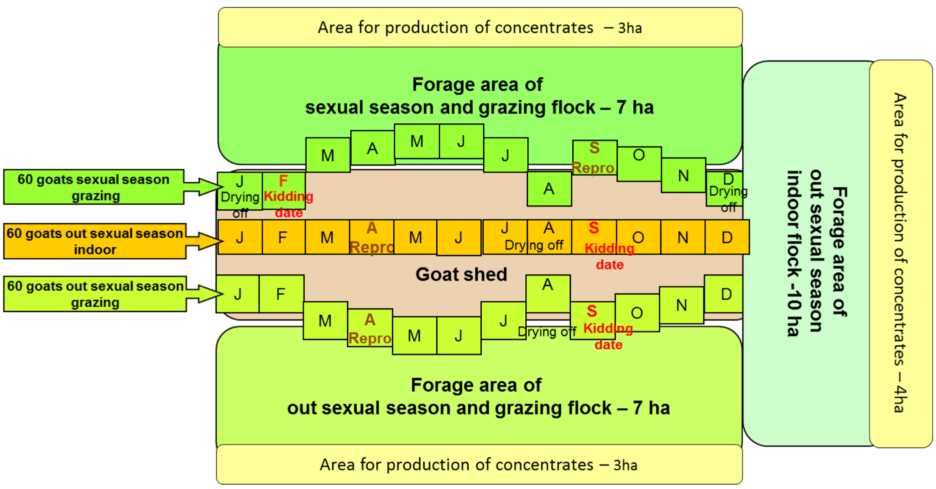

Fig. 1. Scheme of experimental device PATUCHEV

Evaluation and comparison are based on multi-criteria approach with data collected throughout lactation, dairy goats' careers and crop rotations. The functional organization is bases on participative approach. Patuchev project is managed by a steering committee composed with scientists from each INRA division participating to the project, engineers from R&D structures, representants from goat regional professional sector and Région Poitou-Charentes. To improve the diffusion of knowledge, professional goat farming organizations have implemented a coordinated Research and Development scheme called REDCap.

3 REDCap : an experimental and development network in dairy goat production

REDCap is a network of goat breeders, engineers and technicians on the topics of self-sufficiency and grass-use in goat breeding. It was built in 2011 by the regional association of goat's milk producers and processors in Poitou-Charentes and Pays de Loire (West of France). This is a multi-partner network, composed of 15 technicians from 4 regional structures: Chambres d'Agriculture, CIVAM, Contrôle laitier and BTPL. The animation of the project is driven by an engineer of the French livestock Institute (Institut de l'Elevage), which also have to articulate this project with other one existing in France on the same topics. The REDCap is a major place to build references (on self-sufficiency and production costs), to experiment in farms to share knowledges between technician and breeders, and in the same row, to develop a bottom-up approach with researchers. The figure 2 shows the design of the REDCap project, and the articulation between the different partners.

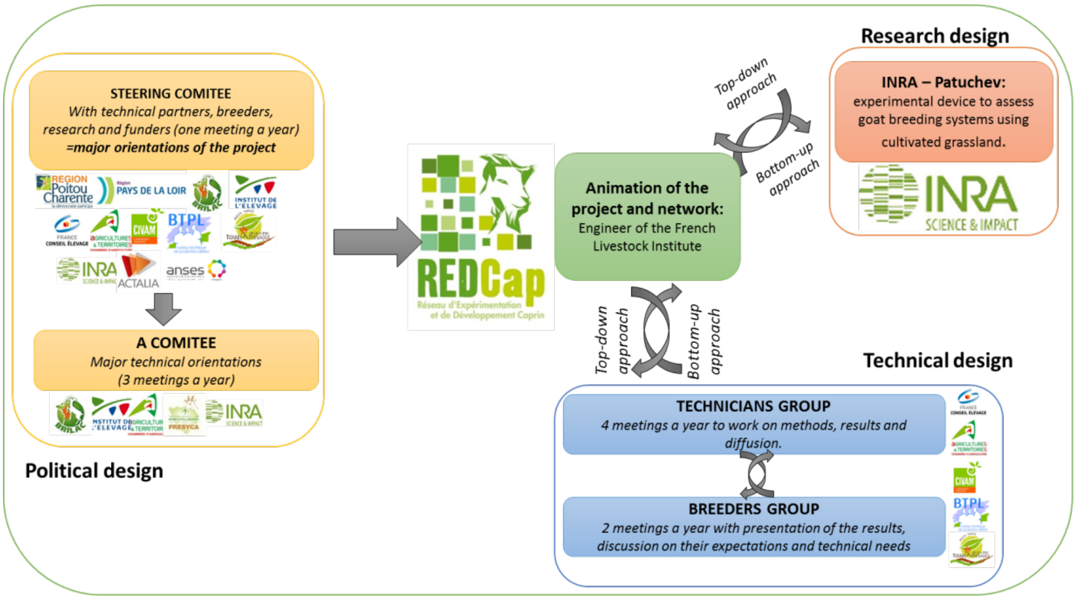

Fig. 1. Design of the REDCap in Poitou-Charentes & Pays de la Loire.

Different kinds of experiments are developed on the experimental device PATUCHEV and in farms (REDCap). The first associated experience between these two projects is a conception and evaluation of a multi-species grassland mixture adapted to specificities of goats, and sown on Patuchev platform and in 10 farms in autumn 2012. Dried hay in barn for goats is a second subject of study with the constitution of a farmers group to exchange and optimize this use.

4 Conclusions

This organization gives a wide place to exchange and thereby eases the emergence of innovative research issues. These two projects are conducted by 2 different organizations, but with a strong wish to work in interaction with each other, and all those involved. Therefore both manager of Patuchev and REDCap participate mutually to consultative and instance decision of each project. This overview shows that the context and tools to support the functioning of Research and Development in the goat sector are structured and operational. All partners have the wish to put these tools to service of goat sector to support its adaptation to the changing expectations and challenges.

Acknowledgements. The construction of experimental facilities (Patuchev) has received financial support Inra, Région Poitou-Charentes, European Union and Pôle d'Excellence Rural du Pays Mélusin. The REDCap network receives financial support of Région Poitou-Charentes and Région Pays de la Loire.

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Redesigning a dairy system based on agroecological principles using a collaborative method

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1 Introduction

Dairy farming in Western Europe has to cope with increasing societal demands *(i.e.* not only milk production but also environment preservation, scarce resources savings, livestock welfare, maintenance of landscape…) in a context of growing uncertainty (climatic hazards, price volatily of farm products and inputs, epizootics….). To face these new challenges, the French National Institute of Agronomy (INRA) tasked three researchers with devising and building, together with experts and stakeholders, an innovative forage system breaking away from existing patterns.
This paper explains the methodology used as well as the main objectives and principles of the devised system.

2 Materials and Methods

In order to favour a real break from existing systems and to improve in deep the sustainability of the whole forage system, we decided to redesign it in a systemic way, as proposed by Hill & Mc Rae (1995). This approach allows widening the scope of possibilities and fits in with the „*de novo*'design as conceptualised by Meynard *et al.* (2012).
The method consisted first to cross-fertilise the ideas of a group of fifteen participants, gathering farmers, extension agents, technical institute engineers, a farm manager of an agricultural school, environmental association and agency representatives and researchers from various disciplines.
In 2012, three one-day workshops based on creativity, listening and kindness permitted to these participants from various disciplines and horizons to i/agree on the general objectives which have to be targeted by the new dairy system, and ii/ propose new ideas jointly deepened by the group to meet these goals. Thereafter the three appointed researchers render coherent these multiple proposals, by considering an agroecological approach at the system level (Novak *et al.*, 2013). From the end of2012, a second group gathering seven experts in agronomy, animal production, forage systems, environmental assessment, and agroforestry already present in the first conception group, built the system operationally. Technicians devoted to the implementation of this new system were also involved in this work. The building of the system began by a clarification of its objectives and by a deepening of the first ideas using a similar methodology as that conceptualised by Hatchuel and Weil (2009) in terms of innovative design. During this work the reflection was broadened to include the livestock farming system which was designed to be consistent with the new devised forage system. The second group also clarified the research hypothesis tested in this project.

3 Results – Discussion

The main objectives of the system

The participants in the design process decided that the main objective of the resulting system will be to permit farmers to live from milk production in a context of climatic hazards while saving scarce resources (water and fossil energy) and contributing to a sustainable agriculture. The sustainability of the system is appreciated regarding its ability to preserve the diverse compartments of environment and to contribute to the attenuation of climate change, while satisfying the demands of farmers and civil society, and improving the welfare of animals. We decided to call such systems aiming to use efficiently natural resources while respecting them and satisfying the expectation of its users as “bioclimatic systems” (in analogy with bioclimatic architecture).
This system aims thus to deliver a diversified panel of ecosystem services and especially, as classified by Zhang *et al.* (2007), provisioning services (milk, cash crops, timber production), supporting services (soil fertility, nutrient recycling, biodiversity) and regulating services (pollination, natural control of pests, water purification).

The main principles of the system

The system relies on an agroecological approach at the farm level aiming to optimize the interactions between forage, crop and livestock systems, so as to save water and energy resources and to secure the forage production. It is based on the diversification of forage resources, the development of grazing, a larger use of legumes, the recycling of water and nutrients, and on a consistent strategy for the livestock system. The production of forage resources relies on three crop rotations (Novak *et al.*, 2014a), one being totally grazed, with diversified multispecies grasslands and annual crops, associated with legumes, and also on the grazing of fodder trees and shrubs. The herd reproduction (Novak *et al.*, 2014b) is based on two calving periods centered on spring and autumn, to ensure the coherence with the availability of grazed forage resources, and to overcome climatic hazards which could occurred at one period. The lactation length is extended to 16 months (calving interval of 18 months) for limiting the non-productive time during cow lifetime, and the negative environmental impacts associated. As this dairy system needs more robust cows, with good reproduction capacity, and well adapted to grazing and to forage resources of contrasting quality, we decided to use a three-way crossing of dairy breeds (Holstein, Scandinavian Red, Jersey).

The innovations relate thus mainly with:

1/the **diversification of the elements of the system**, from the vegetal component (various crop species, cultivars and mixtures), to the animal component (crossing of three breeds, two calving periods), through the functions these elements may fullfill (*e.g.* fodder trees, dual purpose crops, weed control by grazing). These ideas agree with the current trend that diversity in farming systems could reduce their vulnerability to climate change (Mijatovic *et al.*, 2013) while contributing to provide multiple ecosystem services (Kremen *et al.*, 2012).

2/ a **valorisation of all the spatial dimensions** of the system, by introducing a vertical axis thanks to agroforestry which allows a more efficient use of solar radiation and nutrient and water resources. The **temporal dimension** of the system is also reconsidered either in the cropping system by limiting periods of bare soil in the crop rotation, or in the livestock system by taking into account the milk production at the cow lifetime instead of at one single lactation.

The main research hypothesis tested is that the increase of diversity in a dairy production system allows to conciliate good production levels and high environmental performance, and to improve the resilience of the whole system.

This new system began to be implemented in June 2013, at an INRA facility located in Lusignan (Poitou-Charentes, France) on 90 ha and with 72 dairy cows devoted to it. The first calvings resulting from the crossing of the initial Holstein herd with semens of Scandinavian Red and Jersey, as well as the first implementation of agroforestry plots occurred in 2014.

4 Conclusion and perspectives

This innovative dairy system brings together a new combination of elements, some of them being original and sometimes risky while being promising. Its implementation and long term study at the farm level opens the way to innovative approaches in terms of experimentation, indicators and partnership. Collaborations with scientists in agronomy, livestock research, animal and plant genetics and in environmental assessment will be developed in order to characterise this agroecological system and its evolution. This project also aims to give farmers the keys for a successful transition as well as operational results on these new diversified and saving off-farm inputs systems.

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CROP-LIVESTOCK INTEGRATION OF CEREAL-BASED MIXED FARMING SYSTEMS IN THE TERAI AND MID-HILLS IN NEPAL

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1 Introduction

In Nepal, the possibilities for expansion of agriculture are limited due to land scarcity. Therefore, intensification has been the strategy to increase production particularly in the lowland agro-ecosystems (Terai) (Dahal *et al.*, 2007) due to their fertile soils, uniform climate and availability of improved communication systems that contribute to market access. The growing urbanization has increased the demand for livestock products in the area (Yadav and Devkota, 2005). In contrast, due to its topography the Mid-hills agro-ecosystems of Nepal face issues of remoteness, erosion and low availability of external inputs. Similar to almost all the farming systems in Nepal, households in the Mid-hills are based on cereal production (maize, wheat and rice) and livestock is a source of income and buffer against food shortages. The additional role of livestock in providing manure and draught power strengthens the integrated nature of farming systems of the Mid-hills (Kiff *et al.*, 2000). Pilbeam *et al.* (2000) estimated that around 80% of N supplies to the soil are made via the manure pathway. However, the productivity of the crop-livestock systems is low. Farmers face trade-offs at farm and landscape level, especially crop-livestock intensification vs. labor availability, environmental impact and competing uses of natural resources. Although a small amount of fodder is obtained from on-farm trees and/or crop residues, tree leaves are generally gathered from communal forest areas (Kiff *et al.*, 2000; Devendra and Thomas, 2002; Lawrence and Pearson, 2002; Thorne and Tanner, 2002). Yet, the forest resources have been reduced progressively in the whole country (FAO, 2011; Nepal Central Bureau of Statistics, 2012).
The mixed nature of the agro-ecosystems, the increasing demand for livestock products, and the continuous land fragmentation in both Terai and Mid-hills emphasizes the importance of better integrating crop and livestock subsystems to attain agricultural intensification. However, the livestock sector contributes notably to serious environmental issues with substantial impact on demand on land for pasture or feed crops, shortage and water pollution, and loss of biodiversity (Steinfeld *et al.*, 2006). With this study we evaluate the degree of diversity and crop-livestock integration within diverse cereal-based farms in contrasting agro-ecosystems.

2 Materials and Methods

The study took place in two districts in the Mid-hills (Palpa, Dadheldura) and one district in the Terai (Nawalparasi). One hundred households were surveyed to obtain socio-economic and biophysical data. The Y-sampling frame (Tittonell, 2008) was used to select households. One farm was randomly selected, and nine farms were selected at 100, 300 and 900 meters distance in three directions from the first household. The farms were categorized based on resource endowment through hierarchical cluster analysis in R software. One typology was created for each district. From each farm type, ten representative farms were selected and surveyed in detail to calculate nitrogen (N) fluxes through ENA (Ecological Network Analysis) (Rufino *et al.*, 2009). The Farm DESIGN model (Groot *et al.*, 2012) was used to quantify the nitrogen flow matrix for ENA.

3 Results – Discussion

3.1. Socio-economic and structural characteristics of the farming systems

The average productive land size in the Mid-hills was 0.5ha and 1.2ha in Terai. Livestock densities were higher in Mid-hills (20 TLU/ha) than in Terai (9 TLU/ha). Dairy cows and bullocks were more common in the districts of the Mid-hills, and dairy buffalos in Terai.In both districts of the Mid-hills the average number of household members was slightly lower than in Nawalparasi (Terai), of these household members 50% in Mid-hills and 40% in Terai were involved in the farming activities. In all the three districts the farms relied mostly on family labour. The income derived from farming activities was higher in Teraithan in the Mid-hills, being almost 50% of the total income, while 30% in the Mid-hills.

3.2. Farm household typology

Farm households were grouped into four clusters based on labour, yearly income, farm size, food self-sufficiency and TLU considering main drivers of strategies represented by proxy indicators through PCA at each site independently. Clusters were interpreted as four farm types in each of the sites.

3.3 Ecological Network Analysis

Farming systems differed strongly in N flows in the network. The number of animals and associated feed imports largely determined the size and activity of the networks. The T and TST (Throughput and Total System Throughflow), expressing respectively size and activity of the network, were both higher in Mid-hills than in Terai, increasing from the poor to the more wealthy types. As expected, imports of biomass were large but did not contribute in a large extent to internal nitrogen recycling, resulting Finn's cycling indexes (FCL) lower than 10% in all the systems. FCL were comparable to those found in the farms studied by Rufino *et al.* (2009b). Wealthier farm households recycled slightly more than poorer farm households. Imports per hectare were 3.5 times larger in Mid-hills than in the Terai, with great variability in each district.

Farms in the Mid-hills smaller than 0.1 hectare with a high livestock density relied mostly on imported feed to support the requirements of the livestock, thus these farms could be considered as landless livestock production systems. Large imports resulted in large losses. The total N losses per farm were on average 135 kg N and the farm with the highest losses had 315 kg N, in line or to some extent higher than the ones of several studies of nitrogen balances in the mid-hills of Nepal (Pilbeam *et al.* 2000, Bastakoti 2011, Giri and Katzensteiner 2013). The main N loss pathway was found in soil losses. Manure management was identified as one of the main constraints to N recycling. Poor farms had the lowest internal N recycling and highest dependency from external inputs, as well as lower labour and area productivity. Hr, expressing the diversity of N networks, was correlated to area and livestock. Organization of the N flows (AMI) was slightly higher in mid-hills, meaning that flows in the system were distributed more heterogeneously. Poor types farm households had in all the three districts the highest AMI/Hr (few flows connect few compartments), suggesting that these were less diversified systems.

4 Conclusions

The types identified in each of the agro-ecosystems differed in labour, income, land size, TLU and self-sufficiency. The N cycling indicators showed that in general all the farms recycled only a small portion of the nitrogen that flows in the network, therefore having high losses. Losses were higher in the Mid-hills mostly due to high imports and the deficient manure management. In the Terai region, recycling and nitrogen use efficiency at farm level were slightly greater. In all the farms with higher cycling indexes, farmers were growing fodder crops. However, farms across the districts were dependent on external inputs to support the internal N cycling in a similar degree. Diversity of N networks was correlated to land and livestock: farms with more resources were more diverse in N networks, while poor farms had the lowest internal N recycling and the highest dependency on external inputs.

The results of this study allow understanding the high diversity and degree of diversification and integration of distinct types of farms across contrasting agro-ecosystems, which has implications in the design of specific strategies to achieve sustainable intensification in each agro-ecosystem.

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Crop-Livestock Integration improves the Energy Use Efficiency of smallholder mixed farming systems - the case of western Burkina Faso

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1 Introduction

Increased food production to cover growing population needs, while limiting its impact on the environment, is a major challenge faced by the global agricultural sector. In sub-Saharan Africa mixed farming systems dominate. Crop Livestock Integration (CLI) is seen as a crucial pathway for supporting production and strengthening the resilience of family households facing economic and climate changes. Few quantitative studies demonstrate such potential. Indeed, based on three main biotechnical pillars, animal draft, manure production and crop residue storage, integration enhances the use of local renewable resources for production, including the cycling of co-products as resources for another activity within the system (Lhoste, 1987). The cycling of biomass and energy is regarded as an essential property for ensuring ecosystem sustainability (Allesina & Ulanowicz 2004). Based on a diversity of mixed farming systems, the study analyzes the quantitative links between diverse energy flows which are indicators for identifying biomass management practices that are alternatives to using external inputs.

2 Material and Methods

The study was undertaken on eight mixed farms in Koumbia (western Burkina Faso). The panel covered the diversity of farms observed in the cotton zone, including 3 Crop Farmers (CF), 2 Crop-Livestock Farmers (CLF) and 3 Livestock Farmers (LF) (Vall et *al*., 2006). A conceptual model was designed to inventory the gross energy flows between the system and its environment (inflows, outflows) and the internal flows between compartments (humans, cattle, crops and manure, fodder and feed stocks; Fig. 1). An Ecological Network Analysis (ENA, Finn, 1980) was applied to the matrix of flows to describe the ecological functioning of these agro-ecosystems and calculate indicators describing the cycling (Cycling Index, CI) and autonomy (A) of the farms and the proportion of flows into the network caused by CLI practices (CLID). The gross energy efficiency (GEE) was also calculated, as well as other indicators describing integration practices, such as the amount of manure available per Tropical Livestock Unit (OM) and the amount of crop residues and fodder available per Tropical Livestock Unit (FOD).

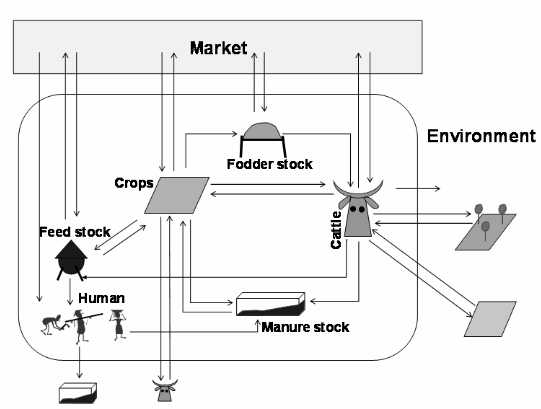

Fig. 1. Conceptual model of gross energy flows for mixed farming systems

3 Results and discussion

Applying an ENA to western Burkina mixed farming systems showed variable levels of cycling ($0.03<CI<0.50$) and autonomy ($0.17<A<0.70$) within and between farm types (Table 1). This variability resulted from a diversity of CLI farming practices (straw, forage crops, manure, compost, digester sludge). ENA applications to eastern Africa and Madagascar gave similar results for nitrogen cycling in mixed systems (Rufino et *al*., 2009; Alvarez *et al.*, 2013).

Moreover, we found that the integration indicator (CLID) and the indicators describing practices (OMand FOD) were higher among crop and crop-livestock farmers, i.e. farms with a stocking rate below 2 TLU.ha^{-1}. Livestock farmers had low to medium levels of integration. Indeed, the large TLU number (> 8TLU.ha^{-1}) of these farms led them to drive their cattle to the surrounding rangelands to meet their forage needs. It decreased their autonomy for locally available common resources and reduced the potential for manure collection and cycling. Also, even though in absolute terms they often stored larger amounts of forage than the other two types compared to the size of the herd, this amounted to small quantities.

Table 1. Gross energy efficiency, cycling and crop-livestock integration indicators for western Burkina mixed farming systems

Farm number	Livestock stocking rate (TLU.ha^{-1})	CI (Dmnl)	GEE (Dmnl)	Autonomy (Dmnl)	CLID= (Dmnl)	OM (kgDM. TLU.year^{-1})	FOD (kgDM.TLU^{-1}.year^{-1})
CF2	0.8	0,50	0,18	0,67	0,57	213	570
CF3	0.6	0,23	1,15	0,70	0,65	564	692
CF7	0.5	0,13	1,93	0,70	0,46	322	788
CLF5	1.7	0,37	0,27	0,59	0,55	752	367
CLF6	0.7	0,30	1,12	0,65	0,49	994	276
LF1	8.5	0,12	0,24	0,37	0,34	278	120
LF4	9.8	0,17	0,29	0,40	0,36	287	78
LF8	35.9	0,03	0,26	0,17	0,20	124	0

The cycling index (CI) was positively correlated with CLID for all farmers, i.e. CLI practices improved energy cycling on farms. The gross energy use efficiency (GEE) varied in turn from 0.18 to 1.93 and was positively correlated with autonomy (Fig. 2). Indeed, storage crop residues led to increased autonomy limiting imports and thus improved the gross energy use efficiency. Crop and crop-livestock farmers left a large amount of crop residues in the field that was subsequently consumed by other herds, thereby reducing energy cycling opportunities on the farm. It thus appeared that a stocking rate of 1.5 TLU ha^{-1}enabled a balance between needs and resources and provided favorable conditions for biomass cycling and optimum farm autonomy.

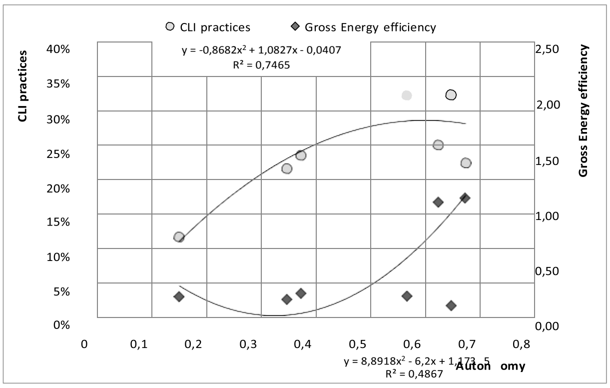

Fig. 2. Relations between autonomy (A) and gross energy efficiency (GEE)

4 Conclusions

Using original indicators, this study confirmed that better crop-livestock integration increases the energy use efficiency and autonomy of farms. The variable levels of energy use efficiency, cycling and autonomy were the consequences of a wide diversity of CLI practices. It showed a lower degree of autonomy and cycling for livestock farmers than for crop and crop-livestock farmers. This diversity indicated that there is still plenty of leeway for improving integration and efficiency, as expected (Blanchard *et al*., 2013; Semporé *et al*., 2013).

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French sheep meat sector and drivers of its evolution since 1970

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1 Introduction

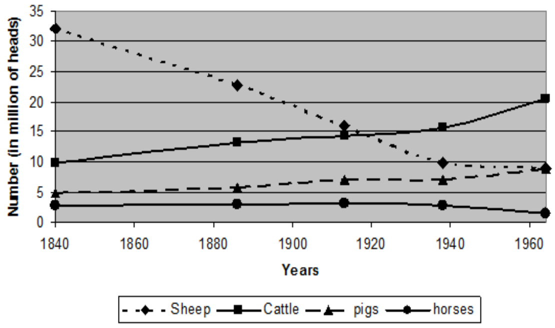
The modernization period of French and European agriculture was characterised by a process of intensification of production systems supported by very proactive agricultural policies, including guaranteed prices to producers. Today, the future of production systems is no longer measured certainty, but it is based on the ability of farmers to adapt to a changing and uncertain world (Dedieu *et al.*, 2008).

Indeed, advent of global warming, recurrent droughts and price volatility of raw materials are many uncertainties that farmers face. Furthermore, the antecedent crises such as BSE *(*Bovine spongiform encephalopathy*),* dioxin in chicken, milk melanised, and the upsurge of collective food intoxication, have driven significant changes in production systems by creating a large consumer confidence crisis. In addition, these changes on the structures and ways of production occur at the same time to the evolution of national and European regulations and generating more uncertainty with which farmers must contend (Tichit *et al.*, 2008). The French sheep production, particularly the sheep meat sector, knows a long crisis for over 30 years. Liberal trading and the European agricultural policies have contributed to jeopardize the future of French and European sheep flocking. Sheep farmers, as other producers, therefore need to adjust their ways of breeding sheep, and also to organize their marketing to sustain their incomes in the uncertainty environment.

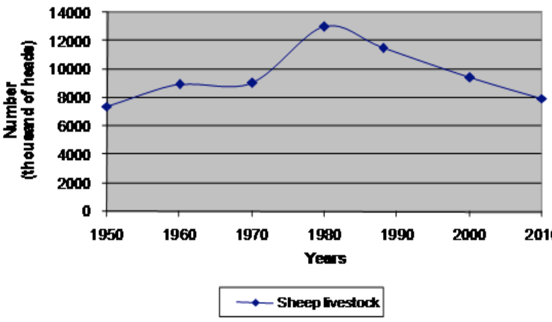
In order to drive a comprehensive evolution of French sheep meat sector, it is useful to have a deep knowledge of its economic policy and environmental context. So, we study the French sheep meat sector from 1970 to 2012 in order to, i) understand the evolution of production and consumption, ii) draw up the evolution of agricultural policies and sheep meat market and, iii) analyse the drivers of these evolution.

2 Material and Methods

To analysis the evolution of sheep meat sector in France since 1970, we firstly proceed to collection and statistical analyses of secondary data. The results were then submitted to a critical analysis of a sheep sector expert, an economist from INRA and specialist of meat sector, especially the sheep meat sector (Boutonnet, 1998). This approach has already been mobilized in others studies on changes in agricultural sectors (Napoléone & Boutonnet, 2010; Labarthe, 2005). Data collected were used to construct graphs showing various evolutions of French sheep meat sector. We then analysis the results, by trying to identify successions of periods for the main element (increase, decrease or stability for quantitative variables; period with the same market rules and policy, different reforms, etc.) and trying to find the elements which could explain different evolutions. The role of sheep expert was, on the one hand, to give an appreciation on how we present the evolution of French sheep meat sector since 1970 and, on the other hand, to have from him more light on the drivers of this evolution.



Source. Adpted from Rieucau (1964)
Fig.1. Evolution of French livestock



Source. Own elaboration
Fig. 2. Evolution of total of French sheep livestock

3 Discussion

Since 1980, the French sheep livestock is declining gradually. This decline appears recurring and specific to sheep production. Indeed, the evolution of livestock production in France from 1840 to 1964 shows a drastic decline of sheep population compared to the stagnation of horse population and increase of cattle and pigs population (Fig. 1). The decrease of French sheep population in 19th century is due mainly to the reduction of use of sheep for soil fertilization with the development of mineral fertilisation and the crisis of the wool market with competition from new countries such as Australia and Argentina. The increase thereafter of French sheep population up to the 1970s (Fig. 2) would be the result of the Common Agricultural Policy (CAP) introduced in 1962.

This voluntary agricultural policy was strongly supported and aimed to ensure food self-sufficiency through the widespread intensification of agricultural productions. However, this growth of French sheep population, is also much related to the protectionist policy of French sheep meat market. Indeed, since the liberalisation of French sheep meat market to England in 1979, the sheep production in France knows enormous difficulties (Rieutort, 1995). The study of evolution of ewe's population in France, since 1970, shows a gradual decline. However, this reduction of ewe's population, more pronounced over the past 20 years, concerns only sheep meat sector because the numbers of dairy ewes are greatly increasing since 1970 (Fig. 3). Also, this drop was accompanied by a decline in productivity per ewe. Even if the approximate productivity per year per ewe has known a gradual increase between 1970 and 1980 from 18, 34 kg to 21, 65 kg, it decreases since this date to reach 18, 45 kg in 2010. Beside the decline of ewe's population, there has been a steady decline in the number of ewe's farms. As an illustration, the number of ewe's farms in France decreased from 168 390 in 1970 to 55 322 in 2010, a decrease of 67% in 40 years. Also, this decline, more pronounced over the past 20 years, concerns only the suckling ewe's farms because the number of dairy ewes farms has remained relatively stable (Fig. 4).

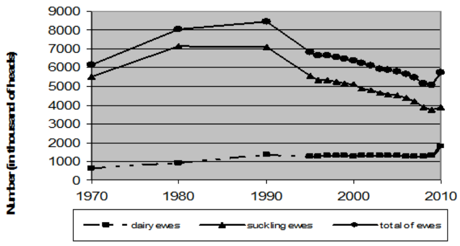


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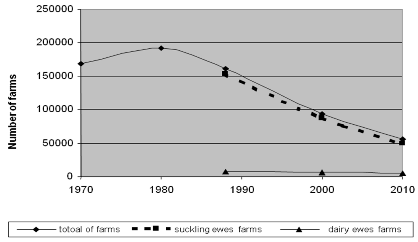
Fig. 3. Evolution in number of suckling and dairy ewes



Source. Own elaboration

Fig. 3. Evolution in number of suckling and dairy ewes farms

We note that the decrease in the number of suckling ewe's farms is much greater than the decrease of suckling ewe's population. Also, despite the considerable increase of dairy ewes population, the number of dairy ewe's farms has remained relatively stable (Laffont, 2012). Indeed, since 1980, we are witnessing a phenomenon of concentration of sheep farms in France with a gradually increase in the number of animals per farm (Rieutort, 1995). The farms with a small numbers, less than 100 head, decreases gradually in favour of farms with a big numbers of sheep's. In 2009, 63% of meat ewes are kept in the farms of over 200 heads. This proportion reaches 84% for milk ewes. There would be a kind of concentration and progressive intensification of the activity of sheep production in France. This decline of national production (sheep population and sheep farms) could be explained by the decrease in the number of sheep farmers by stop of activity, and that is not compensated by the recovery or by the new entry in the activity. This decline in production is not also offset by the increase in the number of sheep per farm among sheep farmers who wishing to remain in the sector are forced to expand their flock for maintain their income.

4 Conclusion

This article presents the drivers of evolution of French sheep meat from 1970 to 2012. According to the results, the evolution of suckling ewes sector in France, since 1970, can be subdivided in three major periods.

The periods from 1970 to 1980, characterized by an increase in the overall level of consumption related to population growth, but mainly due to annual increase in level of consumption per capita. The period from 1980 to 1992, characterized by a decrease of level of national production with massive inflow of sheep meat in France, especially from United Kingdom and New Zealand, following the opening of French market. Finally, the period from 1992 to 2012 characterized by a significant decrease in the level of production, consumption and even imports, which results in significant decrease of self-sufficiency ranging from 80% in 1980 to 48% in 2010.

Hence, there is a real need for different stakeholders and promoters of sheep meat sector in France to more interact and think together for define an appropriate and suitable agricultural policy for sheep meat sector. This could help to address these constraints and provide sustainable solutions to French sheep meat production.

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Mongolian water quality problem and health of free-grazing sheep

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1 Introduction

Water is a major component of the animal body, where it is essential for the transport of nutrients, hormones, and waste products and the regulation of blood osmotic pressure, secretions such as saliva and milk, and body temperature. In grazing animals the amount of wet feces and urine per 1000 kg of live weight per day ranges from 79 to 112 kg; wastes from sheep and dairy cattle contain large amounts of N, P, K, and bacteria and pose a water pollution threat on grazing lands (Hubbard et al., 2004). Water consumption is depressed when manure-contaminated water is provided to cattle. As a result of depressed feed consumption, infection with pathogens and parasites, and less time spent grazing and more time resting, cattle gain less weight when drinking manure-contaminated dirty water than when drinking clean water (Willms *et al*., 2002; Lardner *et al.*, 2005). After Mongolia's transition from a planned to a market economy, the total number of livestock there increased from 15 to 30 million between 1930 and 1990, and by 2014 it had reached about 50 million (National Statistical Office of Mongolia, 2013). Coincident with the resulting overgrazing, water pollution is becoming a problem. Concentrations of suspended particles and orthophosphates are increasing in Mongolia's stream systems, and phosphate levels have recently increased in Mongolian lakes (Shinnerman *et al*., 2009; Maasri & Gelhaus, 2011). Overgrazing is likely to be an important contributor to the eutrophication of Mongolia's water bodies and, through this, threatens animal health. Nevertheless, to our knowledge, no study has yet been published on the effect of livestock waste contamination of Mongolia's water on livestock performance and health. Here, we therefore examined the effect of water quality on the health and performance of Mongolian lambs.

2 Materials and Methods

We allocated 32 free-grazing lambs to four groups and provided each with water from a different source (upper stream, lower stream, well, and pond) for 49 days. We recorded the amount of water consumed by the lambs, as well as their body weight, behavior, white blood cell count, acute phase (haptoglobin) protein level, and fecal condition. We measured the chemical and biological qualities of the four types of water, and we detected enteropathogenic and enterohemorrhagic *Escherichia coli* in fecal samples by using a genetic approach.

3 Results – Discussion

Pond water contained high levels of nitrogen and minerals, and well water contained high levels of bacteria. The odor concentration index decreased in order from pond water to upper stream, lower stream, and well. On day 15 of the experiment, the following parameters were the highest in lambs drinking water from the following sources: water intake (pond or lower stream), body weight gain (pond), WBC count (lower stream), haptoglobin concentration (well), and enteropathogenic *E. coli* infection rate (lower stream). The total water intake per lamb group over a 14-day period was 16.36 L (upper stream), 21.69 L (lower stream), 12.32 L (well), and 20.74 L (pond) (Fig. 1). Water intake was lowest in the lambs given well water (d.f. = 3, F = 3.04, $P = 0.04$). Body weight gain per lamb over the 49-day study period was 4.67 kg (upper stream), 4.83 kg (lower stream), 5.17 kg (well), and 6.83 kg (pond water) (Fig. 2). Lambs that drank well water spent more time lying down and less time grazing than the others, and lambs that drank pond water spent more time standing and less time lying down. Lambs given upper or lower stream water exhibited more severe diarrhea on day 15 of the experiment than before the experiment.

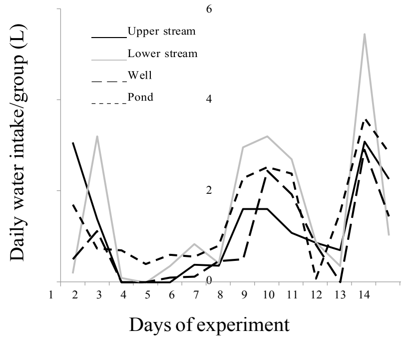

Fig. 1. Changes in total water intake by the 8 lambs in each water source group.

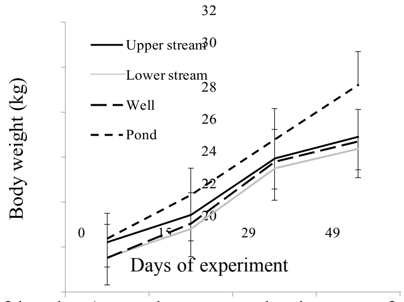

Fig. 2. Changes in mean body weight of lambs (error bars, standard error of the mean) in each group during the water intake experiment.

4 Conclusions

Mongolian sheep seemed to adapt to chemically contaminated water: their productivity benefited the most from pond water, likely owing to its rich mineral content. Lambs that drank lower stream water showed increases in enteropathogenic *E. coli* infection, clinical diarrhea, and WBC count. Lambs that drank well water, which was bacteriologically contaminated, had increased serum acute phase protein levels and poor physical condition; they were thus at increased risk of negative health and production effects.

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W2. Annual crops based systems

Chair: Laure Hossard, INRA
Co-chair: Eric Scopel, CIRAD

Cropping system intensification to increase food security and profitability among smallholder farmers in Zimbabwe

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1 Introduction

Soil degradation, poor soil fertility, recurrent low crop and livestock productivity and food insecurity are the major problems bedevilling smallholder communities in Southern Africa. Most smallholders practise maize mono-cropping under conventional agriculture (CP) allocating minute portions of their fields to intercropping, rotations and sole legume cropping(CIMMYT, 1998) . As a result, continuous maize production has led to chronic losses due to the low maize yields and returns in Zimbabwe. Legume production is however prospectively more promising due to the high producer prices (Akibode, 2011).

Sustainable cropping systems such as conservation agriculture (CA), intercropping, crop rotations and legume sole cropping are potential options for improving soil fertility, crop yields, household incomes and food security (Rusinamhodzi et al., 2012). Prior experience has highlighted great difficulties with implementing blanket interventions for smallholder communities thus necessitating the need for household type specific interventions(Vanlauwe et al., 2014). Few smallholder farmers however practice legume mono-cropping as they prioritize cultivation of food security crops first and then other crops(CIMMYT, 1998) .

On-station research has shown potential long term increases in maize-legume system productivity under CA, intercropping, rotation and sole legume cropping systems. Limited research has, however, been undertaken to assess the productivity and socio-economic impacts of these systems at the farm household scale. Implementation of field experiments at such a scale may, however, prove to be complex, expensive and time consuming. The use of the APSIM and IAT simulation models provides a time and cost saving approach for undertaking this long term research.

2 Materials and Methods

The study was based on Murehwa district (17.7° S, 31.8° E and 1,365 metres above sea level) in Natural Region IIb of Zimbabwe. The area receives 750-1000 mm year^{-1} rainfall and is predominated by low fertile granitic sandy soils (Vincent and Thomas, 1961).

Household, socio-economic, cropping and livestock population dynamics data was collected through a questionnaire. Farmers were categorised into Resource endowed (RE) and Resource constrained (RC) classes. RE farmers are characterised by greater land ownership of at least 4ha arable land and food self-sufficiency. In addition they have greater livestock ownership with an average of 16 cattle, 20 goats, 22 pigs and chicken. RC farmers have land ownership of less than 0.5ha, nil or few livestock and suffer chronic food shortages.

The Agricultural Production Systems Simulator (APSIM) model (Keating et al., 2003) which simulates crop growth and developmentwas calibrated based on the measured yields from CA, non-CA systems, intercropping, rotations and sole legume cropping systems from 2012/13-14/15 seasons in Murehwa. The Integrated Analysis Tool (IAT) which integrates crop productivity, livestock productivity and household socio-economic aspects to assess household productivity was also calibrated based on the household data for different farmer types. Maize and legume yields were simulated using APSIM for the period (1969-2000).

Each of the farmer types (Baseline scenario) were exposed to the following scenarios; adoption of (1) CA, (2) crop rotations, (3) intercropping, (4) sole legume cropping.

Farm household food security and enterprise profitability were then simulated using the IAT for the same period.

3 Results – Discussion

Adoption of CA systems by RC farmers has the potential to increase maize yields by at least 23% whereas RE farmers may experience at least a 6% increase relative to CP (Figure 1).

Maize yields are generally higher ($p<0.05$) under crop rotation as compared to sole cropping systems with Maize-cowpea rotation projected to have the highest ($P<0.05$) yields of at least 3000 kgha^{-1} relative to Maize based Soybean, Groundnut and Mucuna rotation systems with projected yields of between 2000-2500 kgha^{1} (Fig. 1).

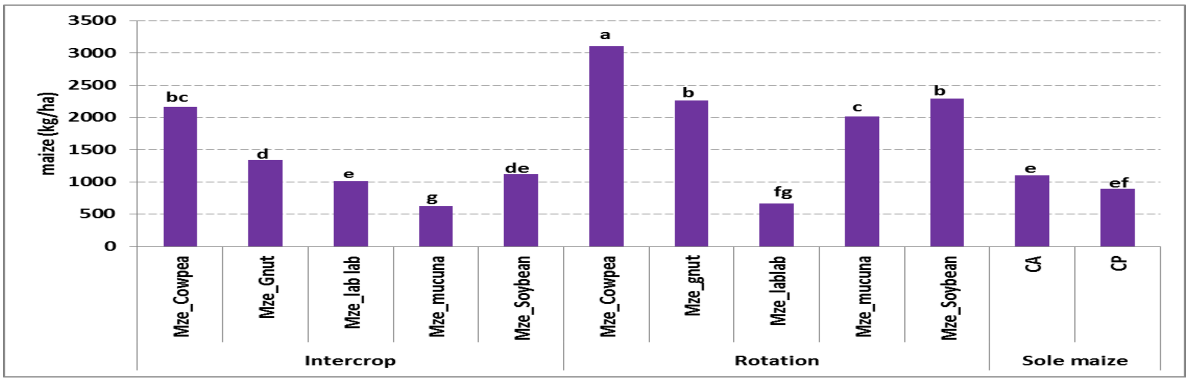

Fig. 1. Mean simulated maize yields under intercropping, rotation, conservation agriculture and conventional agriculture cropping systems.

NB: Means with the same letters denote no significant differences (p<0.05)

RC farmers under the baseline scenario face significant food shortages (P<0.05) of at least $15/month. However adoption of CA, intercropping and rotation systems will reduce (p<0.05) food shortages by at least 50%. Use of CA and rotation systems will increase food availability of RE farmers. Adoption of intercropping will reduce food availability by smaller (P>0.05) margins due to reduction in maize yields due to maize-legume intercrop competition. Sole legume cropping without maize may however, leave both farmers with the greatest (P<0.05) food insecurity (Fig. 2).

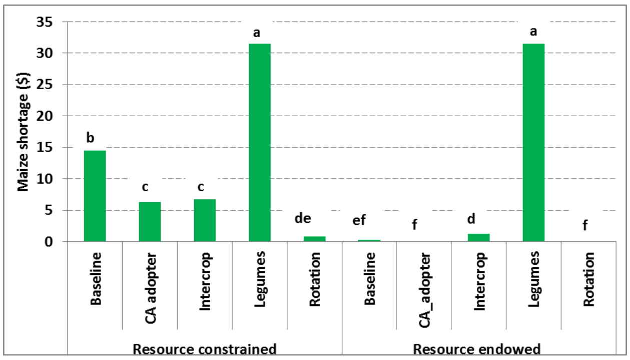

Figure 2: Value of maize deficit of RC and RE households under different cropping systems

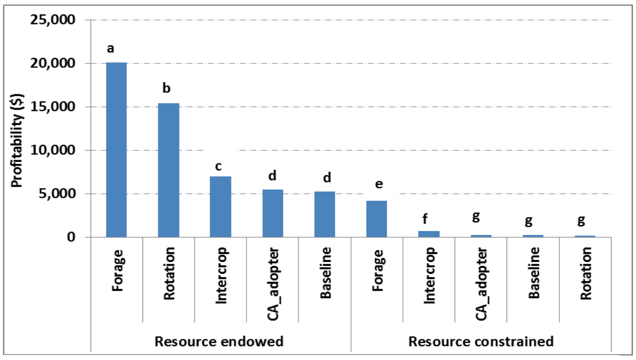

Figure 3: Household profitability of different farmer types under different cropping systems

NB: Means with the same letters denote no significant differences at p<0.05.

Generally RC farmers achieve far lesser (P<0.05) returns than RE farmers regardless of the cropping system. Adoption of forage legumes by both farmer types however increases (P<0.05) farm profitability by at least 100%. Adoption of forage legumes is more profitable to RE farmers with land ownership of at least 2.5 ha as compared to the 0.7 ha available to RC farmers.

4 Conclusions

RC farmers generally face food shortages due to low maize yields as compared to RE farmers due to the low fertilizer use and seed rates attributed to poor resource endowment. Alternate cropping systems such as CA, intercropping and rotations increase maize and legume crop productivity thus increases profitability among the RC farmers. Adoption of forage legumes leaves both farmer types physically food insecure but financially food secure.

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Experimental assessment of winter malting barley genotypes in low-input system

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1 Introduction

Winter six-row malting barley is well adapted to the French agroclimatic conditions, allowing the country to be the first worldwide exporter of malt. Nowadays, government, consumers and brewers are calling for a reduction of agrochemical inputs use. Moreover, the brewing industry asks for specific grain quality that should be reached also in low-input (LI) conditions. Little is known about the impacts of this crop management type on grain yield and malting quality according to the cultivar, while specific genotype characteristics were identified for wheat in LI conditions to reach high agronomic performances (Loyce *et al.,* 2008). This study aimed at assessing the agronomic performances of various barley genotypes in LI conditions in comparison with conventional crop management system.

2 Materials and Methods

A multi-environment trial (5 locations in Northern France) testing 20 genotypes (4 registered and 16 innovative) in 2 crop management systems (conventional and low input) was carried out in cropping season 2013-2014. The conventional system was based on regional recommended practices for farmers. The LI one consisted in a 30% reduction of N fertilizer rate and the suppression of growth regulators and fungicides. Three replicates were laid out in each site. Genotypes were randomized within the main treatment. Individual area plots ranged between 7.5 and 9.8 m². Yield, grain protein content and grain size were measured and averaged for each genotype on the three mechanically harvested replicates in each of the 5 sites. As small grains (size < 2.5 mm) and grains with high (over 11.5 %) or low (under 9%) protein content are not suitable for malting, we determined these thresholds for considering grain convenient or not for malting industry. The calibrated yield was calculated as the grain yield with size over 2.5 mm.

3 Results – Discussion

In the conventional management system, almost 70% of Genotype X Site combinations would have been accepted for malting production (Fig. 1. a). Almost 2/3 of the grain N content measures were between 10 and 11%, with a mean grain protein content of 10.1 %. 31% of the Genotype X Site combinations did not reach the grain size threshold. In the whole, 12 genotypes out of 20 met both specifications of the malting industry in 3 sites out of 5, 7 matched the specifications for 4 sites and only one should have been considered as a malting genotype in all sites. The calibrated yield reached 84 $q.ha^{-1}$ (with genotype mean ranging from 79 to 91 $q.ha^{-1}$) for grains suitable for malting, and 74 $q.ha^{-1}$ in the other cases.

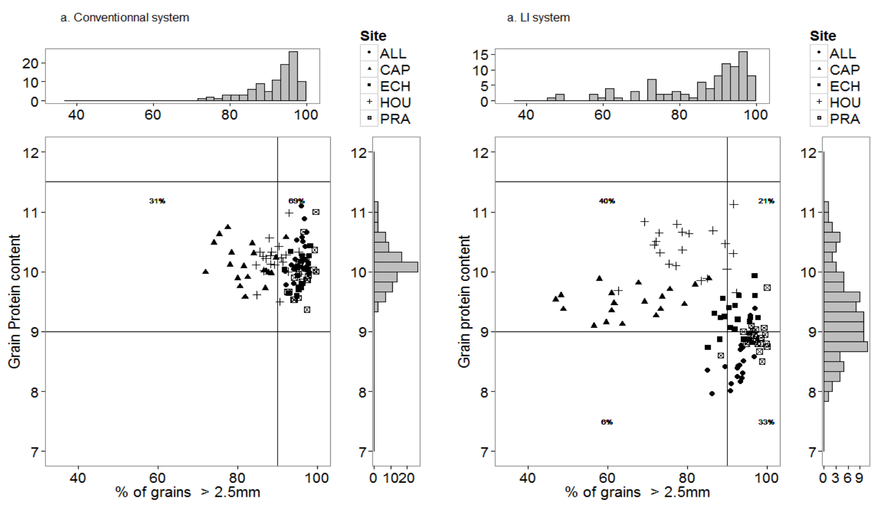

Fig. 1. Grain protein content versus percent of grains over 2.5mm for Site X Genotype combinations in (a) conventional and (b) low input (LI) systems.

The shift to a LI management system increased the number of situations (79% of the Genotype X Site combinations) where genotypes did not satisfy the specifications of the malting industry (Fig.1 b). The thresholds of grain protein content and grain size were not satisfied respectively in 38% and 47% of the situations. In only 6 % of the cases, both criteria were simultaneously not respected. On the whole, 4 genotypes would have always been rejected by malting industry, 12 met the specifications in only one site out of 5, three in 2 sites and only one in 3 sites (Fig. 2.). For both situations matching or not the specifications of malting industry, the calibrated yield was 14 $q.ha^{-1}$ lower in the LI than in the conventional system. When satisfying the malting conditions, LI genotypic yields ranged from 61 to 80 $q.ha^{-1}$.

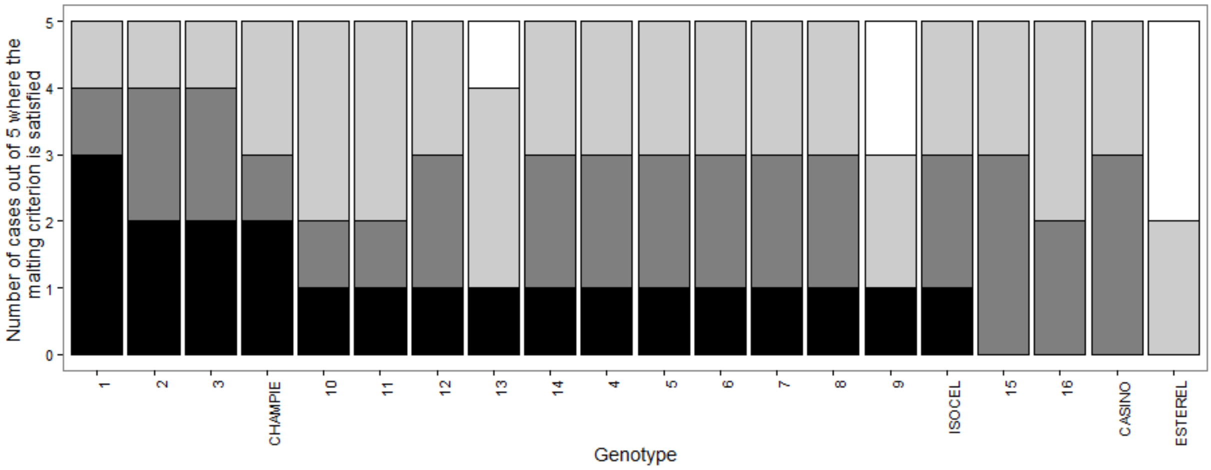

Fig. 2. Number of sites (out of 5) for each genotype in the low-input system where the grain protein content and the grain size (black bars), the grain protein but not the grain size (light gray bars), the grain size but not the grain protein (dark gray bars) or none of these two variables (white bars) are suitable for malting.

The mean protein content was 9.3%, but was particularly low in Prasville (8.9%) and Allemanche (8.5%) sites. Situations where grains did not satisfy the threshold of protein content could be explained by a dilution effect of N uptake by the grain yield. The mean grain N uptake were respectively 137 kg N ha^{-1} and 161 kg N ha^{-1} for situations under and over 9% Proteins in grains, for a same yield (not calibrated) of 71$q.ha^{-1}$ in both cases. The grain yield was generated by a low number of grains per square meter (mean 16 130) combined with a high thousand kernel weight (mean 43.2) for the for situations with less than 9% proteins in grains, and high number of grains per square meter (mean 19 860) combined with a low grain thousand kernel weight (mean 39.6) for situations with more than 9% proteins in grains. The proportion of grains which size was over 2.5 mm ranged from 50 to 100% with a large effect of the genotype. The variability of grain size was more than twice larger in LI than in conventional system. Situations where grains did not satisfy the threshold of grain size could be explained by a lower amount of N in grains, respectively of 133 kg and 174 kg $N.ha^{-1}$. For situations with more and less than 90% of grains over 2.5mm respectively, the mean numbers of grains per square meter were respectively 16 220 and 20 929, and the thousand kernel weights were respectively 43.9 and 37.6.

On the whole, two types of situations led to inappropriate grains characteristics. First, when the number of grains per square meter is low and the plant compensates with higher thousand kernel weight, affecting the grain protein content. Second, when the plant produces a very high number of grains per square meter, affecting the thousand kernel weight and compromising the grain size proportion.

4 Conclusions

The malting barley production was more difficult in the experimented LI system than in the conventional system: no genotype fulfilled malting conditions in the 5 sites for the LI system. The challenge for LI production will be to reach a sufficient high level of protein content without compromising grain size. Optimized N fertilizer management strategies could limit the first problem. Genotype choice could increase the proportion of large grain size. A combined design of crop and genotype ideotypes seems necessary to succeed in low-input malting barley production.

Acknowledgements. This research was funded by the French Ministry of Agriculture and Fisheries under the CASDAR project "ECO2MALT". We would also to thank the Florimond-Desprez, Momont, and INRA UMR Agronomie technical teams for trial management and technical assistance.

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Potential yield and yield gap at farm level are different from the field level: A case study on a large Dutch potato farm

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1 Introduction

Yield gap analysis is receiving increasing interest, as yield increases are needed to feed a growing human population (Van Ittersum *et al*., 2013). For sustainable intensification, yield increases need to go hand in hand with increasing resource use efficiency. Yield gaps and resource use (in-) efficiencies are typically assessed at field level. In the real world, they are explained by a range of factors that intersect and are integrated at farm level. Agro-ecological conditions may vary among and within fields, and crop management may be constrained. Therefore, it is relevant to assess the potential farm level yield and to understand crop yield gaps taking into account farm level information.

2 Materials and Methods

Our case study was performed at Van den Borne Aardappelen, a 500 ha potato farm located on sandy soils in North Brabant (The Netherlands), cultivating around 140 fields per year. Fields are in rotation with dairy farmers, from whom fields are rented. Precision farming techniques and decision support systems are widely used in this farm, resulting in nearly 'optimal' management, relatively high resource use efficiency and high yields. In 2013 and 2014 data have been collected on crop management and yields per field, and measurements were taken throughout the season.
We use the coupled hydrology-crop model SWAP-WOFOST (www.swap.alterra.nl) to estimate the potential and water- and oxygen-limited yields. The potential yield was calibrated on the highest yielding fields in 2014 and validated on the highest yielding fields in 2013. Using soil maps with soil moisture data, and precipitation data from 10 local weather stations, water- and oxygen-limited yields were estimated for a range of fields.
Frontier analysis and statistical methods were used to explain the potato yield gap for the ±140 fields (Fig. 1). Explaining factors were grouped according to Genotype (G) x Environment (E) x Management (M).

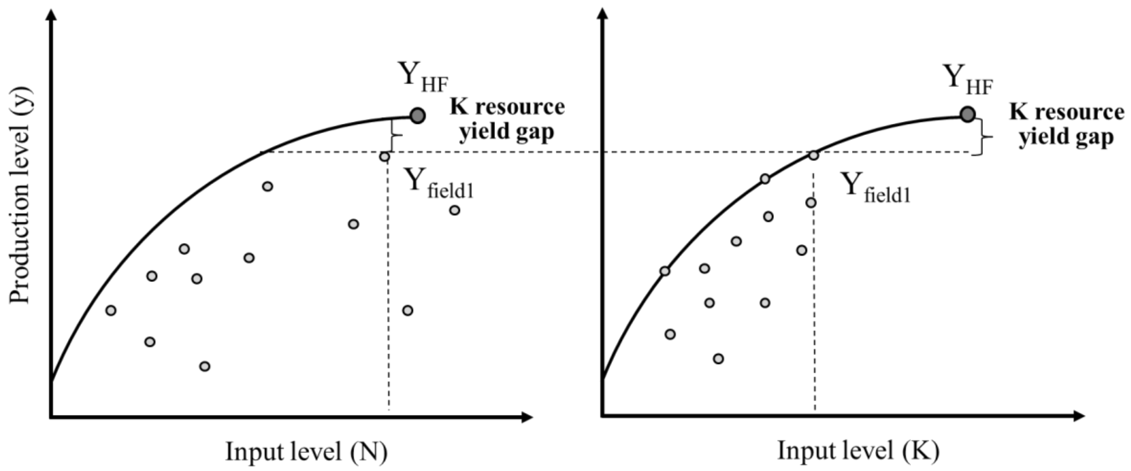

Fig. 1. Using frontier analysis for explaining potato yield gaps in fields within a farm. Each dot represents an individual field.Y_{HF}indicates the yield in the highest yielding field. All fields on the frontier are so-called technical efficient considering the specific input. In the figure, field 1 is efficient regarding K and inefficient regarding N. K is thus the limiting factor. When a field is below the frontier for all inputs, and thus non of the input factors are limiting, inefficiency can be explained by inappropriate management referring to time, space and form of the inputs applied.

3 Results – Discussion

Variability in potato yields among and within fields is high. Yields per field vary between 20 to 100 t ha^{-1}, with an average around 55 t ha^{-1}in 2013 and 65 t ha^{-1} in 2014 (Fig. 2).

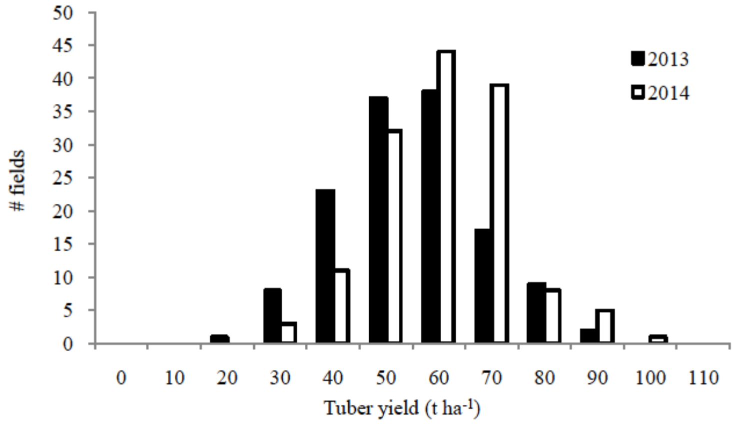

Fig. 2. Amount of fields plotted against obtained tuber yields (in t ha^{-1}) for cultivation years 2013 and 2014 on the farm of Van den Borne Aardappelen.

Considering a planting and harvesting window of one month, and a maximum irrigation capacity for half of the fields, at farm level it is impossible to reach the potential yield in all fields. Yields of some fields are limited by water stress, others by oxygen stress. In addition, due to land pressure, the farmer is forced to rent fields with poor soil quality in combination with fields with good soil quality. Nematode pressure can be very high and difficult to control in some of these fields. Further, nutrient, crop protection and weeding application is not always optimal due to the size and shape of the fields, timing of operations, and tree shading. Also the source of the seed potatoes influence obtained potato yields, and the farmer does not have full control about this.
Fig. 3 shows how planting date influences the maximum possible tuber yield.Both in 2013 and 2014 fields that are planted early and late have lower yields compared to an optimum in the middle. It is however not possible for the farmer to plant all the fields at the optimum date. When combining different inputs in a frontier analysis, limiting factors can be determined per field, and potential yields can be determined per field and at farm level.

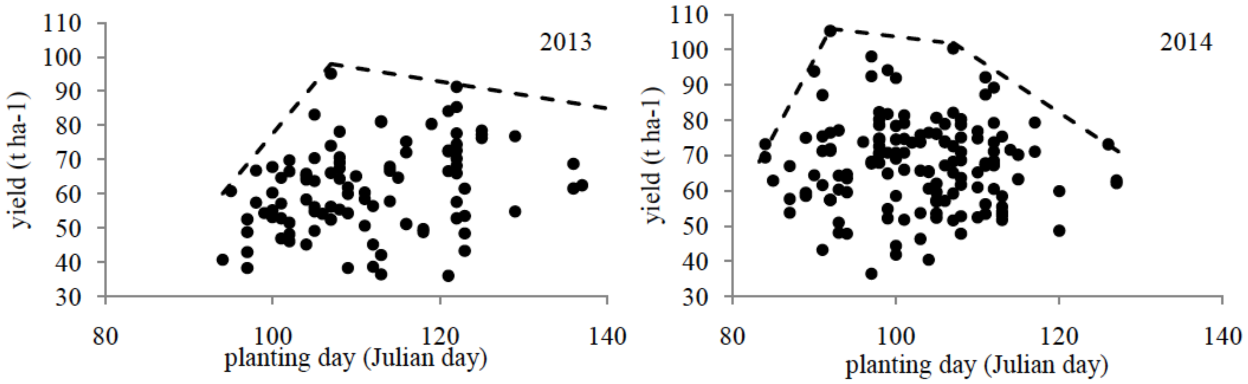

Fig. 3. Obtained yields per field (in t ha^{-1}) plotted against planting date. Frontiers are included to showing the highest yield possible at a certain planting date, according to observations.

4 Conclusions

It is generally acknowledged that potential yields cannot be achieved at farm level, and 80% of the potential yield is considered exploitable. A variety of reasons have been given, including weather variability and economic optimization (e.g. Lobell*et al.* 2009). In this study we make farm level constraints to achieve potential yields in each field specific, and show that although potential yields may be achieved in some fields, at farm level the potential yield is lower.

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Combining systems analysis tools for the integrated assessment of scenarios in rice production systems at different scales.

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1 Introduction

The integrated assessment of farming systems and the ex-ante analysis of future agricultural scenarios commonly make use of simulation models reproducing the sub-domains of the agro-ecosystems(Delmotte, Lopez-Ridaura *et al.* 2013). In the ScenaRice project we propose to integrate the information produced by stand-alone tools and models (e.g., field data, farmers' interviews, remote sensing analysis, crop model results, expert-based rules, farming system typologies, optimization models) to assess at different levels of complexity and scales the consequences of possible evolutions of rice farming systems. Central to our approach is the development of future scenarios considering plausible changes in agricultural policy, technological development and climatic conditions. Then, the different tools and models provide information at different scales to assess these scenarios: the field, the farm and the region. We applied this combination of data source in case studies in the main Italian and French rice areas and to some extent, to case studiesinMadagascar and Sierra Leone. In this paper, we present the articulation of the different sources of information for the assessment of scenarios related to the evolution of the rice farming systems in Camargue, South of France.

2 Materials and Methods

The Camargue is a deltaic region in the South of France, characterized by low lands almost at sea level, and a mosaic landscape composed of natural and cropped area. Rice and wheat are the most important crops and their future in term of production level and presence in the area is threatened by multiple drivers, including climate change, economic and regulatory conditions. Four scenarios were developed through three workshops with representative of the main stakeholders of the region. These scenarios were then assessed using the different tools and data source above mentioned and detailed below. Remote sensing analysis of time series of MODIS satellite images allowed to estimates dates for the main agricultural management practices and phenological stages of rice and wheat based cropping systems(Boschetti, Stroppiana *et al.* 2009). This information has been used as inputs for the STICS (Coucheney, Buis *et al.* 2015) and WARM (Confalonieri, Rosenmund *et al.* 2009) crop models parameterized to reproduce the development and growth of the most cultivated rice varieties. The simulation outputs allowed assessing quantitative (e.g.,aboveground biomass and yield) and qualitative aspects (e.g., head rice yield, protein content) of rice productions and of the other main crops (notably wheat and alfalfa) at field scale. The outputs of crop models, combined with other existing databases and farmers interviews, served to (i) define agricultural activities being currently done in Camargue and that could be possible in the future (considering the scenarios developed), and (ii) to assess the potential performances of these activities (and their variability) under different climate change scenarios. Remote sensing also provided information about the land use(e.g. cultivated surface of winter and summer crops) at farm level for 13 consecutive years, to identify main current trajectories of change. We conducted multivariate analysis of databases (including the farm trajectories identified using remote sensing) to build farm typologies. Finally, a multiple goal linear programming model has been developed to assess the scenarios in term of trade-offs and combinations of resources allocation, regarding a set of indicators at farm and regional level including socio-economic and environmental indicators (e.g. pesticide use and green-house gases emissions)(Lopez Ridaura, Delmotte *et al.* 2014). The integration of all the data allowed the integrated assessment of future farming systems in the context of the four scenarios built together with local stakeholders.

3 Results – Discussion

The four scenarios developed with the main stakeholders of the region are related to the economic and regulatory conditions for the rice production and to the impacts of climate change, including also drivers such as the price of energy and inputs, regulations related to pesticide use and greenhouse gas emissions, and the development of organic farming. In the communication, we will show the results obtained with the different tools and models at the field, farm and regional levels with examples taken from the different scenarios identified. Fig. 1 A presents the validation of the remote sensing analysis of wheat sowing dates, over 3 farms and 3 years. This analysis was extended to the whole region and for the 2001-2010 period, allowing us to analyze and understand the variability of wheat sowing date, notably in relation to the distribution of raining events in fall. From this analysis, we derived rules to determine potential wheat sowing dates to be used for simulations of climate change scenarios with the STICS and WARM crop models. Fig. 1 B shows the validation of the STICS crop model for the simulation of rice in Camargue, by comparing for multiple years observed and simulated yield variability. Both the STICS and WARM were used to simulate rice activities in Camargue, while STICS was used to simulate the other crops. Finally, fig. 1 C shows the impacts of the applicationof a given scenario on multiple indicators of alternative farming systems for a single farm, obtained from both an expert prototype and a bio-economic model. The bio-economic model was used to simulate the consequences of the four scenarios on the different farm types of Camargue (identified in the farm typology) and to upscale the consequences at the regional level, notably including indicators related to the supply-chain, the water quality, the greenhouse gas emissions or the feeding potential of agriculture in the region. These results will be presented in more details in the communication.

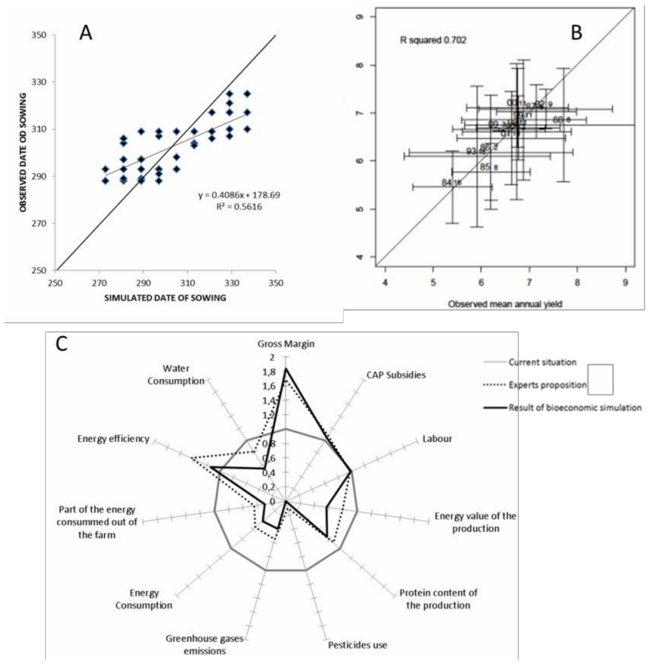

Fig. 1. A. Comparison of observed and simulated (estimated by remote sensing data analysis) sowing dates of wheat for three farms over three years in Camargue. **B.** Comparison of the variability of observed and simulated rice yield in Camargue with the STICS crop model for 11 different years. **C**. Comparison of three farming systems for one of the scenarios: the current situation, a prototype developed by experts and a farming system designed by the bio-economic model.

4 Conclusions

The integrated assessment of the evolution of farming systems in the future requires the mobilization of multiple sources of information, given the great uncertainty associated with changes in agricultural policy, technology and climatic conditions. In the communication, we will report in more details and on the basis of real cases the results of the combination of the different tools and approaches above mentioned, and notably the original combined used of remote sensing, crop models and bio-economic model, and highlight the added value for the integrated assessment of farming systems under scenarios notably related to climate change.

Acknowledgements. This research is being conducted within the Scenarice project (n°1201-008) funded by the Agropolis and Cariplo foundations.

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Trajectories of farming systems and land use changes in Southern Ethiopia

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1 Introduction

Maize is a crucial staple crop for Ethiopia and plays a major role in providing food security. While the region of Hawassa in Southern Ethiopia is one of the main maize production areas of the country, the productivity remains low. Several factors can expel, in this low productivity. In order to understand these factors, and their change over time we undertook this diagnostic study on past farming systems dynamic and their impact on actual farming systems diversity. Farming orientation and practices of individual farmers is constrained by their socio-economic situation, by biophysical conditions and other external drivers such as political context. This produces the diversity observable at farm scale, which in turn shapes the landscape structure. The diversity at farm scale changes over time producing different landscapes structures. The general objective of this study is to describe the land use/land cover changes, the changes in farming systems (in terms of farm typologies) and their drivers. In particular, we aim to answer to the following questions: (i) what is the farm size, production orientation and crop diversity of current farming systems? (ii) How do these characteristics change over time? (iii) How do these changes influence landscape composition? To answer these questions, we used triangulation of information collected via participatory methods, secondary data and satellite images analysis (Fig. 1).

2 Materials and Methods

2.1 Participatory methods

Three districts with contrasting farming systems were selected in the Hawassa area in Southern Ethiopia as study sites (Hawassa Zuria, Tula and Wondo Genet). Primary data were collected via (i) informal discussion, (ii) focus group discussion (FGD), and (iii) life history interviews. The focus group discussion was conducted with key informants in each district to understand their perceptions of the changes in farming systems and how these changes are reflected in the landscape via simple sketches of their district. The life history interviews were conducted on a stratified random sample of 40 households selected from a survey of 177 farmers conducted in 2013. The stratification was based on participatory farm typology data

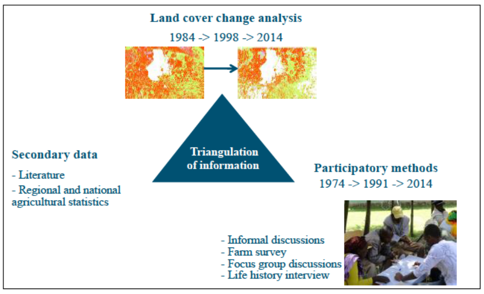

Fig.1. Methodology of the study

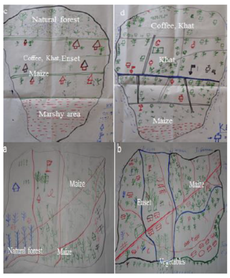

Fig.2. Sketch of Wondo Genet (top) and Hawassa Zuria (down) in 1991 (left) and in 2014 (right)

2.2 Land cover change analysis

Three Landsat images of the study area for the years 2014, 1998, 1984 were chosen to conduct an object-based image analysis (OBIA). The selected dates allow the comparison of the periods prior and after 1991, the year that the communistic Derg regime ended. The analysis focussed on grassland, annual crops, perennial crops and urban areas.

3 Results and Discussion

3.1 In informal discussions elderly people indicated three main periods with a pronounced impact on their farming systems and livelihoods (prior-1974, the period 1975-1991 and post-1991), which coincide with regime changes in Ethiopia. Farmers' sketches of their district in 1991 and 2014 revealed that Before (Fig. 2). before 1991 Wondo Genet was dominated by natural forest and pasture land, coffee, enset and maize crops (Fig. 2). After 1991, the natural forest had disappeared and that the area under that production had expanded. Similarly, in

Hawassa Zuria the natural forest was removed in 1991 and replaced by enset and maize. Along Lake Hawassa vegetables were introduced. The analysis of life histories of 40 farmers of the three districts shows a decrease of land holding and tropical livestock unit (TLU) density (Fig. 3). Changes in area of maize and perennial crops (khat and enset) were district specific. The area of maize was rather constant in Wondo Genet and Tula, but in Hawassa Zuria more dynamic can be observed. In some farms maize area increased, while others remained at the same size. Enset production, an important crop for food security increased significantly in Hawassa Zuria. This increase has been promoted by development projects.

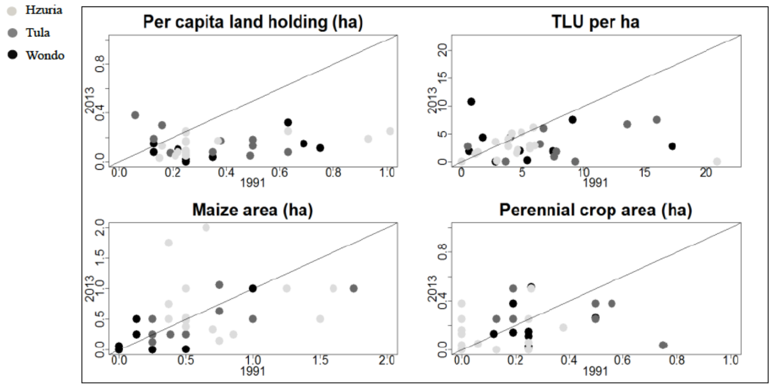

Fig. 3. Changes in land holding, TLU maize area and perennial crop area (khat and enset) between 1991 and 2014 in Hawassa Zuria, Tula and Wondo Genet

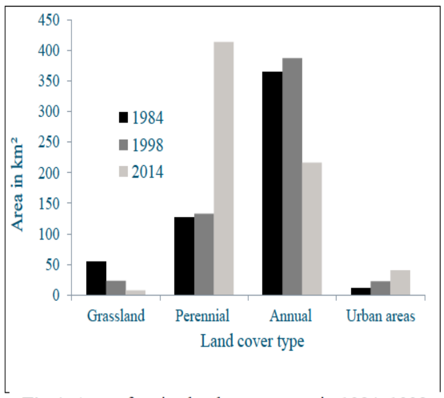

Fig.4. Area of major land cover types in 1984, 1998 and 2014 in the Hawassa area

3.2 Landsat image analysis indicated that most changes in land use occurred after 1998 (Fig. 4). The increase of perennial crops enset and khat between 1998 and 2014 is confirmed by the FGD data indicating that the area of enset increased in Hawassa area and the area of khat increased the most in Wondo Genet. At the same time, the area of annual crops areas decreased because of a shrinking area of maize in Wondo Genet and Tula, and the expansion of Hawassa city and the emergence of three towns in Wondo Genet. Grassland has virtually disappeared in the Hawassa area.

4 Conclusions

This study shows that farming systems and landscape composition in the Hawassa area are highly dynamic. This conclusion is supported from independent analyses of participatory data and land cover change. Across the three study sites natural forest has disappeared, and the per capita land holding and TLU have decreased. In two out of the three districts the area of cash crop (khat) has increased. This suggests that the land holding is no longer sufficient to sustain the livelihood of farmers triggering a shift to cash crop production.

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Sweet sorghum: methodological exploration of a multifunctionality to innovate in Haitian agriculture

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1 Introduction

Sorghum is a hardy tropical plant, less demanding in water and nutrients, that can grow in poor soils. This cereal is used for human and animal consumption. While it is more used for animal consumption in developed countries, in Southern countries, it can represent an important part of the human diet, even if it is less and less popular.
Recently the international scientific community has been more and more interested by this plant particularly the sweet varieties (Damasceno *et al.*, 2014), which are able to combine a grain production with a sugar accumulation in their stalks giving them a multipurpose characteristic (Braconnier *et al*, 2014).
In Haiti, a research and development project (S3F for Haiti) was implemented by CHIBAS (a Haitian foundation for agricultural research), Université Quisqueya (a Haitian university), and CIRAD (a French institution leading research in tropical agriculture), from 2010 to 2015, to introduce and develop sweet sorghum in Haiti. This multipurpose cereal, producing grains and sweet juice extracted from its stalks, can be used to produce bio-ethanol or alcohol while biomass (leaves and bagasse) left after juice extraction, represents a good source of forage or animal feed (Leclerc *et al*, 2014). The development of these uses can provide an answer to Haiti's needs for food, feed and fuel.
The main question discussed in the project is to know how to assess *in itinere* the conditions to develop a cross-sectoral innovation, the sweet sorghum in Haiti. The hypothesis is that these conditions are revealed by: i) the analysis of existing and potential impacts on different sectors which are involved (animal feed, alcohol, human food), ii) the identification of the main bottlenecks, iii) the synergies between stakeholders (producers, industrials, State agents and research) around productions of information, knowledge, technologies and political orientations.

2 Materials and Methods

We mobilize the sectoral innovation system (Malerba, 2002; Touzard *et al*, 2015) as analytical framework. This reference frame characterizes stakeholders system which is mobilized by the innovation process related to the introduction of a new cereal variety, and the conditions of its use in different potential value chains.
The analysis is structured by the sectoral dimension according to two macro-value chains related to food supply (human and animal) and energy supply. It provides a representative frame of the meso-economic relations in terms of vertical relationships between the different stakeholders (Temple *et al.*, 2011) involved in (1) production, (2) processing (grain, sugar and biomass) into intermediate and final products and (3) commercialization for the different uses (granule as cattle food, alcohol as "kleren" which is a local rum, syrup, bran, bagasse silage). It allows us to characterize the appropriate technological, economic and social conditions for sweet sorghum introduction.
An important set of secondary and primary data was collected throughout the project. Three surveys were achieved successively (Charles *et al*, 2012; Lamour, 2013; Levesque, 2014) on a global sample of 70 resource persons from institutions and companies, that structure the Haitian system of research and innovation.
Direct face to face surveys were also conducted successively in 2012, 2013 and 2014 with samples of producers and industrials (small, medium and big processors) in various sectors.
During this study, the sweet sorghum implementation in different value chains was analyzed in three situations: in an industrial sugar cane area where we could find big "kleren"-processing plants, in a craft and hilly area full of small "kleren"-processing plants, and in the poultry industry area where sorghum can be used as animal feed.

3 Discussion

The sweet sorghum innovation can have different impacts on the development of Haiti. It can create jobs through the emergence of a new industry related to "kleren" production that would also stimulate the national sugarcane industry and sorghum grain production. The quantification of this job creation was appreciated by experimental observations realized in the different analysed situations. Thus, in the studied industrial area, from 61 to 131 man-months would be required, while in the hilly craft area the demand would be 60 man-months concerning industrial sectors. Moreover, sweet sorghum can maintain industries and agricultural activities based on sugarcane industry. For food producers, collecting grains in a production area requires people to organize the collection, and to load/unload grains.
The sweet sorghum innovation can also impacts positively on households' food safety through (i) an increased and

diversified income for producers giving them a better access to food and (ii) a higher grain yield from the sweet varieties. This innovation presents potentialities to use co-products in animal feed and could positively impact on the trade balance of Haiti through a decrease of corn and meat imports. The mobilized methodological framework permits to highlight the macroeconomic conditions to achieve these impacts from observations made on users' experimental devices.
Two types of factors limit the innovation processes and thus the achievement of the potentials impacts: technological and socioeconomic factors.
Considering the technological factors, the conditions of sweet sorghum use are heterogeneous in production areas, according to the priority given to potential uses of the stalks co-products ("kleren", animal feed…). It is necessary to adapt sweet sorghum varieties to these different uses. The use of sweet sorghum to produce "kleren" requires to reduce as much as possible the time to harvest and transport stalks process units for preventing °Brix decrease. To challenge these limits, technological, organizational and institutional (Paul, 2012) innovations in the supply chain are needed (moving mills, varieties, contracts).
About the socioeconomic factors, the use of sweet sorghum in industrial sectors (alcohol, animal feed) implies to consider the determinants of their competitiveness, partly linked to the orientations taken by commercial politics and public supports. The use of sweet sorghum grains as feed in the industrial poultry industry depends mainly on the price difference between sorghum grains and the competitor products, particularly imported maize. The use of bagasse as fuel for alcohol production implies to take into account the potentially negative social externality as this prevent other uses as feed for cattle, which play a saving role, or as soil fertilizer (organic matter and nutrients recycling).
Facing these bottlenecks, the adoption of this innovation requires to reinforce the technology as well as the organization of the activities to improve economic profitability of sweet sorghum use by the different stakeholders. Capacity to pool the supply logistics of producers and industrials as well as favourable orientation of public policies are two important axes to develop the market.

4 Conclusions

The innovation, carrying potential positive impacts on the development and the households' economic situation, could be implemented and diffused only if the identified blocking factors are unlocked by adapted policies in research and innovation. A main issue is the development of interactions between stakeholders involved in the technological and organizational aspects that will determine future orientation of innovation processes. Nevertheless, this innovation may result in important upheavals through a reorganization of the livestock and a decrease in soil fertility, if no alternative is proposed to producers for replacing sorghum stalks left on the fields which pay play a role in the production system.
Furthermore, this study strengthens methodological frameworks of *in itinere* assessment of the conditions for implementing an innovation in a context of Southern country agriculture.

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W3. Cropping systems design: what can we do with field experiments and expert knowledge?

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System experiments: methodological progress

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1 Introduction

Unlike traditional analytical experiments, where elementary techniques are tested to analyze their main effects and their interactions, system experiments consist of implementing cropping systems, livestock systems or farming systems, i.e. consistent combinations of technical choices. System experiments aim at testing in the field the capacity of innovative cropping, livestock or farming systems to reach the objectives for which they were designed (Meynard *et al.,* 2012). They are a methodological resource in the design process, making a full-scale assessment of the performances of systems designed by expert prototyping or model-based design, putting their construction principles to the test and helping to improve them. There is an increased interest in system experiments today because of the challenges of redesigning farming systems, mainly associated with the negative externalities of dominant high-input agriculture. These experiments can be carried out in experimental or real farms. System experiments on cropping systems have usually been carried out at field scale, on annual or multiannual time steps. Experiments on livestock systems are often carried out at whole-farm level on multiannual time steps. This paper will give an overview of methodological progresses concerning this experimental paradigm, taking into account both animal and crop productions.

2 Management of experiments with decision rules

The first system experiments (1990s and early 2000s) were carried out on the basis of general directives given to the experimenters (for example « *When possible, meadows were cut early and conserved in wrapped round bales. The nitrogen supply was taken as based on the legumes for the pastures and the protein-rich plants for crops to replace purchased nitrogen fertiliser*", Benoit *et al.,* 2009), or pre-established schedules of operations (for example, Clements *et al.*, 1995). The proposal of Reau *et al.* (1996) to base technical choices on decision rules made it possible to reconcile the flexible adaptation of techniques to diverse farming situations with a formalization enabling all the experimenters in a network (or the same experimenter over several successive years) to make coherent decisions. Usually a rule is made up of (i) a function, which links the decision to the objectives of the system, (ii) a solution, which displays the possible actions according to the context in conditional form ("If. . . then. . . ; else…"), and (iii) an evaluation criterion to check whether the objectives were reached or not. Decision rules are applied on the basis of indicators related to the soil, the plants, the herd or the climate, which are clearly formalised and accessible to the decision-maker (Debaeke *et al.*, 2008). The evaluation of the cropping or livestock system becomes the evaluation of the set of decision rules. Explicitly formulated, these rules make it possible to reproduce the system in other times or other conditions: after assessment, they become the basis for diffusing, to the farmers, the achievements of the system experiment (Dejoux *et al.,* 2003).

3 The assessment of the tested systems, to prepare their scaling out

The multicriteria assessment of the systems tested consists of checking that they achieve their economic, environmental or social objectives. Classically, a list of assessment criterions is drawn up at the beginning of the experiment and indicators or measured variables are identified for each criterion. For example, Benoit *et al.* (2009) assessed two ovine systems differing by the degree of self-sufficiency and by the ewes' reproduction rhythm (one lambing per ewe per year vs. 3 lambings over 2 years) on the following criterions: "*ewes' reproductive performance, lamb growth rate, carcass characteristics and quality, animal health, forage and feed self-sufficiency, soil mineral balance and gross margin*". Loyce *et al.*, (2012) proposed to analyse the sensitivity of economic criterions to the price of grains or of inputs. Setting up multilocal networks of system experiments, in farmers' fields, makes it possible to identify the conditions under which a cropping or livestock system gives satisfactory results; but such networks are still rare, because of the cost and unwieldy nature of these experiments, which sometimes require large areas of land to be realistic (Dejoux *et al.,* 2003).

However, Meynard *et al.* (1996) stressed that this global assessment should be completed by an agronomic evaluation, which consists of checking that the principles on which the system was built are validated. Loyce *et al.* (2008) checked the basic principles of low input wheat management: by reducing crop density and early nitrogen input, and by choosing resistant cultivars, fungal diseases and lodging are controlled just as much as with more classical high input management (using fungicides and growth regulators). To check such principles, additional experimental treatments (e.g. low input system with high yielding disease susceptible cultivar) are sometimes necessary. An agronomic diagnosis, carried out on the systems tested, makes it possible to determine the causes of a yield gap, a health problem or an environmental pollution. An erroneous decision rule can then be corrected, and the scaling out of the tested systems or of their construction principles can be prepared. Dejoux *et al.* (2003) give an example, showing that rapeseed management based on early sowing (1 month earlier than normal sowing) in general gives economically and environmentally satisfactory results, except on shallow soils with low available nitrogen. As shown by these examples, the systems assessments are usually multidisciplinary : the disciplines of plant and animal health are called upon, as well as agronomics and environmental sciences. In long-term experiments, the cumulative effects created by the systems can even become the heart of investigations by specialists in ecology or soil physics (Henneron et al, 2015).

4 Learning in a system experiment; step by step design

Sometimes, in a multiannual experiment, the annual assessment of a system leads to the conclusion that the formulation of a decision rule is inconsistent with the other rules or with the system objectives. What is the best? Leaving the rule unchanged, so that it remains the same set of rules which governs the experiment throughout its duration, or changing it, to improve the system in real time (Debaeke *et al*., 2008)? This second option, based on the fact that the experimenter learns from the assessment, as a farmer would do, is at the heart of "step-by-step design process": Coquil *et al*. (2009) and Meynard *et al*. (2012) thus propose the organization of learning loops within the system experiment, which allows developing gradually a cropping or livestock system to make it more and more successful in achieving its objectives. The function of the system experiment changes from the assessment of a designed system towards the progressive design of the system. This step-by-step design is based on a spiral of continuous improvement: real time assessment indicates the criterions that are not met satisfactorily; an agronomic diagnosis makes it possible to identify the agronomic and ecosystem functions which are in question and technical actions which should be changed; on the basis of this diagnosis, evolutions of the farming systems are proposed and implemented. Then a new assessment is made, new evolutions of the systems follow, etc. According to such an approach, Gouttenoire *et al*. (2010), analyzing the causes of a drop in the fertility of dairy cows in an organic low-input grazing system, suggested modifying the dates of the breeding or lengthening the lactation periods (up to 2 years) to improve reproductive performance.
Step-by-step design also makes it possible to confront situations where, for lack of sufficient knowledge, it is not possible to write some decision rules at the start of the experiment: so, decisions for system management are made on the basis of the expertise of the experimenter; the actions implemented are then evaluated, which leads to learnings and to the progressive formalization of the decision rules. In an experimental farm, learning is collective: while the experimenter learns about decision rules, the tractor drivers or herdsmen also learn how to implement practices; they all change their way of observing crops and animals, in relation with system assessment criterions (Fiorelli *et al.,* 2014). The results of such experiments are not reduced to the design and assessment of innovative systems: they also produce tools to encourage learning, which can then be passed on to the farmers (Coquil *et al.*, 2009). More than the systems themselves, scaling out concerns the step-by-step approach to design, and the tools (indicators, diagnostic tools, library of innovations) which underlie it (Meynard *et al.*, 2012). Examples of step-by-step system experiments, in mixed farming and market-gardening, are given in other papers during this conference (Durant 2015, Lefèvre *et al.,* 2015).

5 Conclusions

Ultimately, from being a resource for assessing systems designed *in silico* or in design workshops, the system experiment also becomes a resource for organizing the mixing between expert knowledge and scientific knowledge in designing new systems, and a resource for collective learnings in the teams of experimenters.

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SYPPRE :A project to promote innovations in arable crop production mobilizing farmers and stakeholders and including co-design, ex-ante evaluation and experimentation of multi- service farming systems matching with regional challenges.

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1 Introduction

Agriculture must succeed in reconciling food production, energy production and conservation of the environment. This requires a shift towards new production systems, based on ecological intensification, adapted to local conditions, and manageable by farmers. To address this issue, the French technical institutes Arvalis-Institut du végétal, Terres Inovia and ITB, launched the collaborative project SYPPRE (SYstèmes de Production Performants et Respectueux de l'Environnement). It is based on three work packages: observatory of current agriculture practices (WP1), four platforms to co-design and experiment innovative cropping systems adapted to local conditions (WP2), and facilitation of farmers groups in the re-design of their farming systems (WP3). In this paper, we highlight the method used in WP2 to co-design and select multi-services cropping systems for long term experiments.

2 Materials and Methods

The national framework for the SYPPRE project has been specifiedfrom the share of a prospective view for crop productions over the fifteen next years. To stay close to farmers issues and to save links with territorial specificities, the project has been then declined in four locations representative of main arable crop productions: PIC (Picardie, northern France, deep loamy soils, industrial productions, irrigated; LAU (Lauragais region, southern France, clay-limestone, arable crops, rainfed); CHAM (Champagne, chalky soils, industrial productions, rainfed); BER (Berry, shallow clay-limestone, arable crops, rainfed). The locations would help to explore a range of soil, climate and production system conditions, and thus a diversity of solutions to achieve the common stakes.
For each location we applied the methodology of '*de novo*'co-design of cropping systems (Meynard *et al.,* 2012) to reconcile global issues and local constraints. Working groups have been set up with farmers, local advisors, researchers, crop specialists, and also grain collectors to keep a view on new production opportunities. Each person was chosen to balance the profiles in the groups, including experts in local issues and local knowledge, experts bringing good exploration knowledge and skills, and changes leaders(Reau *et al.,* 2012).
We followed five steps with each regional group to design innovative farming systems: i) identifying local issues based on a prospective study and defining local framework, ii) defining the most representative cropping system in the region, and its limitations, based on regional statistics and local expertise, iii) identifying candidate crops and suitable agronomic strategies, based on general knowledge and local expertise, iv) designing innovative cropping systems, v) making *ex ante* assessment of each system. The evaluation was performed with SYSTERRE® (Berrodier & Jouy, 2013), Odera-Systèmes (Pernel *et al.,* 2011), AMG (Andriulo *et al.,* 1999) and MASC (Sadok *et al.,* 2009). A loop of improvement was carried out before selecting the most promising prototype to be experimented in each platform.

3 Results – Discussion

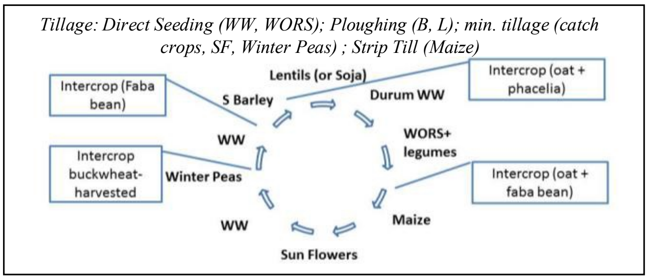
The prospective study led to focus SYPPRE on three main stakes. Indicators were proposed for their assessment: i) High productivity, to achieve higher needs for biomass to face an increasing demand for food, energy and proteins (Gross product and gross energy of whole plants), ii) High profitability for farmer (semi-direct margin), iii) Low inputs and environmental impacts (Treatment Frequency Index - TFI; amount of fertilizer-N; Green House Gas emissions - GHG, energy consumption, C and N stocks).
During the first meeting the designing groups completed the national framework of SYPPRE with local goals and constraints. They also agreed on the most representative cropping system to improve (Tab. 1). Situations are contrasted, from very simplified cropping systems (LAU, BER), to input dependent systems for CHAM and PIC mainly due to industrial crop production and a stronger pressure from pests and disease. The four groups have in common to search for an improvement of soil fertility as a solution to increase plant productivity and/or decrease dependency towards mineral fertilizers.

Table 1. Local stakes and representative systems for each location, and innovations proposed in the workshops
WW : Winter Wheat ; WOSR : Winter Oil Seed Rape S Beet : Sugar Beet ; S Barley : Spring Barley ; W Barley : Winter Barley

	Representative system	Local stakes	Main ideas (crops and agronomic strategies)
PIC	SBeet / WW / Potatoes / WW / WOSR/ WW *Ploughing*	↗productivity ; ↘mineral nitrogen use; ↗soil fertility (less compaction)	Vegetables; legumes (intercrop only); double-cropping; WORS in association
CHAM	WOSR / S Barley / S Beet / WW *Ploughing*	↗quality of the products ; ↗soil fertility ; ↘ GHG	↗Crop rotation (10yrs); legumes; low input needed crops; varieties tolerant to nitrogen stress; double-cropping; soil cover; alternatings in soil tillage; biocontrol
LAU	Sun Flowers / Durum WW *Ploughing*	↗quality of the products ; ↗soil fertility (less erosion)	↗Crop rotation (8yrs); legumes; permanent soil cover; Minimum tillage; double-cropping (biomasse production); decision rules and tools to ↗ nitrogen and water efficiency
BER	WOSR / WW / W Barley *Reduced tillage*	↗economic robustness ; ↘use of inputs ; ↗soil fertility; weed control	↗ Crop rotation (9yrs); legumes; new productions (soja, lentils, …); permanent soil cover; Direct Seeding; robots, drones; catching plant on field margin

„Library of ideas" were complied during the second meetings of the groups (see extract in Table 1). Each practice was described with its agronomic function and expected benefits for the systems. Practices like introduction of legume or permanent cover and reduced tillage have been mentioned in the four groups. Scarcely developed but interesting, double cropping or crops in association (even with cereals) were also proposed to improve soil productivity. Uses of robots, biocontrol solutions or stress tolerant varieties have been considered to reduce inputs dependency. Five to nine systems have been co-designed in each group from the libraries of ideas before selecting the most promising prototype.

Fig. 1. Candidate prototype in Berry and first results of *ex-ante* assessment with Systerre, Odera and AMG-Simeos
WW : Winter Wheat ; WOSR : Winter Oil Seed Rape S Beet : Sugar Beet ; S Barley : Spring Barley ; W Barley : Winter Barley



Criteria	Indicator	Objectives	Results
Productivity	Gross product	↗=	= to ↗
	Gross energy	↗=	↘
Economy	Semi-direct margin	↗ =	↗
Environment	GHG emission	↘	↘
	Energy consumption	↘	↘
	TFI	↘	↘
	Amount of fertilizer	↘	↘
	C & N stocks	↗	=
Agronomy	Weeds density	↘	↘

In the example (Fig. 1), the candidate prototype for BER is an eight-year rotation system. New productions have been introduced to help weeds control and to reduce sensitivity to climatic and market hazards, which is confirmed by the *ex-ante* assessment. Introduction of legumes in the crop sequence even in the intercrop seems to be efficient enough to reduce nitrogen use and energy consumption and GHG emission at the same time. Minimum tillage and permanent cover would help reducing erosion. Impact on organic matter is below the objective but satisfying for the location. Gross product increases. Gross energy production is not satisfying at the moment but calculations have to be fine-tuned.

4 Conclusions

The five-step method we followed was efficient: it led to define the systems to set up in the four plateforms. We made assumptions with experts to carry out *ex-ante* assessments. It led to the identification of lacks of knowledge on the real effect of innovative practices. This would imply the implementation of factorial trials beside the systems, to make these platforms privileged places for knowledge's production and dissemination.

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Describing cropping system tested in an experimental network: contribution to analysis of results and sustainability performances and to inspiration of farmers, trainers and R&D

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1 Introduction

To face the renewed issues of agriculture, research, development and training actors have to join their efforts in order to (i) re-design and develop high performant arable and mixed farming cropping systems (CS), and (ii) inspire (future) farmers (Reau and Doré, 2008). In this way, the Joint Technology Network (JNT) for "innovative cropping systems", created in 2007, coordinates in France a network of cropping system experimentations (Deytieux *et al.*, 2010). Its goals are (i) to develop a knowledge network including different expertises, disciplines and approaches, (ii) to suggest operational approaches to design and evaluate innovative cropping systems in order to identify the most promising ones, (iii) to test in a network of field experiments and farm monitoring the performances and feasibility of new cropping systems in order to share and transfer them to farmers, research, development and training actors.

In this paper, we present a method of description of cropping system which contributes to the analysis of each cropping system and of several cropping systems in multi site analysis by benefiting from the dialogue and reflexivity in the JNT.

2 Materials and Methods

In 2015, the network of cropping system experimentations includes seventy cropping systems, which are experimented in forty-five experimental sites. The network represents a wide range of pedo-climatic conditions, even though most of the sites are located in Northern France (Deytieux *et al.*, 2010; Deytieux *et al.*, 2012). Two complementary experimental approaches are used in the network: experimentations in experimental stations which allow to be more prospective and to avoid some technical or economical constraints; experimentations in farmers "fields" which are more relevant to test the global feasibility of the cropping system by including some economical and social constraints. All tested cropping systems are adapted and designed to meet local issues and contexts.

In the network, three main theme groups are identified (Deytieux *et al.*, 2010): arable cropping systems mainly based on Integrated Crop Management (ICM) principles (Cash crops ICM), mixed farming cropping systems based on ICM principles (Mixed crops ICM), arable cropping systems focused on high energetic and/or greenhouse gases performances research (Energy/Gas) which have a double aim focused on both ICM and energy-gas issues.

To capitalise on the cropping systems tested in multi annual experiment, the animation team of the network developed and formalized a method to describe, understand, analyse and discuss about the tested cropping system. This formalisation consists of describing : (1) the origins of the design and implementation of the tested cropping system, (2) the context (localisation, climate, biotic pressure, socio-economic context...), (3) the experimental plan, (4) the expectation of the territory "sstakeholders", (5) the expectations of the crops "manager" (5) the decisional-model for each agrosystem services (Reau *et al.*, submitted), (6) the praticed system, which is the synthesis of the interventions occured in the fields during several years of test, (7) the agronomic results (crops and soil states, …), (8) the technical results such as yield and quality, (9) the sustainability performances obtained which are analysed in regards to those expected by the designers of the cropping system, (10) the performances of sustainability analysed with MASC 2.0© (Craheix *et al.*, 2012), (11) the keys of a successful management of the cropping system and new knowledge, (12) the main features of the cropping system.

3 Results – Discussion

In the cropping system experimental network, the first step has consisted of describing and analysing more than 33 systems since the second semester of 2013. For example, the Courgenay CS tested in Burgundy, by the Chambers of agriculture, in a clay and limestone soil, in an oceanic climate, was described by a small working group and presented to the experimentaters of the network in December 2014. The aims of this CS are to manage weeds while reducing pesticide use if possible (ryegrass < 1plant.m², control of bromine infestation, circles of thistles ≤ 2 m²), to maintain the system gross margin to 1200 €.ha^{-1} (with a winter wheat price at 200 €.t^{-1}) with a maximal accepted loss of yield of -5 q.ha^{-1} of winter wheat. The decisional-model for weed management (Fig.1) explains the combination of solutions (techniques, decisional rules) implemented to achieve these aims (Reau *et al.*, submitted). The CS, tested since 2005 has succeed in managing weeds except the population of thistles which increased. Its performances of sustainability evaluated in multicriteria analysis with MASC 2.0 were quite high with a very good economic and environmental sustainability (Fig. 2).

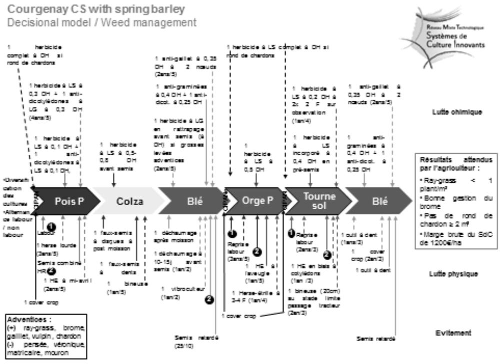

Fig.1. The decisional-model of weed management of the CS tested in Courgenay (Burgundy, France)

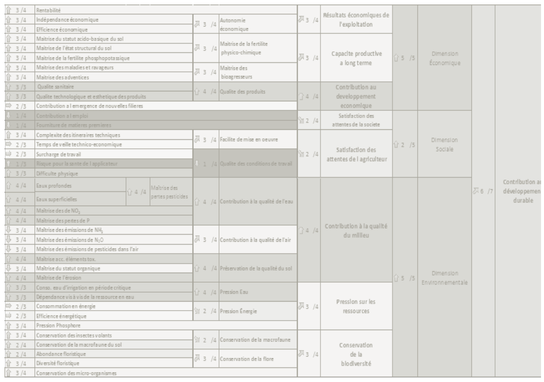

Fig.2. The performances of sustainability of the CS tested in Courgenay (Burgundy, France). The assessment was performed with the MASC 2.0© method.

Once described, the Courgenay CS was presented, in a workshop with 2 other cropping systems identified as quite similar in terms of aims and crop management strategies (Courgenay, Epoisses tested by INRA Dijon in Burgundy, Lusignan tested by INRA and Chamber of Agriculture of Poitou-Charentes). This workshop aimed at describing, understanding, discussing and analysing the 3 CS with the crop managers, the experimentaters involved and other experimentaters of the JNT. This collective workshop allowed to exchange about weed management techniques, to explain and precise some of the strategies and results. It also allowed a dialogue between the crop managers and the experimentaters, helping them to step back from their experimental activities. By the questions and answers with the network members, the understanding of the cropping system was improved thanks a „reflexive" analysis and allowed to discuss the strength of the weed management strategies and their potential extrapolation in other contexts. This exercise needed to well describe the cropping system which took some time.

4 Conclusions

The method to describe tested cropping systems has proved to be a useful tool in the network. By confronting their experience on tested cropping systems, crop managers and experimentaters have the ability to take part and improve cropping system analysis, to capitalize on the global and specific crop management strategies they learned to put in practice. The next steps will be (i) to extend this activity of CS description to all the cropping systems of the network, (ii) to organize worshop to discuss and share on the tested CS, their results and performances. (iii) to study in what extend such CS description is a useful resources for action, advice and training and think about other ways to make useful ressources from knowledge on cropping systems performances produced in the network iv) to communicate.

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Design and multicriteria assessment of low-input cropping systems prototypes based on agroecological principles in southwestern France

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1 Introduction

The challenges of agriculture in the current context of global change and the increasing social awareness of the impacts of agricultural activity on the environment and human health has led to the need of designing more sustainable cropping systems. However, to be viable, those innovative cropping systems must be assessed on a multicriteria basis to determine their long-term performance in agronomical, socioeconomic and environmental terms (Sadok *et al.*, 2009).

2 Materials and Methods

A cropping system experiment was initiated in 2003 at INRA in Auzeville (SW France). Prototypes of low-input alternatives to the traditional durum wheat (*Triticumturgidum L.*) – sunflower (*Helianthus annuus L.*) rainfed rotation were designed using the prototyping methodology mobilizing scientific expert knowledge in co-design workshops (e.g. Vereijken, 1997). In a first step (2004-2009) the prototyping of innovative cropping systems was based on the following goals: (i) reduce the amount of inputs (i.e. N fertilizer, pesticides), (ii) better couple cash crop N needs and N cycling and (iii) reduce N losses as leaching. To reach those goals six rotations of 3-yearswith different levels of inclusion of grain legumes (GL0, GL1 and GL2, no, one and two grain legumes included in the rotation, respectively), with (CC) or without (BF, bare fallow) catch crops were established and tested:(Fig. 1).

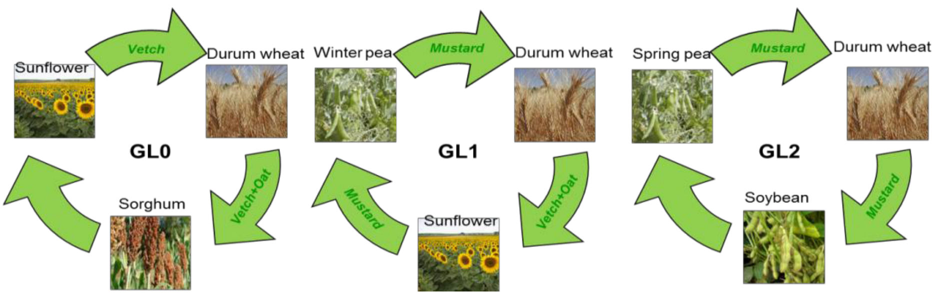

Fig. 1. Conceptual diagram of the 3-year rotations tested in the experiment between 2004 and 2009. Green arrows indicate the cover crops of the CC treatment for the 3 rotation prototypes including these species.

In 2010, a second step aimed at re-designing the protypes based on integrated pest management technics by going further in the mobilization of agroecological principles in terms of (i) building entire rotations based on intercrops to better exploit the potential of resource use complementarity, (ii) establishing a baseline of a 50% reduction in the use of phytosanitary products according to the Ecophyto 2018 plan of the French government and (iii) increasing the diversity of species within the rotation (cash and cover crops)in order to have a biodiversified-based cropping system (Fig. 2).

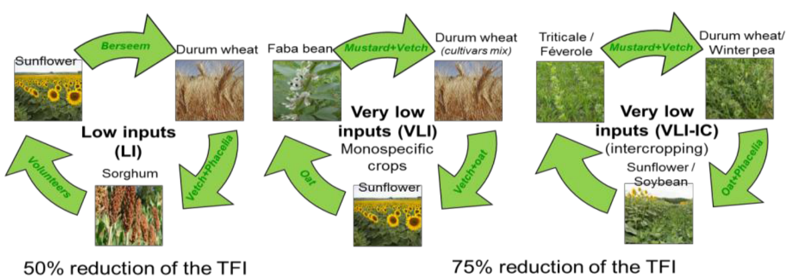

Fig. 2. Conceptual diagram of the 3-year rotations tested in the experiment after 2010.Green arrows indicate the cover crops of the CC treatmentfor the 3 rotation prototypes including these species.

The evaluation of the cropping systems was carried out by complementary experimental and modelling approaches in order to assess their agronomic and economic feasibility and evaluate their environmental impacts in terms of greenhouse gases emissions and pesticides transfer and N leaching to ground waters. Quantitative and qualitative methods and the multicriteria MASC 2.0 analysis were used for identifying strengths and weaknesses of the prototypes.

3 Results - Discussion

During the 2004-2009 period the incorporation of one (GL1) and two (GL2) grain legumes in the 3-year rotations led to a diminution of the soil organic carbon (SOC) stock (0-30 cm soil depth) of 542 and 490 kg $ha^{-1}yr^{-1}$, respectively, as an average of the CC and BF treatments. Contrarily, the GL0 rotation maintained the amount of SOC. The use of cover crops mitigated by a 13 and a 67% the loss of C in the GL1-CC and GL2-CC rotations, respectively.
The results of the multicriteria assessment of the first three-year rotation (2011-2013) are shown in Table 1. To carry out the analysis some key indicators were selected, according to the objectives of the designers.

Table 1. First multicriteria approach: key indicators about production and environmental aspects (average 2011-2013).

Cropping system	SNM* (€ha^{-1})	% diff. reference	Wheat yield (t ha^{-1})	% diff. reference	Sunflower yield (tha^{-1})	% diff. reference	N fertilizer (kg N ha^{-1})	% diff. reference	TFI**	% diff. reference
Reference	**899**		**6.0**		**2.6**		**119**		**2.5**	
Low inputs (LI)	952	+6%	5.6	-8%	3.0	+15%	96	-19%	0.7	-73%
LI-CC	934	+4%	6.1	-	3.2	+21%	96	-19%	0.9	-66%
Very low inputs (VLI)	844	-6%	6.1	-	3.2	+22%	43	-63%	1.4	-43%
VLI-CC	795	-12%	5.8	-4%	3.8	+44%	51	-57%	1.1	-55%
VLI-IC	682	-24%	3.9 (1.6)***		1.5 (1.1)		40	-66%	0.9	-62%
VLI-IC-CC	559	-38%	3.57 (1.4)		1.4 (1.1)		45	-62%	0.8	-70%

*Semi net margin; **Treatment frequency index; *** Values inside () correspond to the yield of the accompanying crop of the mixture.

The last results show that the objectives of reducing the use of pesticides (i.e. TFI reduction) and N inputs while maintaining yields were reached, except for the most innovative systems based on intercropping (i.e. VLI-IC and VLI-IC-CC). However, all the Very low input systems (VLI) showed a significant decrease in their economic performance.
The use of the model MASC 2.0 allowed getting a global view of the sustainability of the prototypes and pointing out eventual side effects not taken into account during the design process. This model based on qualitative attributes allowed taking into account social, economic and environmental issues all together (Table 2).

Table 2. Multicriteria assessment with MASC 2.0: summary of results for the different prototypes (2011-2013 period).

Cropping system	Economic pillar	Social pillar	Environmental pillar	Global sustainability
Reference	**5***	**5**	**3**	**6**
Low inputs (LI)	5	5	4	7
LI-CC	5	5	4	7
Very low inputs (VLI)	5	5	3	6
VLI-CC	4	5	3	6
VLI-IC	4	5	3	6
VLI-IC-CC	4	3	2	3

*The higher, the better

Globally, most of the innovative cropping systems showed a good level of global sustainability, equivalent to the reference and for the case of LI and LI-CC even better. Some attributes belonging to the social pillar were degraded due to a higher complexity of the prototypes (data not shown). Besides, the reduction of the use of pesticides in the VLI cropping systems did not allow improving systematically the environmental pillar since other indicators counterbalanced the results. Finally, these evaluations were a part of an iterative design process and have been integrated through the redesign of the prototypes in 2014.

4 Conclusions

The cropping system prototypes demonstrate that some innovative practices (e.g. use of cover crops, legumes introduction in intercropping) allow reducing the reliance to the use of inputs such as nitrogen fertilizers and pesticides while satisfying economic performances. The break crop positive effect of grain legumes was also pointed out as ever demonstrated by Kirkegaard *et al.* (2008). Nevertheless, some innovative based on intercropping are still limited by technical difficulties (e.g. crop establishment, harvest, grain sorting) and lack of economic performance. Further monitoring of prototypes should allow quantifying better their long term impacts on the different sustainability pillars.

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An example of agro-ecological transition on the Saint-Laurent de la Prée research farm: method and first results

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1 Introduction

Today, there is a general agreement on the need to find a compromise between ensuring agricultural productivity and preserving environment and biodiversity in agro-ecosystems. Combined with financial difficulties that some farmers face due to increasing costs of production, this calls for the development of more sustainable and self-sufficient farming systems. In that aim, the French government has recently launched "The agro-ecological Project for France" to support farmers in their willing to change their agricultural practices (Belna, 2014). This also challenges researchers to work on transitions towards new farming systems (Duru *et al.*, 2014). System-experiments based on a systemic and multi-disciplinary approach at the farm scale are increasingly used to build such systems. Such an experiment, called *Transi'marsh*, is currently set up on the St-Laurent de la Prée research farm located in the marshes of Rochefort-sur-mer (French Atlantic coast). Its aim is to implement an agro-ecological transition on a mixed-crop livestock farming system, and to investigate the sustainability performances of the farm by quantifying its key environmental, technico-economic and social characteristics. We focus here on the methodology and the first encouraging results.

2 Materials and Method

The total area for the experiment covers 160 ha (90 % located in marshes) involving 45 ha of non-irrigated arable land and 115 ha of main fodder area, with 103 ha of permanent grasslands used for cutting and/or grazing. These grasslands are grazed from April to October by a herd of about 50 cows of a local breed, i.e. the Maraîchine breed, and the replacement heifers (a total of ≈ 130 animals). The farm is devoted to meat production, i.e. 6-8-months-old calves, milk calves (4-5 months), finished 3 year-old beefs and cull cows. One part of this production is sold by a direct-to-consumer marketing strategy on the farm. The cultivated crops are aimed in priority at feeding the animals and producing straw which is used for animal housing during winter (the surplus of crops is sold to cooperatives).

The methodology used consists of a gradual changing in agricultural practices and/or landscape management, such as the farming system is progressively turned out into another one. The improvements are brought progressively to the already existing system (in 2009, at the launch of the project). The process starts with a diagnosis, i.e. an evaluation of the farming system performances. On the basis of this diagnosis, an action plan is thus prepared which outlines ideas of what needs to be done. The plan is put into practice and data are collected. The action plan is modified or revised each year in the light of new knowledge acquired from this experience, with a circular or iterative nature of the process. This leads to a process of refining, improving, and re-testing the system over years, i.e. a step-by-step method, so that a transition is taking place. Since 2009, the changes already brought to the system are i) creation of a network of 5 m width grassy field margins around crops (total length: 9 km), ii) promotion of agro-ecological practices in the cropping system (e.g. crop diversification, intercropping, mixed-species crops...), iii) stop spreading nitrogen fertilisation on grazed grasslands in order to favour legumes; test of a rotational grazing, iv) changes from the traditional spring calving to two calving seasons (fall and spring calving) to take advantage of more marketing opportunities throughout the year.

For building the diagnosis, a set of appropriate experimental variables (i.e. indicators) is monitored each year. Through this multi-criteria evaluation, the farm performances are compared to those of preceeding years and to local references of regional groups of conventional farms. From the first period of this project (2009-2013), we analysed:

i) whether biodiversity has changed on the farm, illustrated through the bird diversity and its temporal evolution. The point-count method is used to estimate bird densities on the farm and determine trends in their populations (Bibby *et al.,* 2000);

ii) the first steps towards a higher food self-sufficiency. Self-sufficiency indicators were calculated on a feed units (FU) basis (1 FU = the average energy produced by 1 kg of barley) as the ratio of FU supplies from on-farm produced feeds compared to the total FU consumed by the herd over a year (Benoit & Laignel, 2006).

3 Results and Discussion

Evolution of biodiversity on the farm - the example of birds The mean species richness (SR) of birds at the farm scale is 55-60 species (min: 41 species in 2012; max: 63 species in 2010). Analyses made on farmland bird species (e.g. skylark) showed that the bird community composition has remained rather stable, with respect to natural year-to year variations due to regional population dynamics. Bird data from the Observatory of Biodiversity of the Marais poitevin were used to calculate a bird biodiversity index (the mean SR of the 10% best point counts allowing the establishment of 4 levels of biodiversity): SR/point count on the farm is qualified as 'moderate' or 'good' depending on the year considered (Table 1).

Table 1. Bird biodiversity index (among 4 levels) on the experimental farm

		2010	2011	2012	2013
Mean SR (from the 10% of the best point counts)		28 species	28 species	29 species	28 species
Levels of bird biodiversity index	P: poor M: moderate G: good R: rich	0-9 species 10-17 species 18-26 species ≥ 27 species	0-8 species 9-17 species 18-25 species ≥ 26 species	0-9 species 10-17 species 18-26 species ≥ 27 species	0-8 species 9-17 species 18-25 species ≥ 26 species
Bird biodiversity index on the farm		**“M - G”**	**“M”**	**“M”**	**“G”**

The fact that bird biodiversity did not change over years was not surprising since birds are not only influenced by agricultural practices but also by the neighbouring landscape (e.g. diversity of crops, frequency of semi-natural habitats). Up to now, changes already brought to the agricultural system correspond to a “weak ecologisation” of agriculture (Duru *et al.*, 2014). The establishment of the bird biodiversity index is helpfull as results may be seen as an indication that there is scope for improvement in biodiversity on the farm. We identified practical ways to enhance this biodiversity (e.g. enhancing the lay-out of the ecological infrastructure by adding hedgerows and isolated trees).

First steps towards food self-sufficiency

In 5 years, the system achieved a higher food self-sufficiency in both home-grown forages and concentrate feeds, by mobilizing 3 levers of change: i) growing a greater diversity of crops, including cereals and legumes (e.g. lucerne) for feeding the animals, ii) maximization of the grazing period and changes in the rotational grazing, iii) investment in grain silos and a mill. In 2013, the global food self-sufficiency reached 95 % (Fig. 1). The concentrate self-sufficiency came from 0% in 2009, up to 15-20% in 2012 and 85-90% in 2013. The purchases of concentrates were divided by 6.

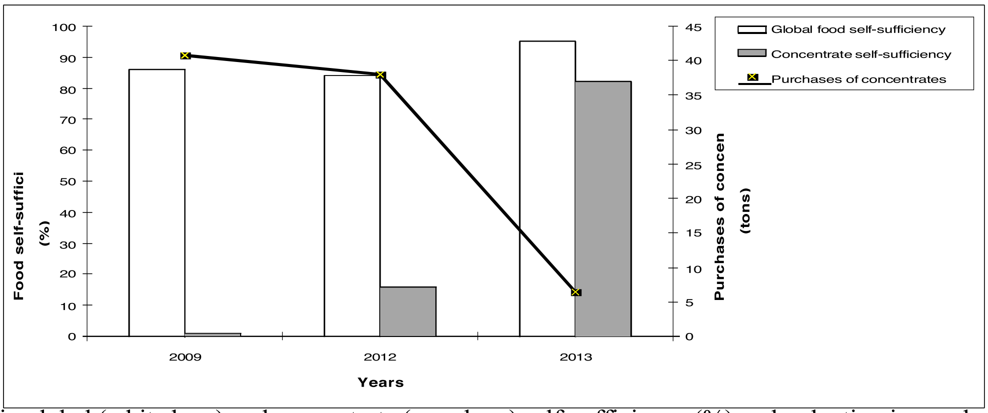

Fig. 1. Changes in global (white bars) and concentrate (grey bars) self-sufficiency (%) and reduction in purchases of concentrates (tons) over time (years 2010 et 2011 without data because of the consequences of a hurricane 'Xynthia' in 2010).

The farm achieved a higher food self-sufficiency by reinforcement of crop-livestock interfaces, e.g. an adapted crop rotation to feed the animals. These results need now to be related to zootechnical and economic performances to check whether, in that case, cost savings are the best way to preseve the farm income.

4 Conclusions

One of the applications of this project is to promote agro-ecological practices adapted to specific soil, water and climate related constraints in marshes, which could then be applied on commercial farms. These first 5 years are like a starting point of this long-term experiment experiencing an agro-ecological transition process. Further improvements of the system according to these first results are now needed. That is the aim of these 5 next years.

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Design and development of Integrated farming system module for various agro ecosystems of Hyderabad- Karnataka region

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1 Introduction

More than 70% of the Indian farming community own less than one hectare of land. They belong to the small and marginal category. These farmers feel that, except going for a single cropping system, there is hardly any possibility of trying new practices or methods for farm improvement. To address the felt needs of such small and marginal farmers, a farming system model has been developed. This low cost model integrates local farming practices. Farmers have to adapt to continuously changing conditions to produce food. 'Integrated farming systems design' is an approach that aims at modifying designs of farming systems to sustainably increase the overall productivity and profitability of the systems and hopefully, the welfare of individual farming families- while considering interactions in the system. The main objective this model is to develop, demonstrate and popularize integrated farming system model with farmers' participatory approach for irrigated and dry land ecosystems, to educate farmers' regarding integrated farming systems technology through training programs, field visits through exposure trips and field days and to create employment generation under different enterprises of integrated farming system.

2 Material and methods

Design of the model for irrigated eco system (1 ha), Main Agricultural Research Station, UAS, Raichur

A unique IFS design was developed and tested in 10 Agricultural research stations of UAS, Raichur, where in 1 ha module was divided into 5 segments of 2000m^2 each consisting of

I. Cropping activities

Paddy - 0.25 ha
Cotton - 0.25 ha
Brinjal -0.1 ha
Bhendi - 0.1 ha
Onion - 0.1 ha
Curry leaf - on bunds of fish pond Drumstick - on bunds of fish pond Banana - on bunds of fish pond
Fodder - 0.1 ha
Green manure - in the inter space of wide row crops

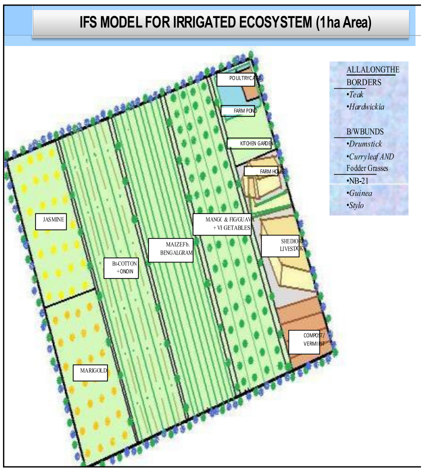
II. Dairy component

Dairy unit of 5 cross bred cows / buffaloes.

III. Fishery component - 0.06 ha

IV. Vermi compost unit - 0.04 ha

V. Tree farming - on farm boundaries



I-Segment	II-Segment	III-Segment	IV-Segment	V-Segment
Jasmine Marigold	Bt.Cotton + Onion	Maize – Chickpea	Mango and Fig, Guava – Vegetables Chilli Onion Carrot Clusterbean+Raddish Brinjal+Tomato Menthi+Corriander Raajgi Sabbasige Pundi Hunsikki Garlic	Fish Pond+ Poultry and Rabbit Cage+Cucumber Farm house Kitchen Garden Nutrition garden Farm pond Azolla unit Biogas plant Shed for livestock Biodigester Compost or vermi pit

3 Discussion

Results of four years of Integrated farming systems are discussed here the productivity of the farming system was based on the quantity of marketable produce obtained during all four years. IFS method records higher net returns and benefit cost ratio in all the four years because this method comprising the components like cropping, Vegetables, Vermi compost, Goat rearing, poultry and cattle (bullocks, cow, calves) rearing. At the end of fourth successive year Irrigated IFS contributed a net return was Rs.1, 70,563 and from cropping system alone Rs.55, 025. The average income Rs.1, 55,538 of additional profit can be earned. Similar results were also reported by Ugwumba *et al.* (2010) and Ortega *et al.* (2009) a). Higher net income generated during fourth year compared to first, second and Third year due to proper recycling of farm resources each other through use of vermin compost , FYM and also from yielding of horticulture components like drumstick, curry leaf, adoption of floriculture and good planning of vegetables according to good seasonal demand might be contributed to good returns. These results are in accordance with channabasavanna *et al.* (2009) were he stated IFS approach recorded 26.3 and 32.3 per cent higher productivity and profitability respectively over conventional rice- rice system. The results indicated IFS become more profitable during perennial years compared to single year.

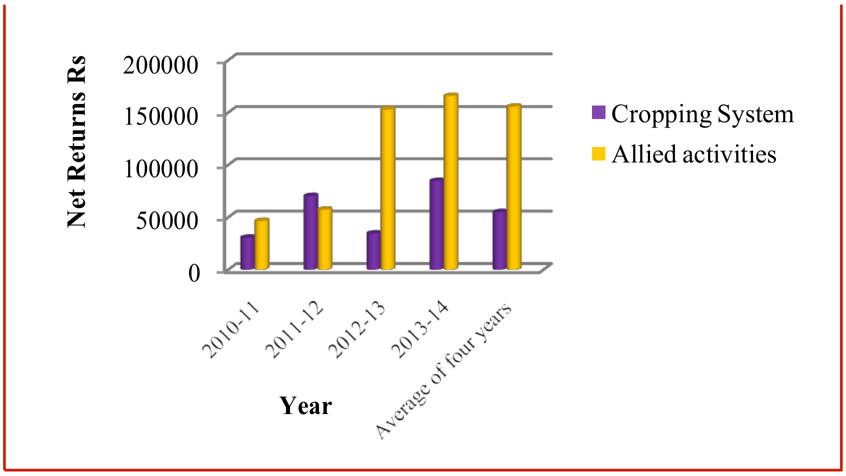


Fig. 1. Integrated farming system (Irrigated condition)

4 Conclusions

It is clear from the above results that IFS method for irrigated situations enhances productivity, profitability and nutritional security of the farmer and sustains soil productivity through recycling of organic sources of nutrients from the enterprises involved. The total average net income obtained from Irrigated IFS was Rs.1, 70,563 and from cropping system alone Rs.55, 025. The average income Rs.1, 55,538 of additional income can be earned. Cropping system+vegetable+Dairy+Vermi compost+ fodder on bunds will be good practice under irrigated condition in Hyderabad Karnataka region. This innovative 1 ha IFS Module designed by University of Agricultural Sciences Raichur, Karnataka, is being adopted by 465 farmers who are repeating the benefits in terms of income and employment generation.

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Decisional-model for analyzing and scaling out innovative cropping systems

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1 Introduction

Since the 1950s, the evolution of agriculture in France has led to quite homogeneous and simplified cropping systems (CS), with numerous negative environmental impacts. The transition towards higher sustainability needs a deep change, which can be enhanced by the identification of high performant systems, followed by the scaling out of part of them.
However, systemic change is difficult. It appears necessary to understand and describe the way these CS are decided, managed and implemented, through a bio-decisional model (Le Gal *et al*., 2009). In this aim, we proposed a four-step functional approach to analyze and to represent the decisional model of a CS. It is based on a conceptual framework where the main agroecosystem services are explained, and includes:(1) the identification of main services of the CS, (2) for each service, the precise targets defined and formulated by the crops' manager (functions), (3) the combination of techniques and decision rules that allow reaching these targets (solutions), and (4) the way the crops' manager monitors the results achieved and prepares his strategic choices.

2 Materials and Methods

Choosen out of more than fifty studies realized with the Joint technology network for 'innovative cropping systems' (ICS-JTN), this paper describes the decisional model of a CS experimented at the station of Kerguéhennec (Brittany region, France) managed by the Chambre d'Agriculture. One of its main functions is to have low nitrogen (N) losses, in order to contribute to water quality with low nitrate pollution (Step 1).
In order to precisely describe the decisional process, some members of the JTN realized a 2-hour interview of the crops' manager of the experimented CS. First questions were about the targets for the control of N losses, which were considered as a routine: what are the criteria you observe or measure on the field to assess that your CS is successful for this goal? What is your target value? (Step 2).
Then, the questions were about the solutions implemented. In order to express how the solutions are combined into the system (Step 3), the information were collected on a white board by a facilitator, and organized through two axes: the horizontal axis representing the time of the crop sequence, the vertical axis representing the different categories of solutions bringing decisive contribution to the target : crop sequence, detailed aspects of chemical N fertilization and organic fertilization management, tillage effect on mineralization efficiency, and N mineral uptake.
Lastly, the questions were about the results obtained last years in the experiment, and especially what were the deviations between obtained results and target values (Step 4). In this case, the conclusion was a collective reflexive activity, about how should be improved the CS in order to be more frequently successful for the analyzed function.

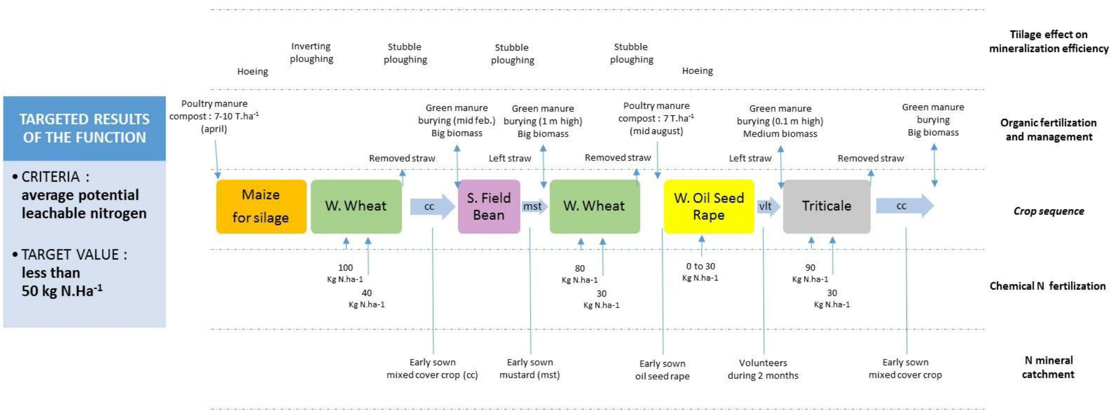

Fig. 1. Description of the decisional model of control of N losses into the experimental cropping system

3 Results – Discussion

The practical criteria used by the crops' manager of the experimented CS to assess year after year the risk of N losses, was the potential leachable nitrogen contained in the soil, which is measured in each plot during autumn. He was expecting an average value less than 50 kg N.ha^{-1}. He described a six-year crop sequence: 6 main crops (maize, winter wheat, spring field bean, winter wheat, winter oil seed rape, and triticale) plus 4 catch crops between the main crops (Fig. 1). While maize and oilseed rape were mainly fertilized with poultry manure compost, the field bean was not N fertilized, triticale and wheat received 110 to 140 kg N.ha^{-1}of mineral fertilizers. In order to catch nitrogen during summer and autumn, catch crops were generalized except after maize and before winter oilseed rape.

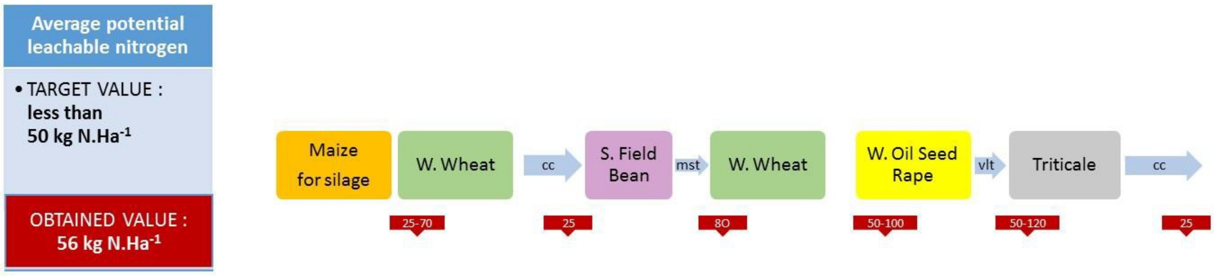

Fig. 2. Ex post assessment and success' analysis with the crops' manager of the experimented cropping system

The measurements of potential leachable nitrogen in the soil observed during the last years were low and below the target value during the first part of the CS sequence, thanks to pre-crop effect of maize and to the high efficiency of catch crop between a cereal and a spring crop (Fig. 2). But average potential leachable nitrogen was over the threshold (56 kg N.ha^{-1}), due to high mineral soil nitrogen after oilseed rape and field beans even with catch crop, and under oilseed rape after a summer organic fertilization.

Table. 1. Ideas and proposals to improve the cropping system in order to be successful with the N losses function

Technical categories	*After field bean*	*After oilseed rape*	*Between wheat & oilseed rape*	*Other*
rganic fertilization and management			Reducing N amount	Exportation of catch crops for fodder feed
Crop sequence	Changing the order of the crops : oilseed rape or maize after field bean			
Chemical fertilization		Reducing N amount		
N mineral catchment		Replacing volunteers with mustard catch crop	Improving emergence date of catch crops and winter crops for high N uptake	

4 Conclusions

The decisional model description explains the function and the solutions proposed for each service targeted from the CS. In the studies cases, it successfully allowed to better understand the combinations of techniques, defining the CS, implemented to reach the service, and gave useful information to agronomists and farmers for out scaling the successful parts of the CS (sequence triticale-maize-wheat in this case). The decisional model was also a useful boundary object to analyze the failure of the second part of the CS (sequence field bean-wheat-oilseed rape), to propose ideas to improve it (Tab. 1) thus contributing to *step by step* design (Meynard *et al*., 2012).
The ICS-JTN is now using the decisional model not only for the monitoring and analysis of the cropping system experiments, but also to accompany changes inside farms and to offer farmers strategic agronomical advices.

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Integrated effects of conservation agriculture in a crop-livestock system on western loess plateau, china

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1 Introduction

Conservation agriculture (CA) is now widely recognized as a viable option for practicing sustainable agriculture (Kassam *et al.* 2012). China is an ancient agricultural country, it has a long history of soil and water conservation practices. However, modern conservation agriculture is fairly new. The area under CA expanded rapidly from 45 million ha in 1999 to 111 million ha in 2009, with an growth rate of 6 million ha per annum (Kassam *et al.* 2009). Soil erosion on the Loess Plateau is the highest in China, and indeed among the highest in the world (Liu 1999). The semi-arid Loess Plateau is the most important region of rainfed agriculture in China. This paper discusses CA effects in a crop-livestock system on western loess plateau.

2 Materials and Methods

An experiment on different tillage systems was designed for a one-year one-crop rotation of spring wheat and field pea, and implemented from August 2001 in Dingxi, a typical semi-arid area on the Loess Plateau. The experimental design included six treatments, replicated four times, and included both phases of the wheat/pea rotation each year, the experiment was last from 2001 till this paper, it is still on going. The six treatments included traditional farmer practice (T, conventional tillage with crop residues removed) and a CA treatment (NTS, no tillage with crop residues retained). To separate the effects of tillage and crop residues, these factors were combined factorially as follows:

- T, traditional tillage with crop residues removed
- NT, no tillage with crop residues removed
- TS, traditional tillage with crop residues retained
- NTS, no tillage with crop residues retained

The design also incorporated plastic mulch with and without tillage. The main aim of this research was to develop suitable CA practices for the rainfed Loess Plateau.

APSIM was used to simulate crop residue retention practices on a daily time step, crop, forage and soil-related processes and the influence of climate and management activities on these processes using local climate and soil data (Keating *et al.*, 2003). APSIM has been previously developed and tested for the spring wheat-field pea rotation in Dingxi (Chen *et al.*, 2008). We set up different simulations where the amount of crop residue retained after harvest changed incrementally by 10% from 0% to 100%.

We calculated the net economic value of the spring wheat-field pea rotation when different amounts of crop residues were retained on a per hectare basis. We therefore calculated the NPV associated with retaining different amounts of crop residues using different planning horizons, i.e. 3, 6, 10 and 20 years.

3 Results - Discussion

The research found that NTS considerably increased surface soil (0–10 cm) moisture at sowing, However, the different tillage patterns had no strong effect on total soil water storage (0–200 cm)(Table 1). Although NTS had no strong effect on soil bulk density and total porosity, the non-capillary porosity and aggregates under NTS greatly improved. Thus, soil saturation conductivity and soil infiltration increased, whereas soil and water erosion decreased, soil loss (sediment load) from erosion decreased by 62.4% (Table 2). Grain yield was generally higher under NTS than under conventional tillage over 12 year (Table 3).

Table 1. Soil water at sowing under different tillage practices (V%)

Crop	Soil depth (cm)	2002		2003		2004	
		T	NTS	T	NTS	T	NTS
Wheat	0–5	10.2	19.5	7.0	12.4	15.7	20.2
	5–10	15.2	20.1	9.6	13.5	19.9	21.1
	10–30	20.1	21.5	15.3	16.2	19.9	20.2
Field pea	0–5	16.9	21.8	14.2	22.1	9.9	11.0
	5–10	23.3	24.3	17.1	21.3	18.4	19.4
	10–30	21.4	22.5	14.3	16.9	20.0	21.7

Table 2. Cumulated runoff, infiltration and sediment under different tillage systems ($P < 0.05$)

Treatment	Rainfall (mm)	Cumulated runoff (mm)	Cumulated infiltration	Sediment (g m^{-2})
T	85	53.10b	31.90b	27.77ab
NT	85	62.90a	22.10b	32.73a
TS	85	66.26a	18.74c	23.79b
NTS	85	44.85c	40.15a	14.89c

Table 3. Average grain yield of crops in 2002-2013 under different tillage systems (kg ha^{-1})

Rotations	T	NT	TS	NTS	TP	NTP
Pea→wheat	1415	1367	1521	1686	1583	1660
wheat→Pea	1422	1361	1531	1786	1715	1637

APSIM modeling results showed that crop residue retention increased grain production, reduced forage production leading to smaller livestock flock sizes and increased family heating and cooking costs. The net effect was that retaining minimal crop residues lead to the highest profits when there was a three year planning horizon and full crop residue retention provided the highest profit when the planning horizon exceeded 10 years. This is because the benefits on crop residue retnetion take time to be realised, but farmers discount the future. When the planning horizon was 3, 6, 10 and 20 years the average maximum NPV was achieved when 0%, 0%, 100% and 100% of crop residues were retained, respectively (Fig. 1). The average NPV for the different planning horizons was within 10% of the maximum average NPV for a wide range of crop residue retention practices (Fig. 1), indicating that crop residue retention has limited impact of economic outcomes, and adoption could be linked to other factors we have not directly observed. Our results were not very sensitive to changes in discount rates.

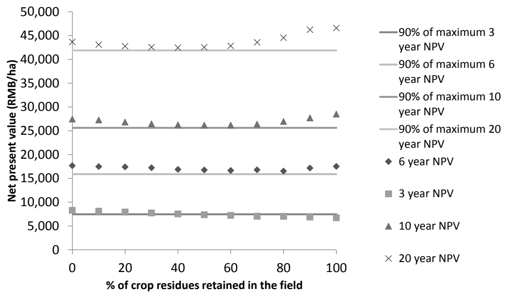

Fig. 1. Average net present value (NPV) of a spring wheat-field pea no-tillage rotation over different simulation periods with different crop residue retention rates and different planning horizons in Dingxi.

4 Conclusions

14-years field study on the rainfed Loess Plateau showed that no till with stubble retention could improve surface soil water availability at sowing, improve soil quality and infiltration, alleviate erosion, and increase grain yield. No-till with stubble retention is the most productive and sustainable practice for the research area. APSIM modeling research indicated that providing financial incentives to retain crop residues during the initial transition years could be a policy option.

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A procedure to analyze multiple Ecosystem Services in apple orchards

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1 Introduction

In order to meet market requirements, current fruit production has been strongly intensified, thus running fossil energy reserves dry in some cases. Arboriculture faces the double task of providing acceptable fruit production levels and preserving natural resources. This duality can be analyzed with the concept of ecosystem services (ES), from which humans draw potential benefits (MEA 2005). This concept has already been used in agroecosystems but very rarely in orchard systems. Yet the perennial nature of orchards, the quasi systematic presence of cover-crops, the possible carbon sequestration in trees and soil, and the permanent provisioning of habitat to natural predators for pest regulation are all characteristics which make them interesting for ES analysis. The interactions between the functions underlying the services are multiple, very complex and strongly influenced by agricultural practices and pedoclimatic conditions. This leads to tradeoffs and synergies amongst ES. The study of these relations is necessary to adjust agroecosystem management towards specific multiple ES profile goals. Hereafter, we present an approach to analyze ES relations within an apple orchard, using indicators of ecosystem functions underlying ES.

2 General approach of multiple ecosystem services analysis in the case of apple orchards

The ‘cascade’ concept of (Haines-Young and Potschin 2009) causally linking biophysical structures, functions, services and benefits has inspired our analysis. Following the CICES (Common International Classification of Ecosystem Services classification (Haines-Young and Potschin 2013) we distinguished different ES groups within the apple orchard agroecosystem: fruit production (provisioning service), pest and disease control, climate regulation, water regulation (regulation services), soil fertility maintenance (maintenance services). Each of these services groups can be determined by services or disservices and more upstream, by ecosystem functions. Ecosystem functions or processes transform physical, chemical and biological elements in the soil-plant-atmosphere continuum within specific time scales and are impacted by agricultural management and pedoclimatic conditions. These transformations are precisely the dynamics creating complex synergies and tradeoffs relationships between ES. The conceptual scheme of Fig. 1 shows how these elements match up within an apple orchard, in close connection with the nitrogen and carbon biogeochemical cycles, as well as the water cycle. Quantifying flows is necessary to understand the relationships between all these transformations and may be subsequently of interest for service indicators.

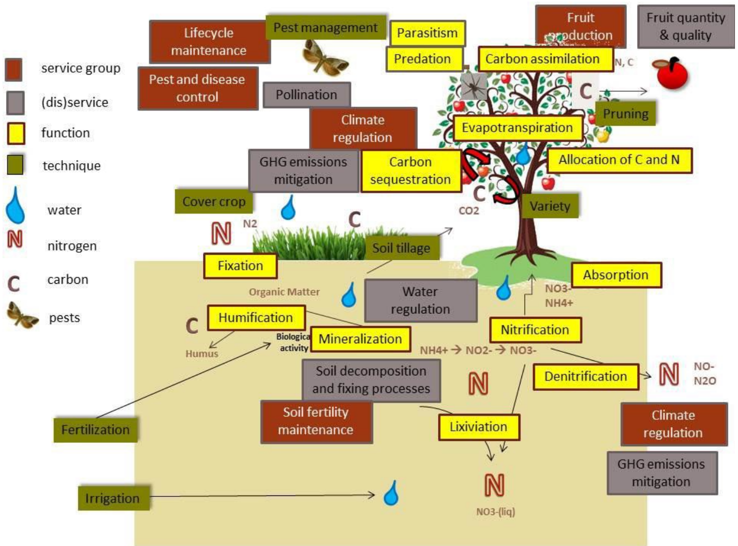

Fig. 1. Conceptual scheme of ecosystem functions and services within an apple orchard framework

In order to quantify a great deal of transformations within an apple orchard, two models were used: STICS (Brisson *et al.* 1998), a dynamic, generic and robust model, which aims at simulating the soil-crop-atmosphere system while considering the impact of agricultural practices and pedoclimatic conditions; IPSIM (Aubertot and Robin 2013), a qualitative aggregative modelling framework to predict crop injury profile as a function of cropping practices as well as the abiotic/biotic environment. STICS has been parametrized on apple tree using bibliography data and field collected data. We focused on specific output variables describing dynamically interest functions such as tree aboveground biomasses (fruit, leaves, stems), mineral and organic nitrogen in soil, net carbon sequestration in soil, greenhouse gases emissions or lixiviation. Some outputs can be appreciated as a function's state indicator (nitrate content at blooming), as a function's dynamic indicator (fruit biomass from blooming to harvest) or a service indicator (yield). Concerning the pest regulation service, a bibliographic review has been made in order to identify the key factors impacting the severity of crop injury by 3 major apple orchard pests (apple scab, rosy apple aphid and codling moth). Experts were then questioned on the same points in order to validate these factor impacts, which are mainly cultural practices, pedoclimatic conditions and landscape management. Model outputs are then to be selected as ecosystem service indicators in order to understand the impact of agricultural management on ES relations.

The third part of this approach deals with field data. We chose to work on two experimental apple orchard sites in south-eastern France, which are marked by different pedoclimatic conditions. Each one presents three different system managements ranging from conventional to organic management. Fruits, leaves and stem growth as well as their nitrogen and carbon content were regularly measured in order to assess specific parameters. Specific soil analyses were performed. Data on water content were registered by capacitive sensors or tensiometers. These field data are crucial to parametrize the STICS as well as IPSIM models and compare model outputs with field data. They can as well be used directly as functions or services indicators together with the model outputs.

3 Conclusion

Recent studies show increasing interest in agriculture seen through the concept of ES. This contributes to change agriculture-environment relations analysis, taking into consideration different stakeholders and most importantly linking natural resources management to agricultural management.

An apple orchard agroecosystem is necessarily impacted by its agricultural management and its pedoclimatic conditions. These impacts modify the agroecosystem resources by triggering different functions, thus creating synergies and trade-offs between ES. Modelling tools help consider the complex transformations and their interaction occurring in the agroecosystem and describe them with output variables, which can be used as ecosystem function or service indicators. Our approach enables to explicit the impact of some cultural practices linked to particular pedoclimatic conditions on the functions underlying the ES and, in this way, to analyze multiple ES relations. Working with models may also allow simulating fictive scenarios combining different agricultural practices and pedoclimatic conditions, thus searching for management options corresponding to various profiles of synergies and trade-offs between ES.

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Intercropping grains, oilseeds and row crops with forage species to enhance cropping system sustainability

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1 Introduction

Producers currently require low-cost and effective management tools to mitigate losses incurred due to agroclimatological and socioeconomic variability. Increased diversity has repeatedly been shown to improve functioning and resilience in agricultural, ecological and economic systems (Symstad *et al.*, 2003; Cardinale *et al.*, 2012; Isbell *et al.*, 2013). By increasing agricultural biodiversity through intercropping, production systems use nutrients more efficiently, soil erosion and water loss is reduced, there is improved biocontrol of pest species, soil organic matter increases, and there is an overall increase in the provision of agro ecosystem services. The practice of underseeding cereal crops with a subordinate forage species is common in Eastern Canada, and has repeatedly been shown to improve soil quality and increase yields of subsequent rotation crops (Carter *et al.*, 2009; Hauggaard-Nielsen *et al.*, 2012). Annual ryegrass intercropped in silage corn production can serve as a cover crop to reduce soil erosion (Malik *et al.*, 2000) and suppress winter annual weeds (Shrestha *et al.*, 2002). Intercropping with cover crops has been shown to increase biodiversity, reduce field runoff and increase soil nutrients for subsequent cash crops (Snapp *et al.*, 2005). There has also been report of biofumigatory and enhanced biocontrol effects of intercropping (Iverson *et al.*, 2014).

2 Materials and Methods

Intercropping soybean and canola with forage species: An experiment was conducted to measure the effects of underseeding (at the time of main crop planting) or overseeding (seeding into the main crop later in the season) forage species into either soybean or canola. Soybean production in Eastern Canada involves a late harvest leaving little time for seeding a winter cover crop. Therefore an intercropped forage species would serve to reduce soil erosion through the winter and help to build soil organic matter through time. Although the majority of canola varieties grown in Canada contain herbicide resistance traits, the potential to reduce the amount of chemical inputs to be replaced with inexpensive and sustainable option to improve soil, would be welcomed by producers. Both soybean (DH420, Sevita Int.) and canola (In Vigor L130, Bayer Crop Science Canada) were planted and underseeded with either cereal rye, red or white clover or an unseeded control. Overseeding was performed at soybean leaf drop using the same species. Additionally, all plots were split to receive either a herbicide application or an untreated water control. Both crop yield and biomass of the intercrop species were measured.
Intercropping potatoes with brown mustard: The larvae of click beetles (*Agroites sputator*), also known as wireworms, are becoming a major agricultural pest across the world. The long life cycle (five years for some species) combined with their wide host range and the lack of efficacious insecticides has made controlling this pest a challenge. Studies with brown mustard grown as rotation crop for two years showed a significant reduction in wireworm damage to the potato crop planted in the third year. A preliminary study was done in 2014 to determine the best time to seed brown mustard in a potato crop. Potato drills (6 x 4 m) were planted with var. Russet Burbank. Treatments consisted of planting an intercrop of brown mustard (var. Centennial) at one of five seeding dates, either 5, 6, 7, 9 or 12 weeks after the potatoes were planted. Treatments were designed to encompass the entire production cycle of the potato crop (pre-canopy, row closure and following desiccation). One week prior to the final seeding date (week 12), a desiccant was applied to the main crop to initiate senesence. Potato tubers were harvested and evaluated for yield and quality.
Intercropping corn with ryegrass: If harvested for grain, corn crops contribute to building soil organic matter levels if cut higher and a significant proportion of residue remains following harvest (Villamil *et al.*, 2015). However if corn is harvested for feed as silage, more of the aboveground biomass is removed which may lead to soil degradation through time. One proposed solution is to overseed common ryegrass into a standing corn crop at the time of fertilizer top-dressing. This concept was tested using on-farm trials in St. Foy Quebec whereby several varieties of ryegrass were evaluated (English, Italian and Westerwold). Ryegrass seed was mixed with topdress fertilizer for application.

3 Results-Discussion

Oilseed/forage: For crop yields, soybean did not respond well to underseeding. As the season progressed, particularly in the red clover plots, soybean plants were visibly overcome by the clover. In all cases, underseeding resulted in significantly lower yields in soybean. Overseeding soybean on the other hand, resulted in slightly higher yields than the control for red and white clover. For canola there were no significant differences between total yield for the control and either underseeded or overseeded red and white clover showing a potential for underseeding canola, despite the crop having traits for herbicide resistance. Cover crop biomass measurements were taken post-harvest from the underseeded treatments. Red clover yields were higher in sprayed intercropped treatments than in treatments that lacked herbicide application for both canola and soybean.
Potato/brown mustard: Although the brown mustard was established and started growing at all seeding dates, growth was slowed due to a lack of light and moisture for the first four seeding dates. Planting following the application of a desiccant (week twelve) resulted in better growth of mustard, however, as a long season variety was used in this trial, the mustard did not have sufficient time to grow before potato harvest. Therefore some of the beneficial effects of the mustard on wireworm control were not observed. There were no significant effects of the intercrop on the main crop quality or yield.
Corn/ryegrass: There were no significant effects of intercropped ryegrass on the overall yield of corn for either ryegrass variety or seeding date. However, there were clear trends showing certain varieties of ryegrass which performed better than others. Westerwold varieties actually produced seed heads during the planting year. Seeding later than the 11-leaf stage resulted in poor rygrass establishment due to shading, and it was determined that seeding at the time of topdressing (3-leaf stage), provided good establishment with no negative effects to the corn crop.

4 Conclusions

In all three experiments described above each one shows indications that intercropping may provide benefits to the cropping system as a whole. However in each case, more research is required to optimize seeding rates, seeding dates, and interactions between main crop and intercrop species. There is potential for the use of intercrop polycultures to mitigate some of the year-to-year variability. With each one of these systems, it is also necessary to develop a solid technology transfer protocol at the initiation of the research in order to facilitate the adoption of intercropping strategies on-farm.

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Origins of the performance gaps in innovative cropping systems under experimental assessment

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1 Introduction

According to the evolution of the economic context and new agricultural issues, innovative cropping systems (ICSs) that take into account current on-farm constraints need to be proposed. The objective of our project was to design, by prototyping (Vereijken, 1997; Reau & Doré, 2008), ICSs meeting different environmental and economic quantified objectives and to assess them in a long-term field experiment. Those ICSs were designed for winter wheat-based rotations in the Paris basin area, in France. The objective of this paper is to identify, after the first complete rotation, the reasons why some of the goals assigned to the ICSs were not reached, and why some environmental characteristics evolved differently than expected.

2 Materials and Methods

In 2008, four ICSs were designed by prototyping to satisfy various environmental constraints. Three out of the four systems had to meet simultaneously three quantitative objectives: (1) to satisfy a major environmental constraint, which represents a major break regarding objectives to be reached by current cropping systems (the banning of pesticide use (No-Pest), reducing fossil energy consumption by 50% (L-EN), or reducing C balance by 50% (L-GHG); (2) to satisfy a wide range of environmental criteria with specific quantitative targets; and (3) to produce the maximum possible yield given the constraint and the environmental targets. A fourth system (PHEP) was designed to reach environmental and production goals with no major constraints. Compared to conventional systems of cereal-based rotations, those ICSs differ largely on the crops of the rotation and on their crop management (including soil tillage, crop protection, fertilization, genotype choices, the use of cover crops, etc.). The crop management systems were defined as a set of decision rules (Debaeke *et al.*, 2006).
The designed candidate systems were assessed *ex ante* with different tools and models (Colnenne-David & Doré, 2014). The GES'TIM database (2010) and IPPC coefficient (2007) were used to calculate GHG emissions as well as energy consumption. The SIMEOS® tool (v. 2010), based on the AMG model (Andriulo *et al.*, 1999), and the Indigo® tool (Bockstaller *et al.*, 2008) were used to calculate respectively C sequestration and several agro-ecological indicators.
Since 2008, the most promising prototype systems have been *ex post* assessed in a long-term field trial, in farming conditions, located in Grignon, France (N 48.84, E 1°57) on 6.5 ha. Three replications of each system have been randomly distributed. Results are analyzed here over a complete crop rotation (*i.e.* five crops for the PHEP and the L-EN cropping systems, six crops for the L-GHG and the No-Pest systems). The environmental performances (*i.e.* energy consumption, GHG emissions, C sequestration and various environmental criteria) of the ICSs, based on real practices performed in this trial since 2008, were calculated with the tools and models used during the prototyping step (*i.e. ex ante* assessment). Crops were harvested at maturity with a farmer combine.

3 Results – Discussion

In the L-EN system, the energy constraint was nearly fulfilled, while in the L-GHG system the C balance constraint was not satisfied (Table 1).

Table 1. Results of total energy consumption (MJ $ha^{-1}year^{-1}$) and C balance (kg $CO_2eq.ha^{-1}year^{-1}$) calculated over a complete rotation for the ICSs

	energy consumption (MJ $ha^{-1}year^{-1}$)		C Balance ($kgCO2eq.ha^{-1}year^{-1}$)	Carbon sequestration ($kgCO2eq.ha^{-1}year^{-1}$)	GHG emissions ($kgCO2eq.ha^{-1}year^{-1}$)
L-EN	5 201 (+/-502)	L-GHG	1 202 (+/-86)	-149 (+/-117)	1 052 (+/-183)
PHEP	7 755 (+/-711)	PHEP	1 188 (+/-270	-117 (+/-150)	1071 (+/-145)
L-EN-PHEP) PHEP	-33%	HG-PHEP) PHEP	+1%	+27%	-2%

As the energy and the C balance constraints are expressed in reference to the PHEP system, the performance of this system plays an important role in the assessment results. In the PHEP system plots, low N fertilization, due to high organic matter content in the soil of the experimental field, allowed high performance of this PHEP system, which contributed to explain why the energy and the C balance constraints were not totally met in the L-EN and the L-GHG systems respectively. All the ICSs satisfy environmental criteria in terms of crop biodiversity, NH_3 and N_2O pollutions, pesticide use and energy consumption. Over the 2009-2014 period, yields nearly reached the goals for all these ICSs. However, there are variations depending on (i) the crops: whatever the cropping system, cereal (except maize), oilseed rape and hemp crop yields were systematically higher than expected, faba bean and flax yields were regularly lower, (ii) the pest pressure: in the No-Pest system, a sharp decrease (-90%) of faba bean yield in 2011 was due to black aphid attacks, and (iii) time: in the L-GHG system, yields were as high as expected during the four first years of the rotation and lower than expected during the two last years of the rotation.
In order to explain why some objectives assigned to the ICSs were not satisfied and some unexpected evolutions of the environment observed in several plots, main agronomical practices were analyzed and ranked in four groups: (1) some agronomical strategies may not be suitable to reach the goals, (2) some practices could not satisfy simultaneously a multiplicity of objectives, (3) some planned practices may not be appropriate in the context of the field-trial conditions, and (4) an unpredicted evolution of the agrosystem, following agronomical practices proposed, occurred. In table 2, one example, collected from the field trial, is presented from each of these four groups.

Table 2. Classification of the agronomical practices and examples collected in the ICSs.

Classification	Examples collected in the ICSs
Some agronomical strategies may not be suitable to reach the goals.	In the L-GHG ICS, forbidden ploughing did not allow to increase C sequestration as expected. After the first rotation, evolution of C sequestration was -149kgCO_2 ha^{-1}year^{-1} instead of +87kgCO_2 ha^{-1}year^{-1} expected during the *ex ante* assessment step.
Some practices could not satisfy simultaneously a multiplicity of objectives.	In the No-Pest ICS, it did not appear possible to satisfy both the constraint (*i.e.* no pesticide use) and the environmental criteria regarding soil organic matter. Within this system, the restitution of small amounts of organic matter, due to low yields achieved in no pesticide use conditions, combined with regular ploughings, necessary to manage weed populations, had an adverse effect on C sequestration. After the first rotation, evolution of C sequestration were -560kgCO_2 ha^{-1}year^{-1} and -117kgCO_2 ha^{-1}year^{-1} respectively in the No-Pest and the PHEP ICSs, the last ICS being considered as a reference in the long-term field trial.
Some planned practices may not be appropriate in the context of the field-trial conditions.	In the L-GHG ICS, in order to produce high amount of aerial biomass, cover crops were sown just after harvest in summer. Over the period 2009-2014, according to very dry conditions in summer in Grignon, cover crops did not grow three years out of six.
An unpredicted evolution of the agrosystem, following practices proposed, occurred.	In no till conditions, *i.e.* the L-EN and the L-GHG ICSs, higher weeds development than expected were observed and led to mow two plots of oilseed rape in 2014.

All agronomical practices need to be analyzed similarly in order to reinforce the relevance of this classification and to validate it. Moreover, a complementary investigation should be implemented in the same way with decision rules defining the crop management, in order to help to design an evolution of the innovative cropping systems.

4 Conclusions

The results gathered during the first complete rotation highlighted gaps between measurements and goals and a first classification of the agronomical practices allowed to identify the major sources of disparities. These knowledge could be used both to re-design the ICSs which do not satisfy their objectives, over a second prototyping design loop, or to design innovative systems defined with other goals to reach. However, a more complete agronomic diagnostic will be necessary to identify and to rank all the causes which explain discrepancies between measurements and objectives in order to reinforce the classification of agronomical practices in these four different groups. Moreover, these "cropping system" experiments should contribute to the learning in terms of design processes and cropping system management.

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Design, experimentation and assessment of four protected vegetable cropping systems adapted to different food systems

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1 Introduction

The objective of the French program Ecophyto is to reduce the farming dependency on pesticides without affecting their economic performances. This is a great challenge in vegetable production given that (i) it concerns a wide range of crop species, pests and pathogens, (ii) biotic and abiotic components evolve quickly, especially under greenhouse conditions, (iii) as vegetables are commercialized as fresh products, failure to control pests and pathogens has a direct impact on producers' incomes. Integrated pest management (IPM) strategies are largely dependent on production objectives and resources available on farm (Navarrete *et al.*, 2014). Here we report the design, experiment and assessment of four cropping systems prototypes suited to different food systems in the French Mediterranean basin.

2 Materials and Methods

We followed a step-by-step design and assessment framework involving four iterative main steps. Iterations aim at accumulating learning and enable continual improvements of the cropping systems (Meynard *et al*., 2012).
Step 1: Diagnosis. We analyzed how differences between food systems affect farm and field management based on the overall characteristics of the national and regional productive contexts. Following this diagnosis, four productive contexts are step-by-step specified as general frameworks to guide the design process.
Step 2: Design. For each productive context, and particularly for the management of both air- and soil-borne pests and pathogens, main agroecological and management processes were targeted at the short and/or longer term. These processes are thought to affect different levels of the multi-trophic chain at the scale of the greenhouse and its immediate surroundings (Messelink *et al.*, 2014). We then identified IPM tools that can involve the cropping sequences and/or IPM decision rules at crop scale, to stimulate or, at the least, not disturb the targeted processes. These tools were used to design a global strategy, *i.e.* the way practices are used, combined and adapted for each of the four contexts.
Steps 3 and 4: Experimentation and assessment. An on-station system experiment (Debaeke *et al*., 2009) of the prototypes started in April 2013 in the Roussillon region (South of France). Experimental features (e.g. field size) were chosen to be close to those used in commercial farms; for example crops are implemented under 400m² unheated greenhouses (silt sandy soil). IPM implementation was supported by weekly qualitative inspections of the crops. Specific quantitative and localized measures were used to describe the evolution of pests, pathogens and beneficial organisms (released or native). Cropping systems were assessed and, when possible, compared to improve the prototypes at every step of the process.

3 Results and Discussion

Diagnosis: differences between food systems affect farm and field management
We identified that long or short commercialization supply chains (LSC or SSC) and organic or conventional farming (OF or CF) certification schemes highly influenced crop management strategies. LSC systems strictly comply with marketing standards: specific categories depending on fruit size and homogeneity, superficial defects and firmness. In contrast, SSC systems accept some superficial defects and give priority to organoleptic quality (mainly resulting from cultivar choice and harvesting ripeness). SSC systems tend to produce relative small quantities of a wide range of products, which encourage the simplification of crop management strategies (time schedule optimization and input reduction). SSC systems also tend to use land more intensively than LSC systems. LSC usually relies on crop specialization which means for example, in our region that lettuce has a major place in the cropping sequence.
Cropping systems design: examples of main targeted agroecological processes and link with IPM strategies
Each prototype was designed to target a specific certification scheme and supply chain. The strategy for the LSC-CF system relies on introducing crop diversity in summer and on regular soil solarization to prevent soil-borne issues. Aerial pests are mainly managed at the crop cycle time scale with short-term effects tools such as biocontrol (e.g. releases of biological control agents). To prevent damage and losses, biocides may be used giving priority to products with the least toxicity on beneficials. In LSC-OF, in addition to regular soil solarization, the cropping sequence involves more botanical diversity in summer and winter to prevent soil-borne diseases. When relevant, crop schedule and harvest date are adapted to reduce damage and income losses. Biocontrol is the main tool used for summer aerial pest

management in LSC-OF, with priority being given to preventive practices, for example to guarantee an early migration and installation of predators or parasitoids into the greenhouse. SSC-OF and SSC-CF strategies rely on cumulative processes and mid-term effects for air- and soil-borne pests and pathogens since they involve natural regulation process and a less intensive management (labour and inputs dedicated to the crops). In SSC systems, the soil is never solarized: soil-borne pathogens are managed through a higher diversity of cultivars and species along the cropping sequence combined with accurate practices for the enhancement of the soil microbial activity. Intercropping is tested to reduce the impacts and damages on plants from soil-borne and aerial pests and pathogens. These systems also enhance migration of indigenous beneficial insects with a relevant management of the surroundings, through implementation and management of semi-natural habitats. Biocides can be sprayed to regulate an explosive situation (chemicals if needed as a last resort only in SSC-CF) using the IPM decision rules.

Two examples of IPM strategies implemented in 2014: LSC-OF and SSC-CF cucumber crop

A long, smooth type cultivar of cucumber was planted in the LSC-OF system in late April. In contrast, a short, thorny cultivar of cucumber was planted in late March in intercropping with sweet pepper and French bean in the SSC-CF system. According to the target and the practice, IPM interventions were implemented systematically or based on weekly inspections and decision rules. For example, in LSC-OF, if whiteflies infestation was poorly controlled by macro-organisms, *Verticillium lecanii* (Z.) could be sprayed to prevent sooty mould damage. Regarding the agroecosystem state (see the biotic pressure in Figure 1) and the practices actually implemented, some pre-defined decision rules were modified on the way. In the LSC-OF system, macro-organisms were released four times to prevent the development of the main pests (whiteflies, thrips and phytophagous mites). Localized spraying of sulfur was done twice to deal with disease development and one microorganism (*Verticillium lecanii*-m) was used.

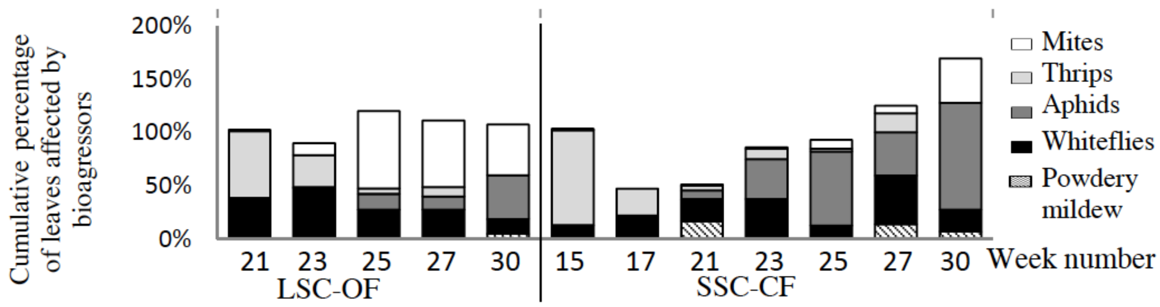

Fig. 1. Evolution of the biotic pressure on cucumber crops in the LSF-OF and SSC-CF systems.

Total and commercial LSC-OF yields were of 32.7 and 23.2 fruit m^{-2} respectively (three harvests per week over 10 weeks). The non-commercial part resulted from biotic damages, abiotic stresses (weak nutritional status) and commercial factors (fruit size). In SSC-CF system, contrary to what was expected (Ratnadass *et al*., 2012), beneficials colonized the crop lately. Therefore, to avoid major income losses due to a general strong pest's infestation, macro-organisms had to be released several times (6). Diseases were controlled with localized applications of sulfur and a general chemical fungicide. Total and commercial yields were of 68.3 and 67 fruit m^{-2} respectively (three harvests per week over 13 weeks). The SSC-CF short, thorny type of cucumber, chosen to satisfy consumer demands, fulfilled the requirements with a long harvest period, a low non-commercial part and a satisfaying total productivity.

4 Conclusions

During the first 18 months of this experiment, global strategies were implemented and assessed particularly according to the agroecological processes targeted. We identified that in addition to decision-making issues, more knowledge production ways should be explored (see Cardona *et al*., 2015) to be able to actually implement the ecological pathways for reducing the impacts of pests via the plants diversity. Future research will focus particularly on cumulative processes and assessment on a long-term scale. Assessment of prototypes will involve particular discussions with producers, technicians and scientists within a participatory research program.

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Farming systems design to facilitate transition toward low input agriculture

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1 Introduction

Can the design of innovative farming systems facilitate transition of rural territory to more sustainable agriculture? We question the relevance of design to support and facilitate the transition towards more self-sufficient and more environmental friendly farming systems. That question is asked to two experiment in the Northern East of France: the first experiment is dedicated to step by step design of autonomous mixed crop dairy systems (self-sufficient, and converted to organic farming) in the Lorraine region; the second experiment is dedicated to the design of organic vineyards in the Alsace Region. Staudenmaier (1985) distinguishes three types of design according to their distance to the uses that are made it in the current world: the invention refers to the creative act and the creation of something that did not exist before; Innovation refers to the processes of acquisition and diffusion of novelty; project management refers to an organizational process of design. Farming System Design is mainly focused on invention of technical or organizational alternatives for the future. The invention of such alternatives relegates innovation to questions of social acceptability of innovation taking the risk of inadequation according to users' current needs and desires (see for example Temple *et al.,* 2011). The two experiments presented in this paper postulate that adhesion to the real work of farmers is necessary to think farming system design as a source of innovation in agricultural areas.

2 Materials and Methods

Step by step design of autonomous mixed crop-dairy farming systems (organic) takes place in the INRA experimental station of ASTER-Mirecourt since 2004. Two agricultural systems are designed from the natural properties of the land without using chemical or organic input (Coquil *et al.*, 2009; Coquil *et al.*, 2014b). Former experience of the staff was built according to conventional farming in mixed crop dairy systems. Design of vineyards takes place in two vineyards owned by private wineries: both farms are converted to organic farming since middle nineties' and to biodynamic since 2008 and 2009 respectively. Experimental vineyards were designed according to winegrowers' goals: the first one wished to reduce its fungicide treatments and especially reducing the amount of copper/ha/year by adding mixed essential oils of citrus fruits. The second winegrower wanted a solution to combine improvement of vineyards vigor, management of weeds and providing an unfavorable environment for fungal diseases extension, by changing the field soil cover management. Design of vineyards used designing methods presented in Metral *et al.*, (2012) and in Thiollet-Scholtus *et al.* (2013).

3 Results - Discussion

Design of autonomous and organic mixed crop dairy systems is done step by step in ASTER-Mirecourt. Scientists of the experimental station initiated this design. This design forced all experimenters to deeply transform their work in terms of practices but also in terms of values. Thus, step-by-step design was managed as a corporate project to facilitate efficient experience of the experimenters working in a new framework of activity: farmers standards and values to which they refer are not the same in 2014 compared to the pre-transition period. The resources mobilized by the experimenters to develop efficient practices are the object of discussions with farmers interested in that kind of transition towards more sustainable dairy systems (Coquil *et al.*, 2014a). These exchanges allow moving towards more efficient and autonomous systems, so that farmers are able to make their own path and develop, in turn, experience. Prior to these exchanges, we demonstrate the technical, environmental and economic efficiency of the designed dairy systems so that farmers can give them credit. From this evidence, nearly 800 visitors (mainly farmers and advisors) a year visit the experimental station of ASTER-Mirecourt.
The question of assessing the technical suitability of designed alternatives is also a prerequisite for winegrowers interested in implementing low input practices on their vineyard. The originality of this device lies on the fact that winegrowers goals have been traduced and set in an experimentation on their own vineyards with scientists and technical staff from INRA in 2013. Winegrowers are responsible of the project management. Scientists and technical staff from INRA make available technical and human resources to equip this design and to assess reliably and accurate biotech, environmental and socio-economic results of designed vineyard systems since 2014.

The main difference between the two approaches returns us to innovation: the design experiment in private vineyards assures the strong adherence of the 2 concerned winegrowers to experimental design of the systems and to the assessment of the systems. But diffusion of results of these experiments is strongly influenced by the socio-professional networks of these two winegrowers. Step-by-step design of mixed crop dairy systems in an INRA station does not *a priori* ensure the production of knowledge in adherence with the concerns of farmers. The new mixed crop-dairy systems ensure the production of knowledge in adherence with experimenters needs and concerns. However, exchanges with farmers are built according to resources used by experimenters to develop efficient way of working in designed systems. Thus, knowledge is contextualized in experimenters' daily work. In this step-by-step design, farmers interested in designed systems, come to visit the INRA experimental farm: the INRA appurtenance might be an advantage, as it is seen by farmers, as a guarantee in terms of assessment, and it makes access easier for farmers from different backgrounds as INRA station is less marked by farmers standards, values and political position than a private farm.

4 Conclusions

Design of farming systems might have a large contribution to transition of rural territories to sustainable agriculture: knowledge must be produced in adherence with farmers' concerns and goals. The design methodologies and design locations can be different, but it seems necessary, however, to consider socio-professional networks of farmers and managers of experimental stations to facilitate the innovation process.

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System approach farming reduces the carbon footprint of crop production

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1 Introduction

Conventional farming systems heavily rely on various inputs such as fuel, inorganic fertilizers, pesticides, labor and equipment to increase productivity. This approach, albeit effective in meeting the primary goals, often ignores its effect on environmental sustainability and long-term systems viability. It is unclear whether an integrated system approach can be developed for farming that is to increase crop productivity while at the same time, reducing negative environmental impacts and enhancing systems sustainability. In a 25-yr (1985-2009) field study, we evaluated the outcomes of using integrated systems approaches in farming and quantified the impacts of system approach farming on agricultural productivity and environmental footprints.

2 Materials and Methods

The study was carried out at the Semiarid Prairie Agricultural Research Center of Agriculture and Agri-Food Canada, Swift Current (50°17‟N, 107°48‟W), Saskatchewan. The following four key farming practices were identified and integrated together to form a "**Suite**" of farming strategies: (i) use of grain legumes to fix atmospheric N_2 into plant-available N and to replace a portion of inorganic N fertilizer; (ii) use of annual soil tests to determine soil nutrients that are available for crops, (iii) adequately applying fertilizers to meet the plants‟ requirements and avoid over- or under-fertilization; and (iv) adoption of more intensified crop rotation systems to sequester more CO_2 from the atmosphere to offset carbon emissions associated with crop inputs. This "**Suite**" was performed on four commonly-adopted cropping systems, namely (a) fallow-flax (*Linumusitatissimum*)-wheat (abbreviation, FFlxW), (b) fallow-wheat-wheat (FWW), (c) continuous wheat (ContW), and (d) lentil (*Lens culinaris*)-wheat (LentW). During the 25-yr period, crop biomass, yield, various inputs (fertilizers, pesticides, labor, energy, fuel, etc), and carbon emissions associated with the inputs and from the soils were determined each year in each plot. Crop productivity and climate consequences associated with the adoption of the "**Suite**" were determined.

3 Results–Discussion

The 25 years were categorized into dry, normal, and wet years based on water availability (Table 1). Using the integrated „Suite‟ of farming practices, the four cropping systems all resulted in negative (desirable) carbon footprints, averaging -223 kg CO_2 eq per tonne of grain in dry years, -176 in normal years, and -129 in wet years. These negative carbon footprint values indicated that for each tonne of wheat grain produced a **net** amount of 27 to 377 kg of CO_2 equivalents was captured from the atmosphere. Among the four systems evaluated, the LentW rotation was most favorable with the most negative carbon footprint at -377 kg CO_2 eq per tonne of grain.

Soil organic carbon (SOC) in those systems increased gradually over years, with the greatest increase occurring between 1993 and 1999 (Figure 1). The LentW system gained an average 1039 kg CO_2 eq ha^{-1} through soil carbon sequestration annually, which was 26% more than the gain for ContW, 56% more than for FWW, and 62% more than for FFlxW. In the legume-cereal system, lentil plants fixed N_2 from the atmosphere (data not presented here) and the increased N availability enhanced plant biomass accumulation, leading to more carbon sequestered into soils.

In the Lentil-wheat system, the wheat produced a similar amount of grain as wheat in the continuous wheat system, averaging 1860±150 kg ha^{-1} yr^{-1}, but the former did so with 29% less N fertilizer supplied because of the lentil fixing atmospheric N through symbiosis. Consequently, fertilizer N use efficiency for wheat in the LentW system averaged 80% greater than for ContW in dry years, 97% greater in normal years, and 36% greater in wet years.

Legume-rhizobial associations are well known to be an effective solar-driven N_2-fixing system in which atmospheric N_2 is transformed into ammonia to provide a large portion of the N requirements for plant growth (Jensen *et al.* 2012). A portion of the fixed-N remains in the crop roots, nodules, and in the soil rhizo deposits contributing to the N pools in the soil and benefiting subsequent crops (Gan *et al.* 2014). It is clear that the use of grain legumes to replace the summer fallow phase of the rotation is one of the key components of integrated systems for obtaining a reduced or even negative carbon footprint in crop production.

In each year, fertilizers were applied to the crops based on annual soil test; this ensured the best estimate between N supplies and N requirements by crop plants. Consequently, N surplus (defined as N input minus total N uptake by crop plants, with the assumption of soil N state remaining unchanged in a given crop season) was near zero in most years. In the study period, wheat crops received an annual N fertilizer rate between 3.7 and 69 kg N ha^{-1}; this was based on soil test recommendations each year. Our sensitivity tests revealed the N_2O emissions were 116 kg CO_2 eq. $ha^{-1}$with N fertilizer application based on annual soil tests, whereas the N_2O emission value was increased to 158 kg CO_2 eq. ha^{-1} if a blanket rate of N fertilizer had been, otherwise, used without soil tests. The former approach reduced N_2O emissions by 27% annually compared to the latter. As a result, the soil-testing approach lowered the annual carbon footprint of wheat by an average of 7%. These results clearly indicate (i) the benefits of soil testing for crop fertilization over a blanket rate of fertilization, and (ii) the benefits of using legume-cereal rotation over wheat monoculture systems, in reducing carbon emissions and lowering carbon footprints.

Table 1. Carbon footprint of various cropping systems in dry, normal, and wet growing seasons.

Cropping system	Carbon footprint			
	Dry	Normal	Wet	Mean
	-------------------------- kg CO_2eqt^{-1} of grain---------------------------			
FFlxW	-3	-49	-5	-27
FWW	-168	-166	-109	-164
ContW	-148	-167	-154	-151
LentW	-570	-322	-249	-377
Mean	-223	-176	-129	-146
LSD(0.05)	256	48	59	79
P-value	0.02	< 0.01	< 0.01	< 0.01

Annual precipitation was 105-210, 211-340, and 341-421 mm, in dry, normal, and wet years, respectively. The four systems are (1) fallow-flax (*Linumusitatissimum*)-wheat (FFlxW), (2) fallow-wheat-wheat (FWW), (3) continuous wheat (ContW), and (4) lentil (*Lens culinaris*Medikus)-wheat (LentW).

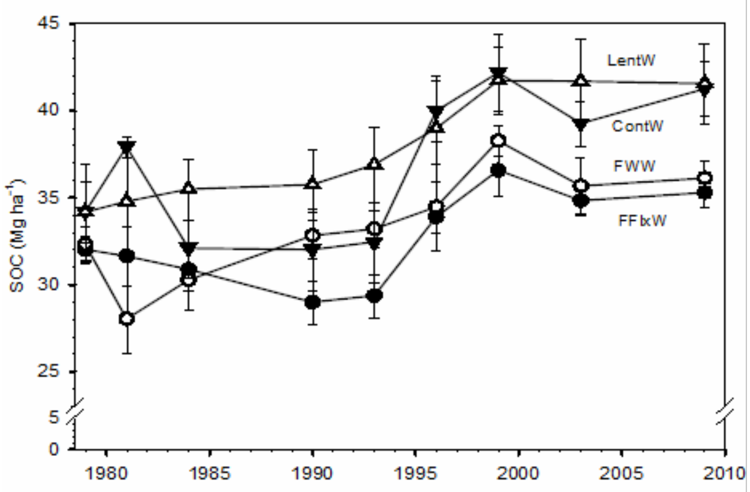

Fig. 1. Changes of soil organic carbon (SOC) during the 1979-2009 period in different cropping systems. The line bars are the standard error of the means.

4 Conclusions

Some key individual farming practices can be identified, selected, and integrated together to form a "Suite" of farming strategies. This "Suite" can allow the increase of crop productivity, while at the same time, substantially reducing the carbon footprints of crop production. With well-designed system approaches, field crops can actually convert more CO_2 from the atmosphere than is actually emitted during its production.

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Open-up the (co)design process of farming systems: a reflexive analysis.

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1 Introduction

Participatory research methods are increasingly used in the agricultural research for several years all over the world. In this perspective, participative methodologies are developed to design and assess innovative farming systems (Cerf *et al.*, 2012). However, as there is a lack of scientific debate about the design methodologies and a lack of consideration of end-users in the agronomic research (Prost *et al.,* 2012); the objectives of these participatory methodologies are not always extremely clear, such as their conditions of implementation (Neuberg, 2000). What is the interest of using participatory methods for designing farming systems? What is expected by the agronomists? What challenges are they facing during the implementation of this participatory design process? What could be the place of a social scientist in this process, how does he take part in the action? How do interactions between agronomists and social scientists feed the evolution of a participatory research program?
To address these questions we developed a reflexive analysis of a research program using participatory methods, involving both social scientists and agronomists, as it has already been done (Eshuis & Stuiver, 2005; Lyon *et al.*, 2010). This communication will show why and how agronomists working on a system experiment on station chose to formally involve technicians, farmers, specialized scientists and extension agents in their design process, how the interactions between social scientists and agronomists fed the evolution of the participative research program and finally to explain why involving all these people doesn't necessary mean that this is a "co-design" process.

2 Materials and Methods

The 4SYSLEG project aims at producing scientific and operational knowledge on pesticide-free practices in protected vegetable crops. To reach this objective and make sure that this knowledge would be shared and used (by producers, scientists), we developed a pluri-disciplinary and reflexive approach, involving social scientists and agronomists to guide the participative design method developed in the 4SYSLEG project. Agronomists developed a step by step participative design methodology (Meynard *et al.*, 2012) to produce and assess innovative prototypes of cropping systems. The participative program can be declined in three main points: (i) Producers or experts (scientists, extension agents) are punctually contacted at different stages of the project. These exchanges contribute to clarify the set of goals and constraints built for each cropping system experimented (first step of an iterative design process; Debaeke *et al.*, 2009), and to collect knowledge to understand biological processes or manage the crops experimented. (ii) Design workshops are implemented one day every semester gathering researchers, technicians, farmers and extension agents to explore in collective hitherto unseen way to design innovative practices, cropping systems and management strategies (e.g. intercropping systems). (iii) Tracking of on-farm innovations developed by producers consists in looking out for innovations designed by farmers and analyzing them to acquire empirical references useful to guide the design process. The prototypes are then experimented on station during the design process and combine practices to reduce pesticides use while maintaining socio-economical performances expected in different sets of productive contexts.
In the same time, social scientists realized interviews with technicians and researchers (15) of the experimental station where takes place the 4SYSLEG project. The interviews aimed at analyzing the context of development of the participative approach and focused on the transformation of the experimental activities, the research themes and the nature of partnerships within the experimental station. A social scientist also made observations of the participative design process and frequently asked agronomists to explicit their choices to maintain the reflexive dynamic. On the basis of these interviews, observations and regular interactions, social scientists are both observers and actors of the participative process. They contribute to formalize the participative method and its evolution through "live feedback" or retrospective analysis which help to integrate social dimensions in the management of the design process.

3 Results – Discussion

This reflexive approach explains the questions who led agronomists to use a participative design approach and the challenges they faced. The two main questions leading them to get involved in a participative approach are: How to design and assess innovative systems responding the challenge of pesticide use reduction at the cropping system scale while considering productive constraints? How to design innovative systems facing the lack of scientific kowledge on market gardening systems? This is to adress these questions that agronomists developed a step by step design methodology, based on the capitalization of learnings to make evolve the prototypes experimented. As this method

maintain open the realm of the possible in terms of design choices, it allows identifying and integrating, in the project, step by step, new research questions and knowledge (coming from the experiment or from partners).
This is also to guide this process that they organized recurrent workshops to gather a fixed collective of stakeholders having experiences and knowledge complementary to the project's carriers. Working with this collective allowed the agronomists to go over "concepts", to face it to "farmer's realities" (normative recommendations, logistic or economic constraints on farm, technical uncertainty). It invited agronomists to consider in the design multiple dimensions of farming systems and allowed producing prototypes of systems more innovative and operational. During these workshops, prototypes and results of the experiment are discussed within the group, which allows bringing scientific results closer to the "practice" and identifying new gaps in scientific knowledge. To fill these gaps (also identified through the experiment) on specific practices or combination of practices (decisional or biological process), agronomists collaborate with specialized scientists, extension agents but also with farmers, knowing to develop innovations on their farms (Goulet *et al.,* 2008).
However, while implementing this participative design process, agronomists faced two new challenges. The first was to develop design methods hinging on participative research and system experiment and to qualify the kind of knowledge produced by these design methods. Social science can contribute saying that the extension agents and farmers provide "experiential knowledge" about the coordination of different "socio-technical growth factors" within specific localities especially useful for systemic approach (Stuiver *et al*., 2004). This "experiential knowledge" is mixed with scientific knowledge. After that, agronomists deal with on-station experimental advantages (e.g. taking risks is more possible than in on-farm experiments) and constraints (e.g. dealing with the overall activities to coordinate in the station). The designed systems are then experimented on station and discussed within the group of participants. Even if the agronomists finally stay the only decision-makers and monitors of the experimentation, we can consider this experience as a step towards "experiential science" (Baars, 2011).
The second challenge was to build and maintain a participative program where scientific and nonscientific interests meet. In this case, as social scientists and agronomists regularly exchanged, the participative design process is the result of a combination between agronomists' needs (e.g. knowledge on intercropping systems) and sociological hypothesis and analysis (e.g. about the interactions between the various actors and about the science-society relationship). These exchanges help the scientists to be more comfortable with the fact that the design process is a dynamic learning process requiring modifications as work progresses and different participants learn or change their expectations – as it is often the case during participatory programs (Cardoso *et al*., 2001). In our case, the design process has been constructed and evolved following the nonlinear "design-experiment-assessment process" where the system experiment appeared to be an interesting "intermediary object" to build and maintain interactions with partners, as it provides results and offers a concrete way to valorize the knowledge exchanged.

4 Conclusions

This reflexive analysis of a co-design process, explains how working with partners allowed the agronomists to bring their work closer to farmer's realities while capitalizing scientific and operational knowledge to design and manage the innovative cropping system experimented. It also shows how interactions between agronomists and social scientists generated a dynamic learning process which contributed to the evolution of the program. This interdisciplinary analysis finally outlines the characteristics of a non-linear and dynamic participative design method opening the door to an "experiential science", which could be the future of the knowledge production on research experimental station.

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Design of innovative orchards: proposal of an adapted conceptual framework

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1 Introduction

System experiments are a developing approach to address complex questions such as the design and management of sustainable cropping systems. If the general framework of system experiments is well documented and adapted to iteratively design annual cropping systems (Debaeke *et al*., 2009), specificities of other crops are not always considered with possible limits at using the approach. As perennial and multi-layer systems that produce fresh fruit, orchards are complex agroecosystems that require specific design and management over space and time. The present work analyzed two contrasted system experiments aiming at decreasing pesticide use in temperate (apple) and Mediterranean/tropical (citrus) fruit productions. Our aim was to examine similarities and differences, and to propose a conceptual framework for designing innovative orchards.

2 Materials and methods

A crossed analysis was used to identify general aims, methodology used to design, type of levers combined to decrease pesticide use and related processes, and nature of outputs of the two studied system experiments (Table 1, Fig. 1).

Table 1. Main outlines of the two studied experiment systems.

	Apple (Simon *et al*., 2011)	**Citrus** (Le Bellec *et al*., 2012)
Research program	BioREco	ECOFRUT followed by Agrum'Aide
Location	South-East France	Reunion Island (France)
Orchard type	System experiment	Growers'orchard network
Study period	2005-2015	2010-2018
General aim / target pests	Pesticide use decrease / insects, diseases, weeds	Pesticide use decrease / insects and weeds
Methodology to design orchards	Mix of prototyping & step by step approach based on scientific knowledge and experience	ıtory approach involving growers, advisors, scientists; Step by step approach
Main levers used to decrease pesticide use (see also Fig. 1)	Low-susceptibility cultivar & combining of several methods	Weeds management with or without introduction of cover crop
Main processes at stake and practices to control pests	Bottom-up and top-down processes & direct measures	Bottom-up and top-down processes & direct measures
Main outputs	Important pesticide decrease(45-60%) when all levers are combined& information of damage risk available	Important pesticide decrease (50 % and more) when the growers are implicated as co-designers of the cropping system http://cosaq.cirad.fr/projets/agrum-aide

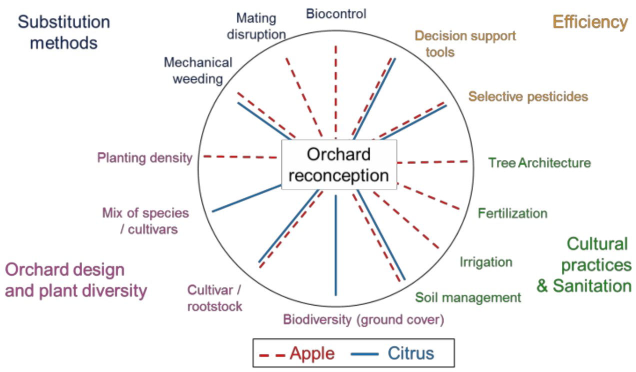

Fig. 1. Main levers combined to (re-)design apple and citrus orchard systems to manage orchard pests. Levers refer to broad non-exclusive groups of levers according to their nature and/or mode of action; Orchard reconception combines all types of levers.

3 Results – Discussion: Spatial and temporal design of innovative orchards towards more sustainability

This cross-analysis outlined (Table 2) three main aspects:
-The young unproductive stage of the orchard that can last for 2 to 5 years according to fruit species and cultivar requires careful management as the development and yield of the adult tree is building up during this stage.
-The permanency of the crop constrains the management of soil fertility: some practices are no more possible (e.g. legume crops in the rotation), fertilizing and ground cover management differentiate between tree rows and alleys.
-The longevity of the crop constrains decision making: a pest can be damageable in the present but also in the following seasons as many serious pests can complete their lifecycle in the orchard and build up important populations or inoculum across years. This is especially true in tropical areas where there is no dormant season. Conversely, the permanency of the orchard habitats facilitates the planting or sowing of plant assemblages (e.g., ground covers, lining hedgerows) to enhance conservation biocontrol and/or compete weeds, provided non-disruptive practices are applied.

Table 2. Specificities of the design and management of orchard systems compared to rotational systems.

	Rotational cropping systems	Orchard systems
Cropping system design	One-layer annual crops, no woody crop	Tree rows;arboreal and herbaceous layers; conservative design, i.e.treedensity, cultivar
Cropping system lifetime	Seasonal crops in the rotation with some exceptions (e.g. alfalfa)	Pluriannual young stage constrains the orchard potential yield
Fertilization and soil management	Whole-field fertilizer supply	Alley/tree row differentiation for fertilization; no tillage/ploughing in the alley
Soil cover and crop management	Successive crops	Permanent ground cover in the alleys and sometimes in the tree row; permanent trees with complex architecture
Weed management	Long-term decisional management	Long-term decisional management
Pest and disease management	Pest/disease lifecycle broken by crop sequences	Possible increase in population/inoculum across years; pest damage can affect yield in the following years (e.g. aphids affect growth)
Natural enemies management	Scarce permanent resources and habitat unless semi-natural habitats are present	Management of within-, peri- and extra-orchard permanent resources and habitats

4Conclusions

Because of their longevity, orchards permit to foster both bottom-up and top-down processes in the food chain. Therefore, they offer opportunities to redesign the cropping system within space and time (Fig. 2), and to enhance ecosystem services such as pest and weed control through the management of cultivated and companion plants (Thies *et al.*, 2003; Tscharntke *et al.*, 2007). In such perennial cropping systems requiring intensive and long-term management, interactions among the orchard life stages, spatial and functional dimensions and practices need to be explicitly considered to optimize the efficiency of the system as a whole. Such complexity in the re-design requires knowledge from many stakeholders in the food system (growers, advisors, scientists…). Co-design also requires more and renewed interactions among these stakeholders with the aim of building capacity in participatory approach appropriation, and for growers in the design of their own orchard and decisional system (Le Bellec *et al.*, 2012; Lauri, 2014).

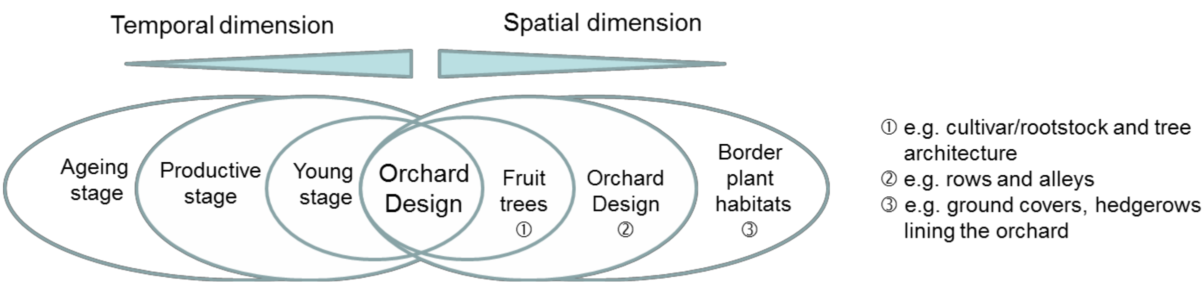

Fig. 2. General framework: main dimensions to consider when designing orchard systems.

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W4. Farms in transition to organic agriculture or agroecology

Chair: Jacques Wery, Montpellier SupAgro

Farmer's proximity to organic farming in two French cashcrop regions: focus on technical practices,commercial strategies and professional networks

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1 Introduction

In developed countries and particularly in France, organic farming (OF) currently enjoys unprecedented support from consumers and from national and, in many cases, regional public agencies that wish to develop OF, especially for environmental reasons. Over the last few years there has been increasing concern about the transition towards and conversion to OF (Lamine & Bellon, 2009). Depending on the case, this transition is said to be progressive, rapid or abrupt, compared to a given conventional system. Different types of proximity to OF thus exist between farms. Our aim was to characterize the processes of transition by analyzing the extent of changes between conventional and organic systems, with a focus on technical practices, commercial strategies and professional networks.

2 Materials and Methods

Regarding the general research question, we assumed that the proximity to OF is developing variously on farms. Technical proximity to OF was evaluated by means of a scoring system with principle-based indicators on the cropping system (Petit & Aubry, 2014). The scoring system enabled us to obtain a final score out of 20, which could be divided into cropping plan / crop sequence sub-scores and crop management sequences sub-scores. This matrix was designed to assess the gap between practices in conventional farming and those in organic farming. The lower the score, the more the technical system presents a configuration close to those typical of OF. Following the scoring process, a typology of technical proximity to OF was produced. This typology was based on patterns of cropping systems and on sub-scores attributed for each farmer.

The analysis of commercial proximity to OF was based on four relevant criteria concerning the organizational dimension of markets for organic produce (presence of crops under quotas or contracts; opportunities for organic outlets; storage capacity on the farm; and commercialization in short supply chains) (Petit & Aubry, op cite).

The analysis of the professional network was based on four relevant criteria concerning opportunities for technical exchanges and the characterization of neighbors (direct or indirect access to organic farming advice; collective events such as training or tours of fields; presence of organic farmers in the neighborhood; contact with organic farmers as part of labor or equipment management).

The study was based on the empirical results of surveys on cash crop farmers in two French regions, Île-de-France and Lorraine. The analytical framework to evaluate technical proximity was initially developed in the context of the Île-de-France region and then applied in Lorraine. Interviews were held with 52 farmers in the two regions, between 2010 and 2012 in Île-de-France and in 2014 in Lorraine. The sample of farmers surveyed is described in Table 1 according to their position with regard to OF: conventional not considering conversion to OF, and conventional considering conversion to OF. The latter group refers to farmers who don't exclude a conversion to OF in the medium or long term and often get in touch with Chambers of Agriculture to ask questions about OF.

Table 1. The sample of farmers surveyed.

	Conventional not considering OF	Conventional considering OF	Total
Ile-de-France region	12	4	16
Lorraine region	21	15	36
Total	33	19	52

3 Discussion

Results of scores obtained by each farmer in the two regions are presented in the form of a scatter graph (Fig. 1). A majority of farmers have high cropping plan/crop sequence sub-scores and high crop management sub-scores. Regarding the breakdown of overall scores, we proposed four degrees of technical leaps to reach OF. The distribution of farmers across the four types of technical leaps is expressed in percentages for the two categories of farmers and the two regions (Fig. 2). The first key result is the absence of STL in the Île de France region compared to the Lorraine region. We then observed a higher proportion of farmers considering OF with MTL-CrP in the two regions. This means that interests for OF tend to lead farmers to rethink especially cropping plans and to apply structural changes. A more surprising result is the high proportion of farmers not considering OF farmers with a STL, in Lorraine. Forms of technical proximity can then occur independently of the interest for OF.

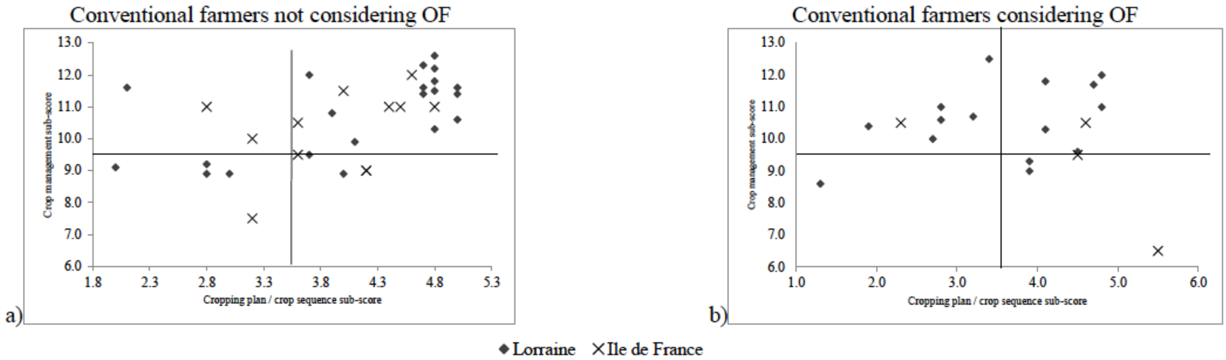
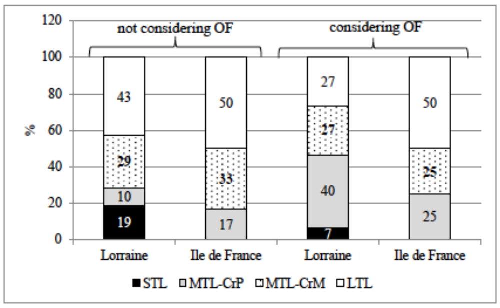


Fig. 1. Individual scores for farmers not considering OF (a) and considering OF (b).



STL: Small Technical Leap (low cropping plan score and low crop management sequences score)
MTL-CrP: Medium Technical Leap section cropping plan/crop sequence (low cropping plan score and high crop management sequences score)
MTL-CrM: Medium Technical Leap section crop management sequences (high cropping plan score and low crop management sequences score)
LTL: Large Technical Leap (high cropping plan score and high crop management sequences score)

Fig. 2. Typology of technical leaps and distribution of farmers, in percentageswithin the four types.

Along with the typology of technical leaps, we focused on professional networks (Lorraine region) and commercial strategies (Île de France region). Small, medium and large professional network and commercial leaps (respectively SPNL, MPNL, LPNL and SCL, MCL, LCL) were defined (Table 2).

Table 2. Cross-comparison of types of technical leaps and professional network and commercial leaps. For each case, results expressed in % of farmers not considering OF / % of farmers considering OF

	LORRAINE				ILE DE FRANCE		
	SPNL	MPNL	LPNL		SCL	MCL	LCL
STL	14/7	0/0	5/0		0/0	0/0	0/0
MTL	0/13	14/27	24/27		0/0	42/25	25/50
LTL	0/0	5/27	38/0		0/0	8/25	25/0

The first key result is that the combination of large technical, commercial and professional network leaps always steams from the fact of not considering OF farmers. Apart from those cases, we observed a gradient of scope of the leaps and consideration for OF. No clear correlation appears. This result can be interpreted as a disconnection between impediments, which are expressed by leaps, and motivations, which are expressed by consideration for OF.

4 Conclusions

Our results in two French regions, based on shared frameworks, reveal different patterns of proximity to OF. Regarding the transition to OF processes, discussion is underway about the necessity to remove the obstacles and simultaneously to enhance farmers' motivations. Part of the study was also dedicated to the analysis of motivations for and resistances to conversion to OF in our sample of conventional farmers and compared to a group of organic farmers in the same regions. Work is in progress on the comparison of types of leaps and types of motivation/impediment.

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Conversion towards organic farming leads to a complexification of the farming system management: application to vineyard systems

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1 Introduction

In the current context of climatic, socio-economic and environmental changes, farmers have to modify their farming systems to reduce environmental impacts while still assuring profitability at farm scale. Organic farming appeared to be an interesting production mode to face these changes. In few farms simple adjustments can be sufficient to operate conversion but in most of farms changes in the crop management sequence are not obvious and can lead to deep evolutions (Lamine & Bellon, 2009). Advisers worry about farm sustainability when converting to organic farming without enough preparation. A state of art of the scientific literature showed that not much attention has been given to the conversion period from conventional to organic farming.
Thus in this work, we analyse technical and organizational changes associated to the conversion and showed that conversion towards organic farming for vineyards systems often leads to a complexification of the cropping system management.

2 Materials and Methods

The work was carried out in Southern France in the Languedoc region. The Languedoc-Roussillon is the larger vineyard area in France. In 2010 it represented 30 % of the total French vineyard (Agreste, 2010). In 2011 (Agence Bio, 2011), 19 907 ha of organic vineyards corresponding to 1199 farms were inventoried in Languedoc-Roussillon. 57% of these 19 907 ha were still in conversion towards organic farming. 16 farms were interviewed from 2009 to 2012 the year before conversion towards organic farming and the first year labelled. The survey was conducted at the vineyard scale. The sample of farms interviewed was based on a 3-key classification of the farms on the study area (Merot *et al.*, 2008): we selected on four soil and landscape zones highly representative of the region. The type of commercialization was also taken into account (wine-growers in cooperative or individual cellars) and the vineyard area. We collected data on production factors, management practices and associated indicators. A characterization of the changes operated in relation to the organic label was performed.

3 Discussion

Results showed that the conversion towards organic farming resulted in an increase of the farming system complexity. Considering the whole set of farms interviewed, the frequency of changes varied largely from one agricultural practice to another but most of agricultural practices were finally impacted by the conversion. It was interesting also to remark the diversity of changes between farms. The intensity of changes was less important in some farms.
We noted that the number of operations was enlarged (+ 15 %). Most particularly soil management was intensified (+ 25% of traffic) and the phytosanitary traffic was higher (+ 14%). The changes observed concerned also the number of crop management sequences (for 8/16 farms – fig. 1).

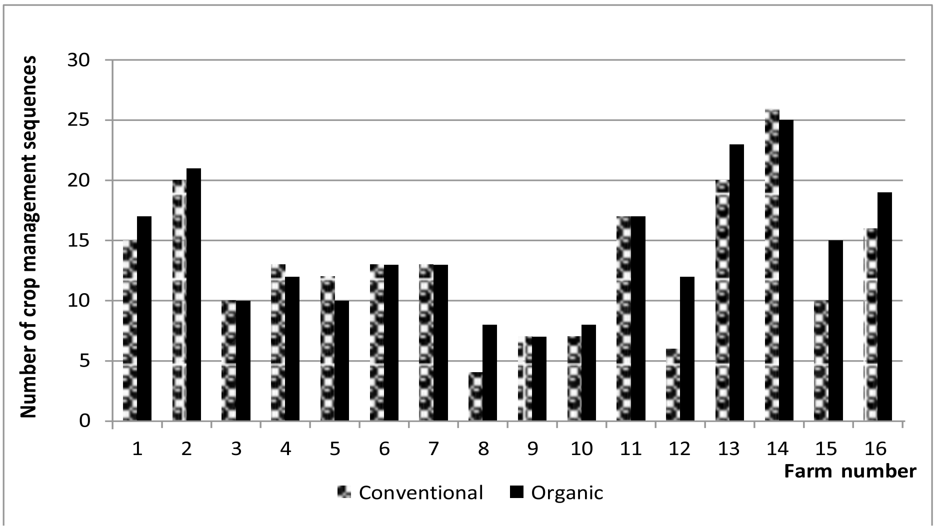

Fig. 1. Evolution of the number of crop management sequences before (conventional) and after conversion (organic) towards organic farming.

Whereas the number of fields in production stayed relatively stable in most of farms surveyed, the number of crop management sequences increased for 50% of vineyards studied.

The number of indicators used for technical decision making was also higher after the conversion towards organic farming (5.5 indicators in average in conventional farming and 6.7 in organic farming). These changes impacted directly production factors so as labor and equipment and the farming system organization leading to a complexification of this organization. To compensate this complexification, two strategies were identified depending on the type of commercialization. Wine growers in cooperative decided to maintain the vineyard area and increased labor whereas individual cellars tended to reduce the number of fields to limit the increase of crop management sequences and labor.

4 Conclusions

These results suggested that conversion towards organic farming implied more than a substitution of products: It was more a complete re-organization of the farming system management in most of farms surveyed. In fact, the label gives the list of pesticides not forbidden. But in reality, organic farming conversion is never an addition of substitutions. It could begin with addition of substitutions. But after one or two years, farmers have to face changes in organization and in labour so that they have to re-organize their vineyard system. Converting to organic farming lead to a complexification of the decision-making: field heterogeneity is taken more deeply into account and crop management sequences are more numerous. Behind this change, there is also an adaptation of the field indicators used for decision-making. Adapting indicators to analyse, manage and assess the conversion is therefore one essential issue for supporting conversions.

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A transdisciplinary approach to structure knowledge gathering on organic farming systems: evaluation of organic farm strategies in the case of Flanders

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1 Introduction

Decision making or adapting farm strategies to environmental and social demands on organic farms faces specific fundamental problems. First, gathering of farm specific data and knowledge is limited due to the small number of farms within each production type. Second, the diversity of organic farms causes difficulties in comparing these individual data. Moreover, as processes on organic farms are more complex and less controlled than on conventional ones, strategy design at farm level needs to account for this specificity and complexity. These problems call for new ways of structuring farming system knowledge for strategy design and strategic choices. Literature provides two key issues in overcoming these problems. First, a system approach delivers tools to understand the complex interactions within and between farming systems (Darnhofer *et al.*, 2012). Second, a transdisciplinary co-production of knowledge is recommended and includes societal actors in the knowledge co-production process (Aeberhard & Rist, 2009). Such an approach should be able to assemble the needed expert and tacit knowledge from different stakeholder groups (farmer, advisors, farm networks, research and educational institutions). As a result, this paper aims to contribute to the aforementioned shortcomings by describing a transdisciplinary and system approach to structure knowledge for strategic choices in organic farming.

2 Materials and Methods

We define the transdisciplinary co-production of knowledge as the collection and analysis of information on the organic farming system involving scientists, farmers, advisors, farm network representatives and educational institutions in all phases of the research process (De Ridder *et al.*, 2007) to set up a learning process that encourages implementation of the outcomes. During the transdisciplinary process, we searched for techniques that include system thinking and explored both quantitative and qualitative techniques because a mixed methods approach can provide strengths that offset the weaknesses of each type of research (Creswell& Clark, 2011). Using both numbers and words, combining inductive and deductive thinking, is highly suitable for solving complex problems. The combination of these techniques resulted in a framework (Fig. 1) that is able to structure knowledge gathering on organic farming leading towards a better understanding of the complex organic farming system.

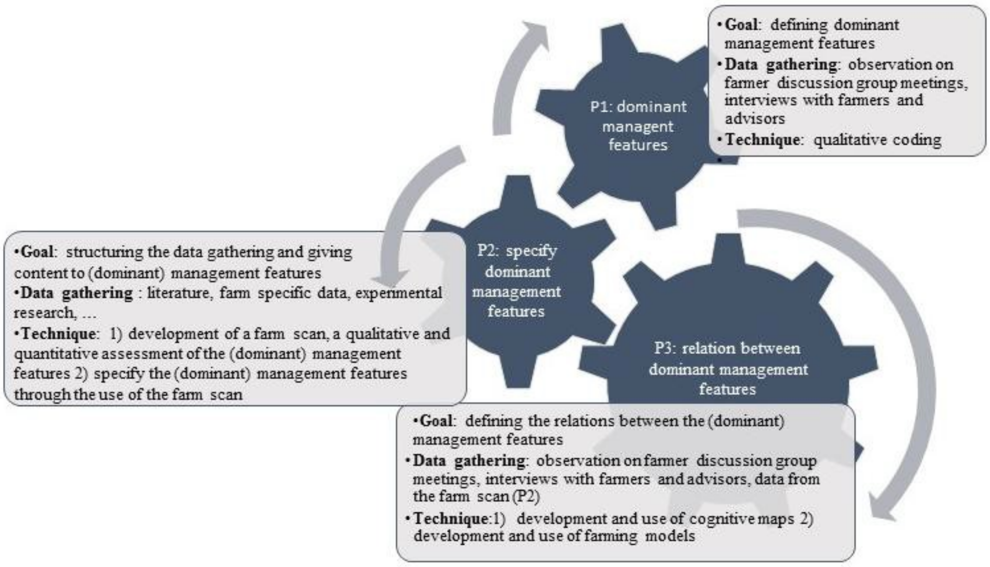

Fig. 1. Overall framework to structure knowledge gathering on organic farming systems.

Since each farming sector has its own context, problems and farming practices, we set up a different process for different sectors (suckler cow farms, dairy farms and arable farms). From the gradual nature of these implementation processes, we could develop an overall framework (Fig. 1) consisting of three main phases (P1-P3). Throughout a first phase (P1), dominant management features are captured during organic network meetings, through observations and participation in discussion groups with farmers making use of mainly qualitative techniques (coding of observations and interview notes). Second (P2), a farm scan is developed and used to structure quantitative and qualitative information on these main system features in a collaboration between advisors, experts and researchers (Bijttebier *et al.* 2015). In a third phase (P3), the focus is defining the relation between the (dominant) management features in which techniques as cognitive mapping and farm modelling are relevant.

3 Results –Discussion

The implementation of the framework for the three cases (suckler cow farms, dairy farms and arable farms) revealed important issues (Table 1) with respect to the effectiveness of the process, the gradual data gathering nature and convergent attention points. First, depending on the identity of the initiators, the initial questions from the stakeholders and the involvement of the farmers, the course of the process is very different. Within each sector, the phases were carried out not through a linear process and not even an iterative one. Instead, depending on the questions and needs of the farmer groups, the phases were succeeded organically. For example, in the case of dairy farms, we started with P2 as the question of production cost was urgent for the farmers at that time. Furthermore, the phases interact highly when additional knowledge is gained. In P3, cognitive maps reveal insights in the main elements of a system and the links and tradeoffs between them. This interacts highly with P1where dominant features were determined through observations and interviews. However, working within this framework structured all relevant information.

Table 1. Implementation for the farm sectors : suckler cow farms, dairy farms and arable farms.

	suckler cow farms	**dairy farms**	**arable farms**
initiators	farmers	advisors	advisors
initial question	data sharing with respect to technical and economic performance on the farms	calculation of cost for the production of 1 liter milk	quantifying indicators
short evaluation	good and efficient process, farmers put forward questions, deliver data easily and search for solutions	slow and less efficient process, farmer involvement is difficult, advisors are needed as moderator/mediator	
Time frame 1	P1: dominant features	P2: specify feature production cost	P1: dominant features
Time frame 2	P3: model development	P1 &3: relation between dominant data features through the use of a model	P2: specify features with scan
Time frame 3	P2: specify features with scan	P3: discussion on relationsbetween features	P3: cognitive mapping (advisors)
Time frame 4	P3: cognitive mapping (advisors&farmers)	P3: cognitive mapping (advisors&farmers)	P3: cognitive mapping (farmers)

Second, although the approach was set up separately for the three cases, outcomes converge to common key features of major importance. These vary from technical and biophysical characteristics such as optimizing crop rotation to characteristics related to sales and logistics. As such, insights in common attention points may incite cooperation and learning between these farming sectors and novel strategy search within the organic farm system. Furthermore, the transdisciplinary stakeholder group also suggest, based on the cognitive maps and the quantitative farm models to further model and simulate system changes when a new farm strategy is considered on the organic farm. This phase is not included in the framework yet, as we have no empirical evidence or experience for this possible phase so far.

4 Conclusions

Through a transdisciplinary research approach, we were able to develop a framework to structure knowledge gathering and sharing on organic farming systems. The implementation through three cases occurred organically and very diverse. However, the common framework provides a tool for advisors and researchers to guide the knowledge structuring, depending on the farmers' questions, within different sectors towards the same system approach. This approach can be used to structure and improve knowledge transfer during network meetings and finally to support farmers decision making when adapting their strategies to fast changing socio-ecological demands. This approach should make learning on common key features between sectors possible and even lead towards cooperation in the long term.

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Co-design of organic farming systems on the Canadian Prairies

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1 Introduction

Functional organic farming systems require diverse rotations and effective nutrient recycling, plus biological integrity for pest management. Current Canadian farming systems, on the other hand, employ simple rotations and rely on agrichemicals for nutrient and pest management. Therefore, transition from conventional to organic farming involves not only a transition to fewer agrichemicals, but farming system redesign. Most extension and outreach services available to farmers in Canada are aimed at individual components of specialized farming system, and are not serving farmers interested in farming system redesign.

Canada has invested in organic agriculture research for over 10 years, and research institutes have generated a wide range of information applicable to organic farmers. However, steps to place this new information into a whole farming system context have been lacking. The objective of this project is to link new academic research on organic farming methods with farmer practice in order to faciliate improved farm system design for organic production.

2 Materials and Methods

This project employes a co-operative innovation model aimed at linking academic research with farmer experience for new cropping system designs in organic agriculture. The model (Fig. 1) begins with a detailed farm scan by the Institute after initial contact between farmer and research team. Information in the scan includes land base, crop production, soil health, machinery inventory, labour resources, etc. This information is analyzed by the institute with a view to identifying gaps in farm integrity and resilience. Gap analysis results are then presented to the farmer, after which scenarios to overcome challenges are developed. The goal is to consider a number of different scenarios and discuss and rank their relative strenghts and weaknesses. Cooperative scenario development is conducted in two phases: Phase I involves „kitchen table" discussions between the research team and individual farmers or farm families. Phase II involves a group of farmers from the region sharing and critiquing each others' scenarios and learning how recent research results can assist them. The next phase involves planning and carrying out selected scenarios in on-farm trials. These trials are conducted by the farmer or together with the institution. Results from on-farm testing are shared between farmers and the institute after the growing season, and again among local farm groups. The entire process is design to be iterative and to work with individual farmers for a minimum of three years.

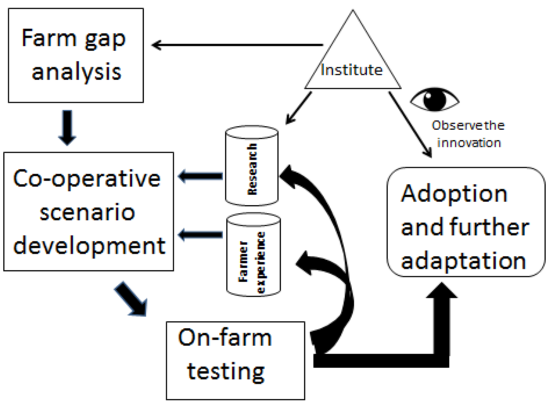

Fig. 1. Co-operative innovation model used by the Natural Systems Agriculture Lab at the University of Manitoba.

This model is being used in two projects: 1) Transition to organic soybean production (9 farms); and 2) Optimizing productivity of long-term organic farmers by improve nutrient cycling (12 farms). Farm visits were conducted between June and October, 2014. University staff spent half days getting a personal tour of the farm and a detailed inventory of farm resources. On-line information supplemented farm data, though in the nutrient optimization project, plant and soil samples were also collected for future nutrient analysis. All information is organized in a database. In the optimization project, we are exploring the use of different models (eg., Integrated farming systems model, APSIM, etc) to help better describe and understand macronutrient balance.

In the soybean project, a graduate student (M. Carkner) is evaluating 15 non-GMO soybean varieties in replicated tests on 5 of the case farms. Soybeans are relatively new to this production region and suitable varieties for organic production are limited. The on-farm soybean experiments allow direct input of local information into farmers' decision making. The varieties are grown under typical farm weeding vs hand weeded conditions thereby providing farmers with information on the relative weed competitiveness of different varieties.

3 Results – Discussion

Soybean project: Gap analysis was conducted in autumn, 2014 and researchers presented results along with some ideas for improvement to individual farmers in December, 2014. Major weaknesses were weed management, specifically lack of suitable equipment and lack of rotation diversity to ensure acceptable weed control. Co-operative scenario development started soon after the initial farm scan. A meeting was held in March, 2015 once each farmer had developed some options to overcome their constraints. At the meeting, each farmer presented their organic soybean production plan including prior crop in rotation, seeding details, tillage management, and specific weed control interventions. The graduate student presented variety test results. Several longer season varieties were damaged by frost in the study, something that farmers took careful note of. Farmers then worked in groups of 3 or 4, and together with a field researcher/facilitator, discussed new options based on responses to each others ideas and questions.

Farmers learned new things from each other – these were recorded. For example, experienced farmers stressed the role of perennial forages for Canada Thistle and wild oat control, while farmers with previous row crop experience explained equipment details. Farmers had heard of flaming for weed control but none had any direct experience. They expressed a strong interest in this practice, especially since several wet springs have made tillage less than effective in early season weed control. All farmers will grow organic soybeans in 2015 and some will transition additional land for future organic soybean production. All farmers are trying new techniques in 2015, based on what they learned in the program. Staff from the institution will visit the farms at least once during the season and be available for questions (phone/email). A follow up meeting will be held in November, 2015.

Organic optimization project: A main goal in this project is to construct whole farm nutrient budgets in order to identify nutrient limitations to organic farm productivity. This involves a simple mass balance; therefore grain samples from the 2014 crops are being tested for nutrient concentrations to determine removal. Assessment of soil nutrient stocks are being tested using a novel approach where aboveground biomass and nutrient concentration in the „soil- building" crop (typically an annual green manure or perennial forage) is tested in order to measure soil nutrient supplying power. This technique is deemed more suitable than standard soil testing as used in previous on-farm surveys (Entz et al. 2001). Early results from this test indicate that tissue phosphorous concentrations range from sufficient to seriously deficient. Gap analysis is currently underway for the optimization project and farm consultations are planned for May to July, 2015.

4 Conclusions

One early conclusion is that farmers are eager to be involved; they are learning a great deal; and they are starting to see possibilities for farming system redesign. Working with other farmers appears very important to participants, though they also appreciate the institute's involvement. Early indications are that farm system design changes for improved weed management in soybean are related to equipment resources, farmer experience, and crop rotation for control of perennial weeds. Farm system design changes for optimizing productivity of long-term organic systems, especially where soil phosphorous levels are low, regard livestock integration and changes to livestock management (eg., more grazing than haying, which removes more nutrients from land).

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Decision making processes and factors driving apple protection strategies at farm level

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1 Introduction

Apple growers apply numerous chemical treatments to protect fruits from both pests and diseases. Alternative methods exist but their efficiency on pest control can be limited, while public regulations, retailers, supermarkets and consumers are increasingly demanding regarding fruit sanitary quality, both on national and export markets (Simon et al., 2011; Drogué and DeMaria, 2012). Few pesticide residues, no symptom of diseases, standardized visual aspect and high nutrient quality are then included in contract specifications putting pressure on apple growers and their first buyers to fulfill all these requirements (Simon et al., 2010). In that context encouraging transitions towards sustainable practices requires understanding decision making processes and factors that drive growers' design and implementation of crop protection strategies at farm level, where trade-offs have to be made regarding allocation of resources between farm activities. This ongoing study is based on semi-qualitative surveys of 35 apple farms. It characterizes the diversity of their protection strategies, according to their natural environment, their own resources and their marketing strategy, and identifies the decision-making processes and factors that drive this diversity.

2 Materials and Methods

The study has been carried out in South-East and Center-West of France. Orchards of the South-East region are more susceptible to insects due to a hot and dry climate, while the wetter climate of the Center West region makes them more susceptible to fungal diseases. Interviewed growers were selected in order to have a diversified sample regarding their main market channel, i.e. Apple Grower Cooperatives (AGC) and self-sellers, their farm circumstances and their protection practices. One AGC per region was studied and 10 to 13 members were interviewed per AGC. Twelve self-seller growers were also met per area. AGC growers were selected based on the diversity of protection practices observed in the AGC database storing the crop protection treatments applied by all their members every year. Self-sellers were contacted based on local networks and selected for their diversity of both context and assumed practices. Individual semi-structured interviews were conducted to better understand growers' protection strategies and practices. Technicians supporting growers in their protection management were also interviewed in order to understand the way they provide advices and their relationship with growers. Protection practices were analyzed based on the whole annual set of treatment records per grower. Practices were differentiated according to the type of products used rather than the number of sprays, which is linked to the annual weather context. Six protection strategies were identified based on the following orchard management variables: selection of market segment, selection of planted varieties, selection of restricted pesticides, choice of alternative methods to pesticides, objectives of fruit quality.

3 Results

A set of common factors driving decision making processes: All the growers take their protection decisions according to a common framework including public regulations, private requirements, and climate. Public regulations define the authorized products, doses, mixes, pre-harvest intervals, maximum number of applications of a given product, and width of untreated areas. Every grower has to adapt his strategy to the public regulation rules and may be controlled in that respect by public officers. Private requirements imposed by buyers, especially supermarket chains and exporters, add specifications possibly stricter than public regulations, for instance regarding accepted number and quantities of pesticide residues. Requirements depend on the marketing channel or firm, but all the growers interviewed had contracted specific requirements with a given body such as AGC, organic certification agency or regional council (e.g. Sud Nature in Languedoc-Roussillon region). Daily climatic conditions also determine a set of decision rules such as disease control in relation with rainfall or treatment triggering in relation with wind speed.

But yet a diversity of protection practices in the same framework: Both AGC treatment databases and growers' interviews highlight the large diversity of practices encountered in a shared decision-making framework. A gradient arises from growers trying to avoid toxic pesticides and managing their orchard only with natural products to growers using only and frequently synthetic products. As a result application of pesticides varies largely in each treatment group (Table 1). This diversity within a same set of private specifications and climatic context is linked to each grower's own choices regarding the design and implementation of his protection strategy.

Table 1. Range of pesticide use according to the type of treatment in a given GO (# of copper/mancozeb-captan/sulphur based treatments over total # of fungicides, and # of bio-insecticides over total # of insecticides)

Treatment group	Treatment product	Range of treatment per farm (%)
Fungicide	Copper-based	0-44
	Sulphur-based	0-56
	Mancozeb/Captan-based	0-62
Insecticide	Bio-product	0-72

… Leading to six protection strategies: Six protection strategies were identified corresponding to specific combinations of five variables (Table 2). The growers adopting bio-ecologic (S1) and ecologic (S2) strategies aim to reduce chemicals use as much as possible in order to protect consumers and workers' health and the environment. In that respect they try to reach a balance between pests and natural enemies and to only use organic products and pesticide alternative methods such as releases of natural enemies and implementing bird nest boxes. Most of these practices are based on orchard observations. Since their apple yields are usually low (around 20t/ha), these growers target niche markets where apple is sold at higher prices than usual (1 to 2€/kg), such as short chain. They also valorize damaged apple as juice and they diversify their production with other crops to satisfy their customers. But since their incomes are not high enough to hire workers, they show a high workload seen as a major constraint for extending their activities. Compared to S2, S1 growers have self-imposed bans of authorized organic products that they think environmentally unsuitable because their formulation is based on toxic molecules for other insects. They experiment new protection practices such as biodynamic ones ahead of research institutes and are considered as information source.

The growers adopting the combined strategy (S3) aim to reach a trade-off between their income objective and their will to evolve towards sustainable practices. As such they try to achieve a high yield and commercial quality (premium fruits) to secure their income, by using both conventional and organic methods. They generalize alternative methods on their whole orchard, to jointly protect consumers, workers' health and environment. Most of these practices are based on orchard observations. All of them except one belong to AGC and their selling price is low, around 0.5€/kg with an average yield of 44t/ha. They work with several information sources and with AGC technicians.

The financial strategy (S4) is adopted by young producers or growers who have faced financial difficulties in the past few years. As AGC members they get low selling prices, 0.3€/kg. Thus they try to improve their financial situation by minimizing technical and economic risks, i.e. reaching high yields (e.g. 60-80t/ha for Golden) and high commercial fruit quality (premium category) while reducing production costs. As such they avoid using natural treatments like copper or bio-insecticides since they do not trust their pest control efficiency which could negatively impact their economic results. They are also careful with the number of sprays they apply in order to reduce costs. They are supported by AGC technicians to find trade-offs between their objectives of respectively high production and low protection costs.

The growers adopting the risk-limited strategy (S5) aim to maintain their good economic situation by reaching high yield and maximizing premium quality every year. They grow high valued cultivars like Pink Lady® and they combine apple production with other activities on the farm or outside the farm. The apple orchard is seen as a way to increase the farm profits independently of environmental impacts. They follow technician advice only (from AGC or agricultural chambers) in order to be sure to respect public regulation. As a consequence, their practices are influenced by technicians' advice. Their treatments are based on synthetic pesticides.

Compared to S5, the no-risk strategy (S6) regroups growers who aim not only to maintain but to maximize their profits by achieving the highest yields and quality. They are AGC growers with a strong link with their cooperative. Their focus is more on how to reduce production costs at a farm scale and maximize labor force and equipment efficiency, than changing their protection strategy.

Table 2. Characterization of the six protection strategies

	Growers (n)	% of surface with resistant cultivar	specific requirements contracted	Product self-restrictions	˥lternative methods to pesticides	ɜctives of fruit quality*
S1: bio-ecologic	4	>50%	100% Organic or Biodynamic	Yes	4	A+G+S
S2: biologic	2	>50%	100% Organic	No	4	A+G+S
S3: combined	10	5-50%	5-50% organic/BabyFood	Yes	At least 2	A+C+G+S
S4: financial	6	<25%	No	No	0-1	C
S5: risk-limited	10	0%	No	No	0-1	C
S6: no risk	3	0%	No	No	1-2	C

*A: Agronomic; C: Commercial; G: Gustative; S: Sanitary

4 Discussion and conclusion

Although growers located in a similar area and AGC face common buyer specifications and weather conditions they show a diversity of protection strategies depending on a range of management components: the farm financial situation, selling prices according to their marketing strategy, their technical environment and information sources, their specialization in apple production. Formalizing the farm set of structural and management characteristics that drive growers' decision making processes is still in progress. Growers' own knowledge and values may also play a part in the strategy implemented. For instance, agroecological methods require new technical skills and some ecological consciousness. This complex combination of factors finally makes each farm a specific case that should require targeted support in order to evolve towards more agroecological protection strategies and practices.

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Production2020: designing and assessing sustainable farming systems in Switzerland

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1 Introduction

With the introduction of integrated production, the proof of ecological performance (PEP) and the ethology programmes, developments in Swiss agriculture in the 1990's were well regarded, and were met with high credibility ratings by consumers. In terms of ecology and animal welfare, Swiss agriculture achieved an internationally leading position. Although the Swiss agricultural system has proven its worth in principle, however, in recent years it has also shown its limitations. A comprehensive analysis of farming systems in Switzerland showed that several benchmarks were not achieved. For instance, the nitrogen load is still too high and the quality of ecological compensation areas should be improved (Herzog *et al.*, 2008). Furthermore, in intensive production regions pesticide concentrations are above water quality standards (Moschet *et al.*, 2014). In general, the sustainability development process of Swiss farming systems has stagnated for the recent years. Moreover, the Swiss agricultural production system shows high variability among groups of comparable farms in various aspects such as environmental impacts, energy use, and earnings from farming, indicating a considerable potential for improvement. In this context and considering a multitude of challenges facing the agricultural sector, Agroscope has launched a research initiative named "Production2020". It aims at the development of a seminal knowledge system for the design and management of agricultural systems in Switzerland.

2 Main Principles

The initiative is based on seven main principles and focuses on the improvement of sustainability of Swiss agricultural production systems:

1. Consideration of all three dimensions of sustainability,
2. Focus on primary production,
3. Action at farm-manager level,
4. Embedding primary production in the entire value chain with optimal use of resources,
5. Consideration of the entire life cycle,
6. Striving towards impact goals, and
7. Strengthening the personal responsibility of the farmers.

The first main principle emphasizes that all three dimensions of sustainability, economic, environmental and social, should be equally integrated in a design for sustainability. The present-day confrontation between economy and ecology must be resolved and the public service compensations for environmental performance should be reduced to a minimum based on effectiveness. The second principle refers to the specific challenges in food production and it is therefore strategically crucial to focus on primary production rather than on the other services of agriculture. The third principle indicates that the farmer is the main actor who ultimately decides and implements the actions. We have to keep in mind that farmers see themselves first of all as agricultural producers and not as forest rangers, hoteliers or landscape gardeners. Alternative management options to the predominant family farming may also be considered in order to remain flexible with respect to organisation forms for food production. The fourth principle indicates that primary production cannot be designed and managed independently of the value chain, bearing in mind product choice and product quality. Production must be adapted to the market guaranteeing demand by the food sector up to the consumer, and by the citizen as a taxpayer. In this regard, a reasonable use of natural resources is of common interest. The design for sustainability takes place along the entire life cycle of the observed systems, which is emphasized by the fifth principle. There should be no shifting of a sustainability burden from primary production to the upstream or downstream value-added stages, and vice-versa. Neither should there be a one-sided improvement of a sustainability criterion at the expense of other criteria not considered. The sixth principle is based upon the DPSIR framework, which describes causal links from the driving force to pressure, state, impact and the response. The intention of the seventh principle refers to the personal responsibility of farmers so that they can act meaningfully by using the best options for their business rather than limiting their creativity by externally imposed commands or prohibitions.

3 Initiation of the Research Initiative

Based on these seven principles, research activities have been initiated in order to develop, test and provide possible courses of action for progressing towards next-generation agricultural systems.

The research initiative is organised into nine work packages:

- WP1: Lead of the research initiative
- WP2: Strategy definition
- WP3: Sustainability assessment and design
- WP4: Options for action in plant production
- WP5: Options for action in animal husbandry
- WP6: Options for action in management
- WP7: Pilot farm network
- WP8: Institutional integration
- WP9: System integration and synthesis

It is essential for Agroscope to place this research initiative into the European context, where similar research efforts have already been initiated. The development and implementation of indicators for a sustainability assessment of Swiss agriculture system is new and key for this initiative. It will include indicators for resource efficiency, climate, nutrient management, ecotoxicity, biodiversity, soil quality, animal welfare, social factors including landscape aesthetics, and the economic short- and long-term situation of the farm. A main focus of the initiative lies on elaborating production systems and closing research gaps in order to provide additional options for action to farmers. A prerequisite of these options for action is that they are successfully tested and verified under practical conditions. A network of farms will be established to involve farmers in performing applied research under practical conditions and to receive feedback about these options for action on farm level. Farmers can then select appropriate options for action for their production needs to achieve the best possible sustainability assessment. The outcome of the sustainability assessment will be integrated into agricultural policy instruments. The initiative is guided by a scientific advisory group comprised of leading international experts in their fields ensuring a high level of research quality. We performed a stakeholder analysis to retrieve information about the challenges and opportunities of the Swiss agriculture and food sector. For this purpose we developed a questionnaire to interview stakeholders to explore their priorities and requirements. We interviewed 12 stakeholders including retailers, federal offices, non-governmental organisations, representatives of major food labels, farmers' associations, public institutions and industry representatives.

4 Preliminary Results from the stakeholder process

The analysis of the stakeholder interviews is still on going. However, first results were deduced from this analysis by identifying four main topics. A major requirement is to investigate and establish site-specific farming systems. This takes into account that sustainable food production is adapted to a specific location within a region. A second thematic priority is an effectively and efficiently producing agricultural and food sector. An effective agricultural production conforms to the criteria of sustainability and high-quality food by continually increasing the output/input ratio. A third important issue is to position Swiss food production in the context of a globalised world with direct competition with other producers and processors especially in the neighbour European countries. This deals with the question of how much and what kind of food should be home-produced and how much food should be imported, and which degree of self-sufficiency should be achieved in Switzerland. A fourth major topic is the perspective of the profession of the farmer in the future. Farmers have to meet high requirements, and the pressure on prices reduces margins for their products, which makes farming less attractive. In the light of this, basic information and possible solutions of technical nature as well as in management will be established for a seminal agricultural production.

Within these four major topics, current research activities from different disciplines are now being scanned for potential links between disciplines. In order to cover the remaining research gaps, new project proposals will be developed to provide knowledge for the current challenges of Swiss agriculture in the frame of the four major topics identified. At the time of the conference, our experiences and first results of this comprehensive initiative to further Swiss agricultural systems will be reported.

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Projections to Latent Structures (PLS) to evaluate farming system effects on agro-ecosystem services: Changes after transition from conventional to organic farming system

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1 Introduction

Farm management strategies impact targeted functions and services, such as crop productivity, soil fertility, nutrient cycling, weed dynamics, biodiversity, etc. The dynamic and diverse decisions on farm management, the diversity of the desired outcomes and the various ways to assess them require evaluation techniques that can handle many variables at time. To account for multi-factorial and multivariate dimensions of agro-ecosystems, the use of multivariate modeling for the evaluation of crop production systems have been recommended (Kenkel *et al.*, 2002; Bianconi *et al.*, 2013; Schipanski *et al.*, 2014). One of the main advantages of the multivariate methods is that they can inform on major contributing factors to the variation of multiple functions and services from an agro-ecosystem. Doing so, the provided knowledge allows fine-tuning the factors of high importance under specific circumstances. One such method is Projections to Latent Structures (PLS, an extension of principal component analysis; also known as partial least squares, Eriksson *et al.*, 2006). We used data from 36 farms to examine how historical and current management strategies and time since transition from conventional to organic farming systems (CFS to OFS) affected soil carbon (C) and nitrogen (N), and barley performance in two agro-ecological zones in Sweden.

2 Materials and Methods

Two study regions, Scania in Southern Sweden and Uppland in East-Central Sweden, were chosen. The regions differ in climate, soil parent material and landscape, but have similar extension services and national policy. In each region, eighteen farms were selected, in three groups of six farmers: old OFS converted before 2006, new OFS converted after 2006, and CFS. With PLS, (Eriksson *et al.*, 2006), we explored the effects of management practices 1) on spring barley performance, 2) soil characteristics, and 3) the effects of soil characteristics on barley performances. For each region, we constructed X-Y matrices of managerial data retrieved from interviews and collected barley and soil data. For the two first models, we used approximately 100 management options over the period 2009-2012 (answers on 40 interview questions), the time since transition and a landscape complexity index in the X-matrix. The Y-matrix, soil and crop data, were collected from the same field of each farm in 2012, always in spring barley. In the third model, soil data was the X-matrix and spring barley data the Y-matrix. Barley data included biomass and N-concentration at different growth stages, and grain yield. Soil data included mineral-N (NO3-N, NH4-N), total carbon (tot-C) and nitrogen (tot-N), pH and texture. Each farm was considered as an observation and mean values of the measured crop and barley data were used. We used a filter method with the variable importance in the projection (VIP) for variable selection (Mehmood *et al.*, 2012). After the first analysis, all VIPs less than 1 were eliminated and then, after a second model run, VIPs with a low-bound below zero were eliminated according to the jack-knife bootstrapping method in the model cross-validation (Afanador *et al.*, 2013). PLS analyses were performed with the software SIMCA-P V 13.0 (Umetrics, Umeå, Sweden).

3 Results and Discussion

One or two principal components (PC) gave the best models, with goodness of fit (R^2Y) ranging from 0.46 to 0.57 and from 0.16 and 0.30 for two PC and one PC, respectively. This indicates that the overall models, based on R^2Y as a main criterion to evaluate the explained variation of all the response variables (Eriksson, 2006), were rather good. Model 1 had the best fit in Uppland and model 3 in Scania (Table 1). The cross-validation of the three models showed a prediction fit ranging from 0.26 to 0.40 (Table 1). The prediction of soil characteristics were rather difficult to model for both regions. The individual responses to management practices were better predicted for barley performances (Fig. 1a) than for soil characteristics (Fig. 1b). Long-term effects such as such as tot-C, tot-N and pH and humus content were the most difficult to predict (low R^2Y and Q^2 in Fig. 1b).

Time since transition, the proportion of grass/clover ley in the farming system and the techniques used to spread organic fertilizers were the most contributing factors to biomass, grain yield of barley and soil mineral N. The latter was also associated to higher crop performances. This suggests that, where mineral N-fertilizer is being reduced when converting to OFS, more and well spread organic fertilizers will be needed to keep up biomass production at similar level as of CFS. Higher grain N concentrations were associated with OFS, probably because of the lower dry matter yield. The greater difficulty to model soil characteristic than barley performances could be explained by the fact that farm decisions are evaluated, in first place, by the outcome in terms of crop performances even though the latter depend on soil characteristics. Soil characteristics such as N can be amended with additional mineral N and we kept both CFS and OFS in the analyses to allow the comparison of both systems.

Table 1. Summary of the three models predicting crop performances and soil characteristic for respective agro-ecological zones. The initial explanatory variables of each model, the selected significant variables of importance in the model, the number of principal components (PC), the cumulated goodness of fit (R^2X, R^2Y) and the model cumulated goodness of prediction (Q^2) are given

Models	Initial variables	Selected variables	No of PC	R^2X (cum)	R^2Y (cum)	Q^2(cum)
Uppland						
1: Management --- >Crop	86	25	2	0.59	0.57	0.34
2: Management---->Soil	28	5	1	0.64	0.30	0.01
3: Soil ----> Crop	17	11	2	0.93	0.46	0.40
Scania						
1: Management ---> Crop	101	12	1	0.55	0.24	0.16
2: Management---->Soil	32	8	1	0.36	0.16	0.04
3: Soil -----> Crop	17	6	2	0.78	0.51	0.26

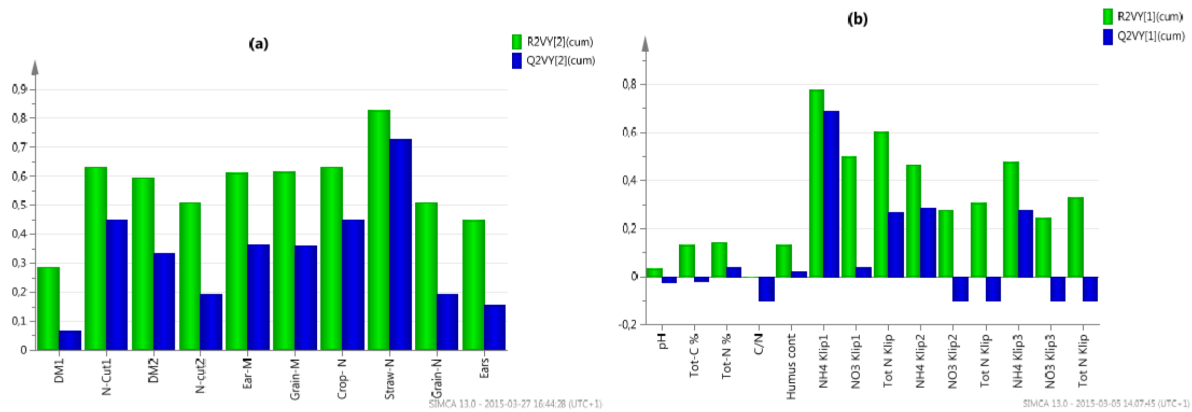

Fig. 1. Example of the cumulated goodness of fits (R^2Y) and the goodness of predictions (Q^2) for individual responses of management practices in Uppland: a) model 3 and b) model 2.

4 Conclusion

The PLS allowed to analyse the effects of management practices covering many years on barley performances and soil characteristics. Nitrogen content in barley grain increased with longer time since transition to organic farming, but with lower yield. We relatively well modelled barley performance, but it remained challenging to model the long-term management effects on soil characteristics, such as total-N and -C. The most important factors affecting the targeted ecosystem services were selected, for example the organic matter spreading techniques and leys proportion on the farm, and their manipulation can contribute to the design of better farming systems.

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Characterizing agroecological farming systems by combining the resilience and ESR framework

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1 Introduction

Industrialized agriculture depends on increasingly scarce external inputs like water, fuel and artificial fertilizers. Furthermore, literature describes negative externalities and a lack of food security and sovereignty associated with this type of agriculture. As a response to these urging issues, an expanding academic field suggests agroecology as a possible solution (Altieri, 1995; Holt-Giménez e*t al*., 2013; Khumairoh *et al*., 2012). Altieri (1995) defines agroecology as the use of ecological concepts and principles for the design and management of sustainable agroecosystems where external inputs are replaced by natural processes. The concept covers three aspects; a scientific discipline, a set of principles and practices and a social movement (Silici, 2014). The scientific discipline involves the holistic study of agroecosystems. Agroecological principles and practices enhance resilience and ecological, socio-economic and cultural sustainability of farming systems. As a movement it seeks a new way of considering agriculture and its relationship with society.

In this paper, we focus on the way agroecology can be studied and represented. To do so, we use the case of Flanders, where agriculture is highly specialized and export-oriented. We want to analyze why and how farmers apply agroecological principles and which factors influence their decisions. As agroecology focusses on interaction and relationships within the agroecosystem, we need a systems approach to perform this analysis. However, a clear approach in literature is lacking. Therefore, we developed a conceptual framework to tackle the aforementioned questions.

2 Materials and Methods

We started this research with an extensive literature research, focusing on agroecology from different perspectives. This resulted in an overview of possible frameworks suited for systems analysis. Through interdisciplinary discussions and feedback from a transdisciplinary sounding board, we selected and combined the most promising frameworks for studying agroecosystems and their evolution towards sustainability.

3 Results – Discussion

To perform a system analysis taking into account different levels of the farming and food system and their interactions, we developed a conceptual framework, consisting of a combination of three existing frameworks. This combination is represented below (Fig. 1).

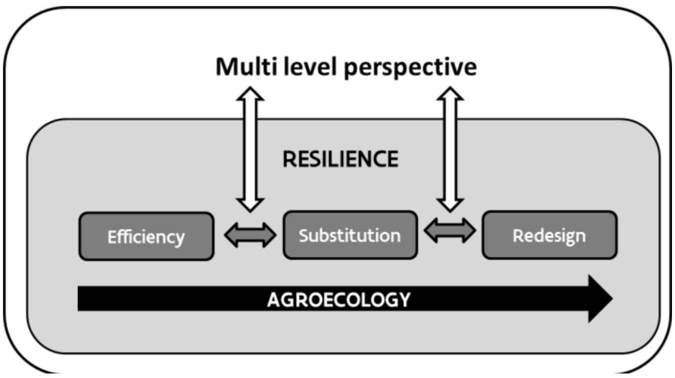

Fig. 1. Conceptual framework – combination efficiency-substitution-redesign (ESR), resilience and multilevel perspective (MLP).

Central in Fig. 1 is the efficiency-substitution-redesign framework (E-S-R) (Bellon *et al.*, 2010; Chantre *et al.*, 2014; Lamine, 2011), used for analyzing practices at farm level. This framework differentiates between three production stages during the transition to more sustainable agriculture. Efficiency stands for improving input efficiency, but without reducing farm dependence on external inputs. Substitution implies that chemical inputs are substituted with organic ones and alternative practices are implemented, but without (greatly) modifying the basic system structure. Redesign occurs when the farm system is redesigned on the basis of a new set of ecological processes and works as a functioning agroecosystem.

The resilience framework is used to analyze how farmers assure resilience of their farming system within the broader food system. This framework is derived from the work of the Resilience Alliance and Stockholm Resilience Centre, among others (Darnhofer *et al.*, 2010a; Folke *et al.*, 2010; Olsson *et al.*, 2014; Rist *et al.*, 2014). Darnhofer *et al.* (2010a) use resilience thinking to assess a farm's sustainability. Because agroecological farming systems are characterized as production systems which are locally embedded and adaptable to ensure continuity in farm income, these systems are assumed to be resilient. Through the combination of the ESR and resilience framework, it's possible to identify if the three different production phases show differences in their strategies to strengthen resilience. If so, characterizing farming systems by their resilience strategies (Darnhofer, 2010) can be an approach for distinguishing more agroecological systems from more conventional ones. We can also identify how strategies evolve when moving from one stage to another by analyzing farms who changed agricultural practices over time.

To identify the influencing factors on the strategy choices, we use the multilevel perspective framework (MLP) (Paredis, 2009). These factors can occur on landscape, regime, farm or niche level, with each level having a different impact on the strategies applied. Factors can also occur during different time spans, ranging from short and sudden shocks (e.g. market collapse) to constantly present stress factors (e.g. climate change).

By combining these three frameworks we constructed a systems approach for analyzing agroecology, taking into account as well ecological, social and economic aspects and their interrelation. The frameworks are well described in scientific literature – see references above – and have proven their relevance in (agro)ecosystem research. The innovatory aspect of this research is their combination and the application to agroecology. In the near future this conceptual framework will be used to characterize the livestock farming systems in Flanders, during which it will be tested and adapted if necessary.

4 Conclusions

This conceptual framework provides a holistic way of analyzing and representing agroecosystems, contributing to the scientific pillar of agroecology. It takes into account different levels from the food system, the interaction between ecological, social and economic aspects and their influence on farm level practices. Through the actual application of this framework agroecosystems can be characterized by their strategies for strengthening resilience. Combined with the study of evolutions in strategies and the influencing factors this may generate interesting results for upscaling agroecology in practice.

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Modelling Adaptive Decision-Making of Farmer: an Integrated Economic and Management Model, with an Application to Smallholders in India

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1 Introduction

Farmers plan their cropping systems and farm operations depending on their expectations on economic, social and environmental contexts, and they make tactical adjustments to face uncertain rainfall, variable market prices, and changing resource availability. We use modeling to represent a farming system and we define its adaptation opportunities to drought events, delay in monsoon onset, limited irrigation water and market prices fluctuation in the Berambadi watershed, Karnataka, India. It is represented as three interacting sub-systems: the agent system, the operating system and the biophysical system (Martin-Clouaire & Rellier 2009; Le Gal *et al.* 2010). We focus on the agent system representation. Once the objectives and farm representation of the farmer have been identified, we use a double loop process to combine a proactive economic model with a reactive farm management model to simulate the planning and adapting process of the farmer under water constraint.

2 Materials and Methods

A case-based survey provided specific information on 27 farmers. Farmers were asked to detail their farm practices and management decisions. Changes and adaptation of their practices when facing downside climatic and price conditions were discussed to bring out adaptation decision-rules.

Individual farm representation were first formalized with a Belief-Desire-Intention architecture (Bratman 1987) and conceptualized with UML object diagrams. Genericity was allowed by introducing expert knowledge. An ontology was built with UML class diagrams.

Decisions on irrigation equipment and infrastructure investments were optimized using a stochastic dynamic programming approach. Our economic model described the strategic decision of the farmer to upgrade his irrigation capital stock (e.g., borewells, pumps) in order to optimize access to irrigation water.

Cropping system decisions and management practices were represented with UML sequence diagrams. Our farm management model used decision-rules to allow tactical adaptations in the crop choice and operational flexibility in the daily crop management tasks.

The agent system and its interactions with the biophysical system of crop growth and ground water level were implemented within the RECORD modeling platform (Bergez *et al.* 2013).

3 Results - Discussion

The conceptual approach is presented in Fig. 1. *AMBHAS* model (http://ambhas.com) provides information on the ground water (GW) volume available to the farmer for irrigation (1). Considering possible investments in irrigation equipment at the beginning of the year (e.g. dig a new borewell, buy a new pump, rebore a borewell), a converter combines the GW with other water resources (tank, canal, river), and irrigation equipment, and predicts the total available water for irrigation on the farm per irrigation investments (2).

Based on rainfall and crop price expectations, farm resources (equipment, labor, manure, and production techniques) (3), water available (2), the *tactical season bele* model provides to the *tactical season farm* model a matrix of crop yields per bele (i.e. per plot) and irrigation investment levels (4). Crops considered include any suitable crops that respect a crop rotation constraint, a preceding effect constraint, and a crop return time constraint. The *tactical season farm* model then selects the optimal cropping system that maximizes farmer's income for each irrigation investment level (5). The *strategical year farm* model selects the irrigation investment at the beginning of the year associated with the highest income. The *economic* model (*tactic season bele* + *tactic season farm* + *strategic year farm*) returns this value to the *farmer* model (6) and updates the available water volume on the farm at the beginning of the *Kharif* season that is sent to the second loop within the management model (7).

In the *tactical* part of the management model, decision rules (8) allow the farmer to adapt his cropping system to actual rainfalls and prices at the beginning of the season (9). Once crop choice is made, the *operational* management model applies production techniques (10) to trigger the daily farm operations. This model strongly interacts with a resource manager module (10') and crop model *STICS* (Brisson *et al.* 2003) (10') as a loop where rainfall, soil moisture, weed and pest pressures, and crop stage are checked before each operation (10). After each irrigation or rainfall event, *STICS* sends the water abstracted and drainage to *AMBHAS* (11).

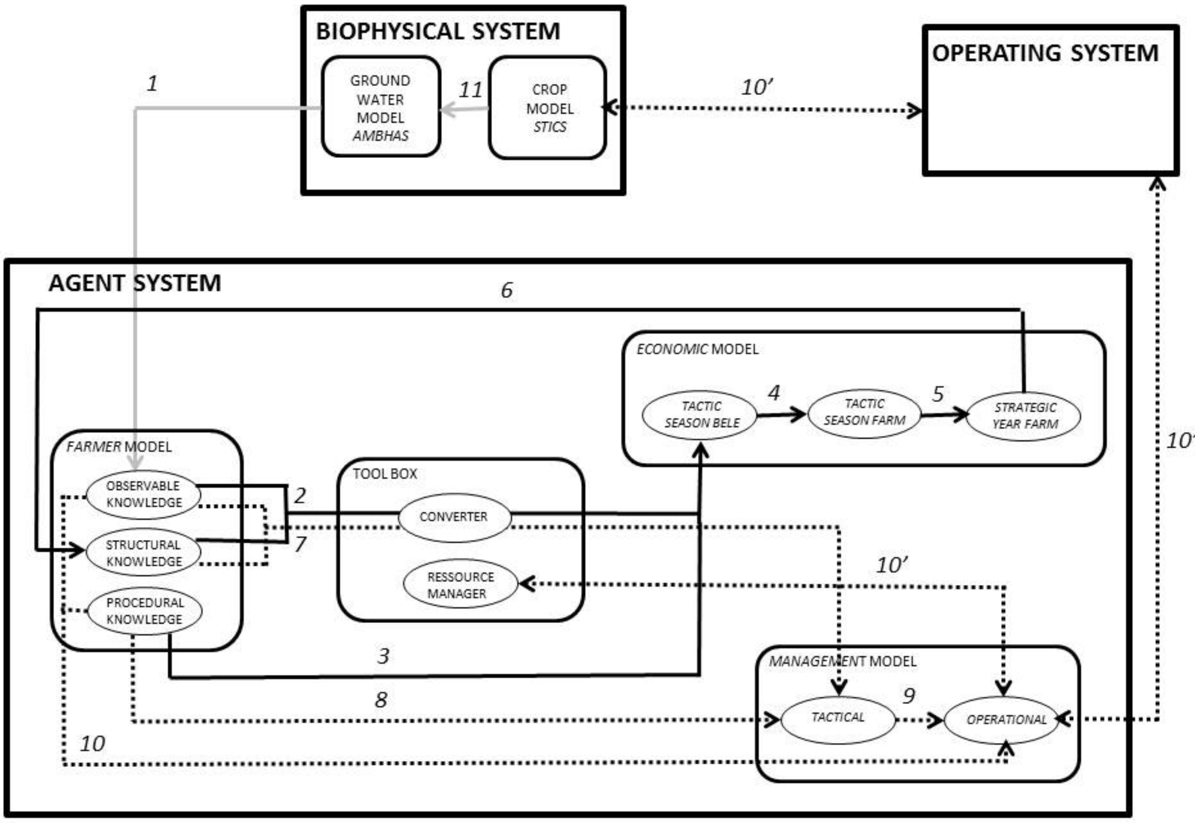

Fig. 1. Conceptual representation of the farm system, information flux between sub-systems and double loop in the agent model (loop 1 as continuous dark line in economic model, loop 2 as dotted line in management model).

4 Conclusions

The double-loop process used in our approach models the sequential and continuous aspect of the farmer's decision-making process. As time passes and more information become available, the farmer is able to adjust his strategical choices (economic model and optimization) and adapt his farming practices (management model and tactical and operational decision-rules) to his changing environment.

This farm system design helps in modelling farm practices in a context of water scarcity and climate change and their impacts on the ground water level evolution.

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The viability of small islands agro-systems: the case of the French West Indies

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1 Introduction

Farm modeling has a long history from mainly microeconomic approaches looking to maximize an agricultural income to bio-economic models that take into account the functioning of various biological processes and to probabilistic models or simulation-based approaches that grasp the market or production uncertainties. Nowadays agriculture is required to provide income and food security, to preserve environmental resources and cultural identities while being able to adapt to climatic change or to abet its mitigation. The aim of this study is to conceive a new way of farm modeling providing the sequential and simultaneous decisions to undertake on different parcels of a farm in order to abide by environmental and economic concerns. This research is applied to the case of the French West Indies, small tropical islands, where a major challenge for the sustainability of agricultural systems is to preserve the quality of soils. Soil functioning and its interactions with the various agricultural practices are highly complex. We resort to GISQ (Global Indicator of Soil Quality, Velasquez *et al.*, 2007) a synthetic and recognized global indicator of soil quality since the evolution of its value depending on crops and agricultural practices can be known for a variety of tropical soils. A farm is composed of several parcels with different GISQ values on which crops or livestock with semi-annual, annual, semi-perennial or perennial cycles and specific production costs can be implemented. A farmer may also decide between two practices: intensive agriculture with high level of inputs (fertilizers, pesticides, enclosed breeding …) or reasoned agriculture with limited plant treatments. All these farmer's choices made successively at different times on each parcel determine the evolution of the farmer's global income and of the soil quality in each parcel. We used viability theory to obtain the *viable controls* that can be implemented at each date of the end of a production cycle on a given parcel. These *viable controls* (choice of a new production on a given parcel along with a practice and eventually a soil treatment) guarantee the preservation of the soil quality on each parcel and a minimum global income to the farmer. The exercise spans on all a farmer's active life with the objective to reach a given level of GISQ on all the parcels when the farm will be transmitted to the next generation.

2 Materials and Methods

Viability theory is a set valued mathematical analysis designed for the control of dynamical systems with constraints and submitted to uncertainties (Aubin *et al.,* 2011). Unlike the usual approaches based on simulations techniques, viability theory relies on an inverse approach allowing to know the set of all the current states variables for which there exist controls such that the evolution of the states variables governed by these controls always comply with a set of constraints. The main drawback is the huge memory needed for the calculus of sets which limits the number of possible state variables, and, for the time being, the absence of a general and friendly viability calculus software. A software, specially designed for the purpose of this study, is presently in development. A mathematical and computational challenge is the handling of different durations for the cycles of various agricultural productions implemented on the different parcels of a farm. Some productions may span over years (e.g. bananas) while other can be produced in one month (e.g. salads). This is solved by introducing a time variable with the smaller unit (the month) and for each parcel an indicator of the remaining time before the end of a cycle in order to have the dates of possible changes of production which fatally increases the number of state variables. Currently, calculus have been done for a farm with only one parcel but the obtained results are more focused on the problem of long term soil management (sequential choice of production in order to achieve a satisfying value of GISQ at the end of the exercise while being profitable) than on a farm management (sequential choice of several productions simultaneously implemented with environmental and economic objectives).

The data have been obtained from field research carried out for this research and from literature. For each possible production and practice we collected the costs per hectare and per month (various agricultural inputs, workforce, depreciation charges…), the subsidies (possibly attached to the quantity produced, the surface implemented or a onetime incitement for a given production) and the sale prices per ton. For each production, the quantities produced per hectare depend on the practice chosen and on the value of the GISQ at the beginning of the cycle. These parameters are given by the field experts. The evolution of the GISQ value depends on the production and practice that are implemented as well as on the GISQ value at the beginning of the production cycle. We considered that the GISQ decrease at the end of a production cycle is mainly determined by the percentage of exported biomass relatively to the total biomass produced which is characteristic of each combination of crop and practice. At the end of an agricultural season, soil amendment can be introduced to enhance the GISQ value before the beginning of a new campaign. It is possible to consider any number of production, they are only limited by the possibility to document the required parameters.

The control variables are the choices of production, practice and amendment. The system is depicted by three state variables: the GISQ (I), the time (t) and an indicator of economic performance (W). Earnings of each agricultural campaign are the difference between sales and all the expenditures occurred during the cycle. Economic performance is the sum of earnings cumulated all along a given period of time. It is required that at the end of the exploitation, the GISQ be over a target value considered as desirable. In viability theory this translates in the computation of a *capture basin of a target.* This capture basin of a target provides all the triples (I,t,W) of initial values of GISQ, exploitation period and economic performance for which there exists, from all the available range of productions and practices, at least one farm management suitable to restitute a soil with the desired quality. Furthermore, for a given period of exploitation, the software provides the best economic performance that can be obtained with a viable initial value of GISQ along with all the control rules that can be possibly or necessarily applied at each decision time in order to obtain both the desired soil quality and the best economic performance in final time. These optimal decisions may be reduced to a unique sequence of productions and practices imposed to the farmer but not necessarily, several optimal farm managements can lead to the same value of best economic performance and wished soil quality. In this case, it is possible to select a preferred pattern by defining some choice priorities in the range of possible productions and agricultural practices.

3 Results - Discussion

Six productions have been documented (plantain banana, tomato, yam, goat breeding, cattle breeding and fallow) for two types of agricultural practice (intensive and reasoned). The exploitation period spans on a maximum of 40 years.

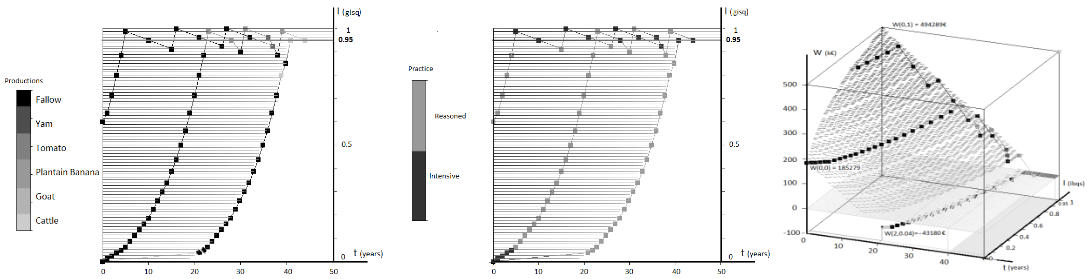

Fig. 1. Examples of farm conducts

Figures on the left and center give examples of farm conducts guaranteeing the desired soil quality and the best economic performance at the end time when starting from either good or bad values of GISQ and with 40 or 20 years for the accomplishment. For the three cases, it is by beginning with a period of fallow that the best economic performance is achieved. The target level of GISQ is reached sooner when the initial GISQ level is higher. When 40 years are at disposal to realize the objective of soil restoration it is then more profitable to undertake an "intensive fallow" during the first years and an "extensive fallow" afterwards. This conduct must not be used if the time at disposal is only of 20 years since a better economic performance will be obtained with a succession of "extensive fallow" only. These trajectories are depicted on the right figure that shows the graph of the best economic performance as a function of time to elapse, spanning from 1 to 40 years, and of values of initial GISQ.

4 Conclusions

This one parcel farm model can also offer a new perspective to the "soil value evaluation" problem. As shown on the right figure, restoring the soil quality in only 20 years is possible but with a negative "best economic performance". In this case, the "best economic performance" indicates the minimal cost that would be necessary to invest from the starting date to be able to restore the soil quality in only 20 years. Computations for a several parcels farm are currently in development.

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Agronomic, environmental and social assessment of soil management strategies limiting herbicide application in Mediterranean vineyards, at the catchment scale

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1 Introduction

Maintaining and restoring the ability of agricultural soils to limit water and pesticides fluxes by overland flow is a particularly important issue in the Mediterranean wine growing area where overland flow has been shown to be a major factor of the contamination of water resources by pesticides (Louchart *et al.*, 2003). If the soil infiltration capacity is high, the soil exerts a buffering effect against floods, erosion and potential pesticide transfers. It is therefore important to identify soil management practices and their spatial distributions at the catchment scale that contribute to the preservation or restoration of soil infiltration properties throughout the year. Identifying these practices and their distribution implies to be able to assess their benefits and costs, ie: (1) the effects of those practices and of their spatial distribution on the soil's function to be preserved and (2) the constraints of implementation of these practices by the vine growers. The objective of the SP3A project was to identify and evaluate in Mediterranean viticulture, the soil management practices and their spatial distributions that limit the contamination of runoff waters by herbicides at the catchment scale while remaining acceptable by vine growers (Andrieux *et al.*, 2014).

2 Materials and Methods

The study was carried out in the Rieutort catchment. This catchment covers 45 km², one third of which is covered by vineyards that are managed by about 150 full or part time vine growers. It is located north of Beziers, 90 km west of Montpellier, on the edge of the foothills of the Massif Central in France. The climate is Mediterranean, characterized by rainy autumns and springs and hot dry summers with heavy rainfall and strong inter-annual variability of rainfall (the average annual rainfall over 20 years is 690mmwith a maximum of1585mmand a minimum of311mm). Five major classes of soil can be distinguished including: (1) stony superficial soils, (2) clay soils of the transition zone between the northern slopes of shale and sandstone farther south; (3) sandstone soil; (4) fersiallitic soils; (5) sandy alluvial soils. Analysis of the quality of the water ressources in this catchment used for the production of drinking water showed an almost permanent contamination by herbicides and placed the catchment in the list of the 500 most threatened water drinking ressources in France according to the French Ministry of Ecology, Sustainable Development and Energie.

The scientific approach was in three steps. First, a group of scientists and local agricultural experts in viticulture identified adequate soil management strategies to reduce the use of herbicides across the catchment. These strategies define (i) targets in terms of herbicide use intensity at the plot and catchment scales, (ii) soil management practices to achieve these targets, while reducing the risk of runoff and (iii) spatial distribution rules of those practices according to the characteristics of the different plots of vines in the catchment. Second, an assessment of the environmental and production performances after implementation of these strategies was then simulated at the catchment and/or plot scales taking into account soil types and local climate. These evaluations were carried out for nine representative seasonal climate scenarios using an original chain of models. The chain of models was based on the use of (i) the DHIVINE decision model (Martin-Clouaire *et al.*, submitted) to simulate timing of soil management operations at the plot resolution over the whole vine area, (ii) an extended version of the MHYDAS eco-hydrological model (Moussa *et al.*, 2002) to simulate the evolution of soil surface features at the plot scale, and runoff and herbicide concentrations at the catchment outlet, (iii) the WaLIS water balance model (Celette *et al.*, 2010) and a N balance model to simulate consequences of grass cover practices on yield reduction at the plot scale (Guilpart *et al.*, 2014). Third, a survey of 31 full time vine growers in the Rieutort catchment was conducted in order to determine the current and possible future soil management practices and the dialogue network that structures the exchange of technical information among vine growers (Compagnone, 2014).

3 Results – Discussion

The environmentally friendly soil management strategies that were identified are given in Table 1. They consist in four main types defined according to a target in terms of a treatment frequency index (TFI). Two strategies aimed at no or rare herbicide applications whereas two others aimed at a medium rate of herbicide applications. All favoured, when possible, grass cover of the vineyard inter-rows.

The results of the environmental assessment of these strategies at the catchment scale (Table 2) showed the occurrence of herbicide concentration peaks at the catchment outlet exceeding the limit allowed for drinking water in the EU (0,1 µg/l) even for the strategy with a very small use of herbicides (Strategy 1b). Strategy 1a (no herbicide use) evidently respected the water quality requirements for drinking water, while the simulated herbicide concentrations for Strategy 2a and 2b were well above.

The agronomic assessment of water and nitrogen vine stress and consequences on grapevine yield at the plot scale (Table 3) highlighted the risks of decrease in grape production according to the spatial extent and duration of grass cover in the interrows. Permanent grass cover was shown to be possible only on deep alluvial soils whereas grass cover, even if limited to the winter period, was never possible on shallow stony soils due to the risks of water and nitrogen stressses. For the other soils types, grass cover is possible but there is a need to adapt its spatial and temporal extent to the annual climatic conditions.

Eventually, the analysis of the socio-technical networks in the Rieutort catchment revealed a collective ability of the wine grower community for technical change. Although the actual soil management techniques preferentially use herbicides for controlling weed, the community admit growers who apply alternatives practices.

Table 1. Description of the strategiesselected to reduce the use of herbicides across the catchment. TFI: Treatment frequency index (number of full-dose treatments per hectare)

Strategy	Target of herbicide use intensity at catchment scale	Associated soil management practices
1a	TFI = 0	0 herbicide on the row (R) and inter-row (IR) – The soil is maintained by permanent grass cover (PGC) or winter grass cover (WGC) combined with tillage
1b	TFI ≤ 0,1	Idem strategy 1a with permissionofpost-emergence herbicide on the whole surface of veryconstrained plots (maxi 10 % on the vineyards area in the catchment)
2a	TFI ≤ 0,3	The IR are maintained by PGC or WGC combined with tillage. Permission of post-emergence herbicide on 1/3 of the plot area (≈ on the Row)
2b	TFI ≤ 0,4	Idem stratégy 2a with permissionofpost-emergence herbicide on the whole surface of veryconstrained plots (maxi 10 % on the vineyards area in the catchment)

Table 3. Environmental performances of the strategies considering herbicide leaching at the outlet of the catchment.

Simulated spatial distribution of practices and contamination by herbicide	Strategy			
	1a	1b	2a	2b
% of vine area maintained by PGC	28	28	27	27
% of vine area maintained by WGC and tillage	72	38	70	35
% of vine area maintained by WGC and herbicide	0	4	34	38
Average annual maximum peak of contamination (µg/l)	0	0.17	2.0	2.1
Maximum peak of contamination (µg/l)	0	0.33	3.4	3.5

Table 2. Acceptability of grass cover practices according to type of soil, at the plot scale.+: acceptable(the simulatedyield reduction was under 15%); -: unacceptable (the simulated yield reduction was above 15%); ½ IR: 1 inter-row out of 2, ½ year: 1 year out of 2, 2/3years: 2 years out of 3

Grass cover pratice	Type of soil				
	Allu-vial	Fersial -litic	Sand-stone	Clay	Stony
PGC all IR	+	+ 2/3years	+ ½ year	-	-
PGC ½ IR WGC½ IR	+	+	+	+ ½ year	-
WGC all IR	+	+	+	+	-

4 Conclusions

Reducing herbicides while maintaining grapevine yield is possible in the Rieutort catchment by favouring tillage and grass cover on the inter-rows, and possibly on the rows, of vine plots. But agronomic and environmental assessments highlighted a strong inter-annual variability of performances (yields and contaminations) due to the strong variability of soil and climate conditions in the catchment. Consequently, both assessments converge on the issue of introducing more temporal flexibility in the definition of strategies to reduce herbicide use as well as on the associated modalities of soil management practices associated. The results of each of these assessments should help vine growers to choose new strategies best suited to both the environmental constraints and the agronomical and economical constraints they face.

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Pesticides pressure assessment using TFI (treatment frequency index) at the field, farm and watershed scale

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1 Introduction

In the French West Indies, pesticides highly impacts water bodies' quality (ODE Martinique, 2014). This is mainly due to farm practices associated with the high pest and disease pressure on crops, and also to the accelerated geochemical cycles increasing pesticide transfer (Mottes, 2013).
'Ecophyto 2018' Plan clearly targeted a reduction in pesticide use in all agricultural systems as a key option to reduce the contamination of the environment. The pesticide use reduction is monitored with a set of indicators, among them the treatment frequency index (TFI).
Little information is available on the phyto-sanitary practices according to cropping and farming systems in tropical areas. Our aim was to identify and assess the pressures sources at different space and time scales.

2 Materials and Methods

According to a farm typology, we surveyed 25 farms in Martinique and 23 farms in Guadeloupe, at two watersheds scale, accounting for contrasted agrosystems in terms of global farm strategy, of crop rotations and crop durations, of targeted markets (vegetables for farm consumption, sugarcane for transformation, export banana plantation…). To account for pesticide pressure for these agrosystems, we adapted the Treatment Frequency Index (TFI) (Brunet *et al.*, 2008) initially build for annual crops to infra or supra annual crops. We defined cropping units with homogeneous crop production management (vegetable cropping systems; planting year, medium production year, fallow year in banana production…) to assess different level of TFI (equation 1).

$$TFI_{field_i,cropj} = \sum_{t=1}^{t=T} \frac{Dt}{DAt} \times \frac{St}{Sfield_i} \quad \text{(equation 1)}$$

with T:total number of pesticide treatments (in one or more category of pesticides); Dt: applied rate in active substances; DAt: approved rate for the active substances; St/$Sfield_i$ part of the $field_i$ with the treatment t; normalized on an annual basis.
For a multi-year crop with different type of management as the banana cropping system, we summed up the TFI for each homogeneous crop units (plantation, production and fallow periods) proportionally to their duration in the cropping system.
For a given farm, we summed up the TFI proportionally to the weight of each cropping system in the farm.
Spatializing these indices led to identify the contributive areas or cropping systems to pesticide pressure in both watersheds.

3 Results – Discussion

TFI values varied from 0 to 27 for one year between fields knowing that almost all practices complied with the regulation. Banana cropping systems had the highest TFI while sugarcane cropping systems had the lowest, because only herbicides are used. Horticultural and diversified cropping systems had intermediate TFI values. However, if farming systems including a high proportion of banana had the highest TFI they still showed a large variability of this index (Fig.1b). For part of them, animal or mechanical weeding was used instead of chemical mowing and the use field sanitation practices (use of *in vitro* plantlets after a fallow period) could explain the decrease of nematicides.
The TFI variability was also high considering the different phases of a crop cycle (Fig. 1a). For banana cropping systems, fungicides accounted for more than 80% of the TFI during the productive period, while herbicides accounted for the major part of TFI during fallow period. The plantation period differed with the productive period mainly because of a lowest $TFI_{insecticide}$. The variability depended on the duration of the productive period and fallow (Fig. 1b)

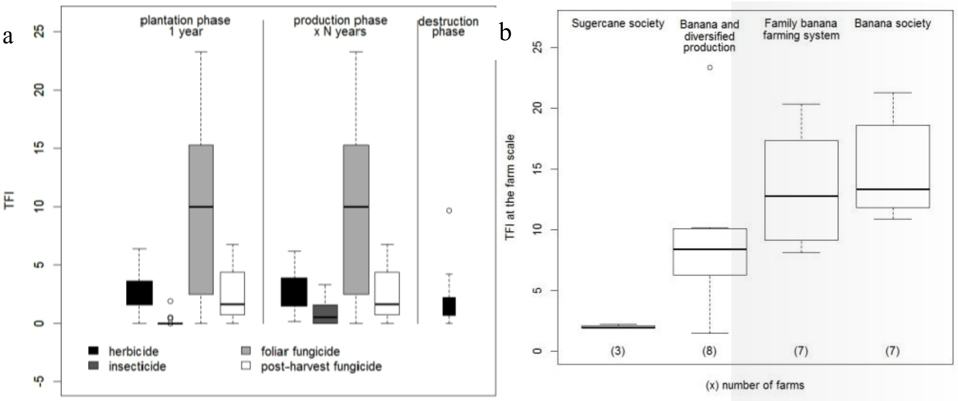

Fig. 1. TFIaccording to a. the cycle period for banana crop;
b. the farm system; Perou river Guadeloupe

At the watershed scale, the TFI spatialization according to pesticide use accounts for a diffuse high pressure of all systems for herbicides (Fig. 2a), compared to the local pressure of insecticides (Fig. 2b) and for a focused pressure of agro industrial systems for fungicides (Fig.2c). The contribution to the pesticides pressure of each system varied also according to the applied molecule: glyphosate pressure is the highest.

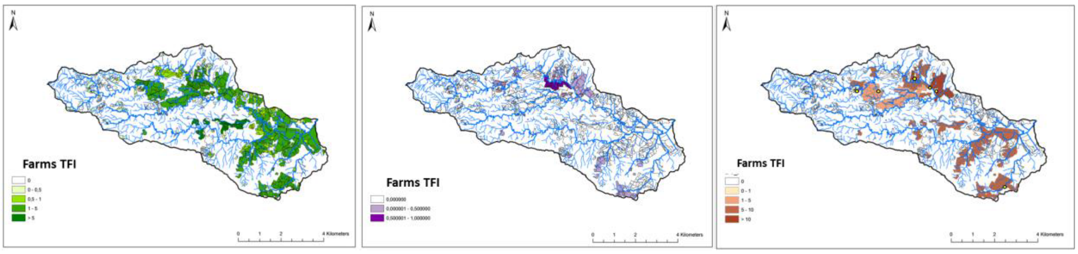

Fig. 2. TFIs at the Galion river (Martinique) watershed scale according to the pesticide target
a. herbicides (green) b. insecticides (purple) c. fungicides (red)

However, TFI is not enough to account for pesticide pressure and risk of river contamination (Bockstaller *et al.*, 2008). First, when the applied quantities (kg of active matter) are considered at the watershed scale, herbicides are the major contributor to the pesticide pressure and are frequently found in surface water. Second when TFIs are related with the pesticides residues measured in the river, post-harvest fungicides are more frequently detected in water while foliar fungicides accounted for the highest TFI. Thus the inflow source is of importance: a concentrated source had a major effect than a diffuse field source. Finally, TFIs do not account for the molecule characteristics, i.e. the hypothetic pesticide transfer route through water bodies, and thus it is not possible to clearly link pressure with impact for water quality.

4 Conclusions

The pesticide pressure assessment using TFIs, is part of the agrosystem diagnosis in the in order to improve pesticide management at the territory scale. Our results will help us to identify the major efforts of pesticide use reduction to focus on (herbicides and fungicides), the major contributors to the pesticide pressure and the ability of certain farming systems to reduce their pesticides. Those results will open to define a monitoring system for water resources quality, using additional information such as applied pesticides quantities, molecular characteristics and application modes.

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Food production typology of farms: an assessment of periurban farming systems.

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1 Introduction

In literature periurban agriculture has been assessed for its capacity to provide different services, especially social, educational and environmental (Allen, 2003; Zasada, 2011), in order to demonstrate the relevance of preserving agricultural activities in the periurban fringe. The recent debates about the development of Local Food Systems (Kneafsey *et al.*, 2013) and the emergence in several countries of food policies and plans (Sonnino, 2014) have raised questions about the capacity of agriculture to assure food provision to urban consumers. In this context, several authors have considered the food production function of agriculture in periurban areas, also related to the new opportunities emerging with the development of short food supply chains (e.g. Zasada, 2011).
Nevertheless, few studies have been made on the food production of periurban farming systems (e.g. Soulard & Thareau, 2009). Moreover, considering the specific constraints and conflicts that periurban farming system needs to face (Darly and Torre, 2013), a specific attention needs to be paid on what kind of food production is possible around the cities. Literature has at first stressed the environmental constraints, that ask for new patterns of food production's intensity and evaluation of food quality (Cavailhès and Wavresky, 2007; Wortman and Lovell, 2013). Secondly, several studies have began to assess the food production capacity of periurban farming system in order to understand the real contribution that periurban farming system can offer in terms of production's yields (Filippini *et al.*, 2014).
Several studies on farms typologies have been made (e.g. Andersen *et al.*, 2007) but to our knowledge, none of them has focused on the characterization of the periurban farming systems and the practices that farmers put in place to produce food for urban dwellers. The purpose of this contribution is to develop a methodology for the assessment of periurban farming systems' food production through farms' typologies. Food production will be assessed in terms of quantity, quality and intensity of the on-farm food production.

2 Materials and Methods

The case study is the periurban farming system of Pisa, a medium-sized city of Tuscany (Italy). It is representative of the main dynamics of periurban agriculture in coastal plains of Mediterranean areas; moreover in the area local institutions have developed a food plan, *Piano del Cibo della Provincia di Pisa*, which one of the purposes was to recognise the contribution of local farming system to the local food demand. The methodology of this analysis is based on semi-structured interviews to 51 farmers selected considering the farm's size, the production and the distance from the main urban centre of Pisa. 50 farm-gate indicators were identified and calculated to estimate the food quality, the food quantity and food production's intensity. Throughout a principal component Analysis (PCA) we has selected 12 indicators able to describe the farm's sample. Thus, a cluster analysis has been performed, in order to analyse the principal characteristics of food producing for each types of farms. During the process two farms were considered outliers.

3 Results - Discussion

The PCA analysis' results are summarized in Fig. 1. The total variance explained is higher without quality's indicators (around 63%) than with them (around 50%); for this reason we have chosen not to take quality's indicators related to organic and certified production in the analysis. The lack of significance of quality's indicators may suggest that certified quality is not always related with the farms' performances in terms of intensity. In other words the presence of any kind of certifications doesn't seem to differentiate the sample's farms. Moreover, horticultural and olive farms have a percentage of primary products devolved to the human consumption (PFood) higher than the farms with forage and industrial crops. This result is explained by the fact in livestock production most of the primary produces are for animals. The percentages of olive production and of cereals have a negative correlation. PLocal seems to be more correlated to intensity's indicators as the percentage of fodder (percfod), or manure (Manure), than to the percentage of food production (PFood). This result seems to suggest that in this area, when the percentage of food production is higher in farms (especially horticultural, olive and cereal farms), farms allocate less production to the local market.

We identified from a cluster analysis five farms' types (Table 1). First of all the negative correlation between two indicators of food quantity: the percentage of production allocated locally (PLocal) and the percentage of food production in the farm (PFood) is better specified (see especially groups 1 and 4).
The cluster analysis helps in distinguish better among farms with industrial and fodder crops. Group 2 has the higher percentage of manure and fodder, for this reason it distinguishes itself from groups 3 and 5, because of its less intensive production.

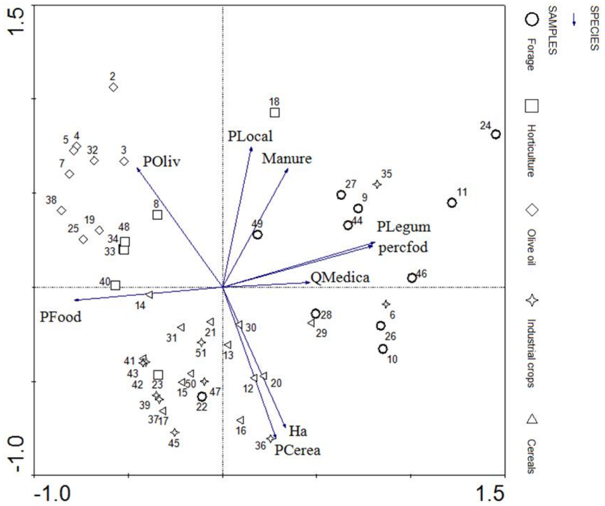

Fig. 1. PCA analysis. *PLocal* refers to "percentage of food production devolved to local market"; *PLegum*, "percentage of leguminous plants"; *POliv*, "percentage of olive production"; *Ha*, "Total UAA of the farm"; *PCereal*, "percentage of cereal crops"; *Qmedica*, "quantity of alfalfa in the rotation"; *percfod*, "percentage of fodder in the rotation"; *Manure*, "percentage UAA fertilised with organic manure".

Table 1. Average indicators values for each class. For the indicators' explanation see Fig.1

Group	Members	Food Quantity							Food production Intensity	
		Pfood	PLegum	POliv	PLocal	Ha	PCerea	Qmedica	percfod	Manure
Small farms	20	87.6	6.4	37.2	33.2	16	10.1	3.0	5.3	15.7
Less intensive big farms	2	20.0	38.7	0.0	40.0	183	34.7	1500.0	55.2	83.7
More intensive big farms	3	25.7	50.6	0.0	30.0	254	27.4	3153.3	47.8	3.6
Cereals farms	15	78.5	9.3	0.1	3.9	252	40.6	8.0	12.8	3.7
Local markets farms	9	46.8	33.6	0.0	50.6	102	27.4	335.0	35.6	36.0

4 Conclusions

Considering the negative correlation between two quantity's indicators, the number of primary products and the percentage of production locally allocated, further studies could focus on the possible constraints for local markets, in order to properly assess the contribution of farms for the local food system (Kneafsey *et al.*, 2013). Moreover the fact that not always a less intensive production is associated with a labelled production, and that quality's indicators are expected in almost all farm's groups, may suggest the need to consider the quality of productions by periurban farms beyond their labels. In conclusion our results suggest the need to accurately analyse the periurban farming systems' performance, characterised by a high degree of heterogeneity of food intensity's production and food quantity. This will finally help the development of more efficient food policies.

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W5. Silvo-pastoral systems

Chair: Bruno Rapidel, CIRAD
Co-chair: Marie Gosme, INRA

Multi-scale studies of the relationships between cropping structure and pest and disease regulation services.

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1 Introduction

Farmers need to regulate numerous pests on each of their crops, using as little pesticide as possible. Several practices can be used to reach this target, yet most of them focus on a single pest. Some control practices implemented for one pest, however, can have antagonistic effects on the development of another pest. Today, with the will to decrease pesticide use while increasing production, studies must take into account the diversity of pests and must focus on tradeoffs in their regulations.
The concept of agroecology proposes to use natural ecological mechanisms in agroecosystems. Plant diversity impacts pest regulation services through biological mechanisms and physical mechanisms. Biological mechanisms typically depend on the species composition of the communities of crop and associated plant. Physical mechanisms typically depend on the spatial structure of crop and associated plant (Schroth *et al*., 2000). These mechanisms are both supported by empirical research and epidemiological models, yet their relative importance and independent effects are not well known. In the present study, our aim was to assess the relative importance and the independent effects of plant communities' composition and spatial structure on pest communities in tropical and temperate areas. Here we postulate that i) crop composition, sensitive host tissue amount and crop spatial configuration impact pest presence through resource availability and accessibility, ii) associated plant composition and spatial configuration impact pest presence by providing other resources or shelters and through microclimatic variations. The scale necessary to observe such mechanisms would depend on the scale necessary to observe a given level of diversity. In tropical areas, many species can be found in association within small plots, while in simplified temperate agroecosystem a much larger scale would be needed to observe a similar diversity. We first investigate biological and physical effects of biodiversity observationally on tropical agroecosystems in cameroon and second assess through modelling if such mechanisms could be of importance in temperate agroecosystems at a much larger scale.

2 Materials and Methods

In the center region of Cameroon, we did field measures and point pattern analysis in 20 cacao-based agroforest plots (50 x 50 m) to evaluate the impact of plant composition and spatial structure on mirid and black pod regulation, *i.e.* a pest and a disease of cacao (Gidoin *et al.*, 2014). For the temperate region, numerical simulations with population dynamic models were used to study the potential impact of landscape (5000 x 5000 m) composition and configuration on the pollen beetles and phoma stem canker dynamics, *i.e.* a pest and a disease of oilseed rape. Two models were used: i) Mosaïc-Pest (Vinatier *et al.*, 2012) to study the spatio-temporal dynamics of *Meligethes aeneus*, and ii) SIPPOM-WOSR (Lô-Pelzer *et al.*, 2010) to study the spatio-temporal dynamics of stem canker. Finally, we used hierarchical partitioning to quantify the observed or simulated impact of plant structure variables on i) mirid density and black pod prevalence at the plot scale and ii) pollen beetle density and phoma stem canker severity at the landscape scale.

3 Results – Discussion

At the plot scale, in cacao-based agroforests, we found mirid density to linearly increase with sensitive host tissue amount. This relationship explained 18.9 % of mirid density variance independently of the other variables (Fig. 1). On the contrary, host (cacao tree) abundance had a negative relationship with black pod prevalence and explained 20.3% of the variance independently of the other variables (Fig. 1). This was not coherent with the dilution hypothesis (Keesing *et al.*, 2006) as a decrease in host abundance did not correspond to a decrease in disease infection. In addition, the rarely studied horizontal structure of forest trees explained 14.5% of mirid density variance independently of the other variables. Finally, mirid density was lower in plots with aggregated forest trees than in plots with low forest tree density and it was even lower in plots with forest trees distributed randomly. This is coherent with the known aggregation of mirids on cacao trees that are exposed to direct sun light, a situation favored when high forest trees are aggregated (Babin *et al.*, 2010). Interestingly, mirid density and black pod prevalence were impacted by different features of the biodiversity, respectively spatial aggregation of forest trees and host relative abundance. This opens perspectives in reducing mirid density through forest tree spatial structure optimization without increase in black pod prevalence.

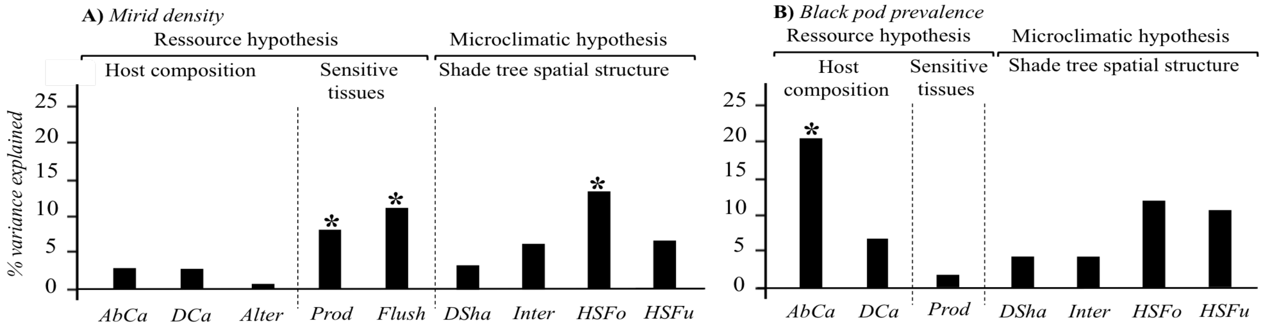

Fig. 1. Results of the hierarchical partitioning analyses: independent contributions of host composition (*AbCa*: cacao tree abundance, *Dca*: cacao tree density, *Alter*: presence/absence of alternative hosts), sensitive host tissues (*Prod*: amount of pods, *Flush*: new leaves presence) and shade tree spatial structure variables (*Dsha*: shade tree density, *Inter*: proportion of shade trees in the intermediate stratum, *HSFo*: horizontal structure of forest trees, *HSFu*: horizontal structure of fruit trees) on A) mirid density and B) black pod prevalence. *Significant contributions (Z-score value).

At the landscape scale, in temperate areas, the first results showed that crop rotation (2 or 10 years, *i.e.* proportion of oilseed rape was about 50% or 10% in the landscape each year) would have a major effect on pollen beetle explaining 86.6% of pollen beetle density variance independently of the other variables tested, *i.e.* trap crop (present or absent) and the forest proportion (less than 3% or more than 25%, which is a wintering site for pollen beetles). This result emphasizes the importance of hosts composition and is consistent with the dilution hypothesis: an increase in rotation length leads to a decrease in oilseed rape proportion and thus a decrease in resource availability for pollen beetles. As changing the crops composition might comes with a very high cost for the farmer, it is important to assess the potential of spatial structure modifications. Aggregation of colza fields has been shown to decrease stem canker severity (Lô-Pelzer *et al.*, 2010). A broader factorial simulation plan is currently designed to test the impact of structural aggregation jointly on pollen beetle density and phoma stem canker severity (with SIPPOM-WOSR).

4 Conclusions

Based on our observations and modelling results, we showed that the dilution of pest resources acts on pest infestation but potentially in opposite directions for black rot on cacao tree in tropical areas and pollen beetles on oil seed rape in temperate areas. Other plant communities' structure variables can affect the pest regulation service and at least in the specific case of black rot and mirid on cacao tree could be used to optimize natural regulations. The impact of plant structures on oil seed rape is still under study but the great diversity of observed relationships between plant diversity and pests natural control suggests that general rules can not be used to guide agronomical practices. In consequence, future research should aim to model the specific characteristics of the main pests of an agrosystem to predict the effect of composition and spatial structures at the relevant scale (Gosme *et al.*, 2013).

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Ecosystem services provided by coffee agroecosystems across a range of topo-climatic conditions and management strategies

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1 Introduction

There is an urgent need to ensure that farming systems not only provide high yields, but also the provision of ecosystem services (ES) on which agriculture and farmer households depend. We compared the provision of four ES indifferent types of coffee agroecosystems: i) regulation of pests and diseases (P&D); ii) provision of agroforestry products (coffee, bananas, fruits, timber); iii) maintenance of soil fertility; andiv) carbon sequestration. We provide key insights on how coffee agroecosystems could be most effectively managed to ensure the continued provision of ES.

2 Materials and Methods

We established a coffee research network (69 coffee plots) in Turrialba, Costa Rica for two years of field measurements (2014-2015). Coffee agroecosystems were selected according to the combination of three factors: i) Altitude: low (<850m.a.s.l.) and high (>850m.a.s.l.); ii) Shade: full sun coffee, simple shade (dominated by *Erythrinapoeppigiana*) and diversified shade (musaceas, service trees, fruit trees and timber trees); iii) Management: low (few cropping practices and low inputs) and high (many cropping practices and high inputs). We calculated the areas under the disease progress curve (AUDPC) of P&D, registered the severity, and counted the number of dead branches. We also assessed the effectiveness of coffee agroecosystem in regulating P&D by estimating the coffee yield losses (=attainable yields minus actual yields; estimated by modelling). Yields, costs and incomes of agroforestry products were used to calculate economic indicators and to assess their overall contribution to farmer households (Cerda *et al.,* 2014). Soil fertility was determined by laboratory analysis. Above-ground biomass carbon was estimated with the use of allometric equations. **Statistical analysis:** analyses of variance using general linear mixed models and the test LSD (Fisher) with p <0.05 to compare the effect of the three factors (altitude, shade and management) and their interactions on the provision of ES.

3 Results – Discussion

The interaction of shade and management was the most important for explaining the regulation of P&D. Coffee leaf rust (*Hemileiavastatrix*), the severity of P&D attacks and the number of dead branches were higher in full sun coffee plantations with high management as well as in coffee under diversified shade with low management; indicating that none of those extremes are good for avoiding P&D. Coffee under diversified shade with high management showed fewer P&D impacts, suggesting that complex agroforestry systems can contribute to the regulation of P&D (Fig. 1).

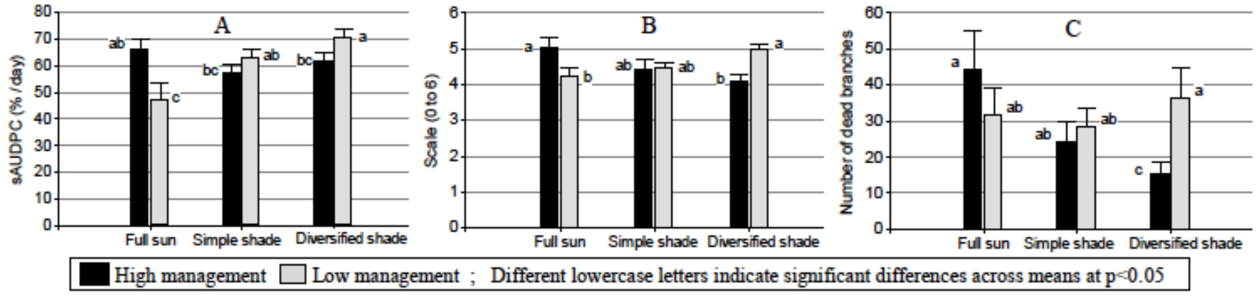


Fig. 1.A) Coffee leaf rust, B) Maximum severity, and C) Dead branches, according to shade and management.

Attainable yields and actual yields of coffee were similar among coffee in full sun with high management and coffee agroforestry systems, but coffee under diversified shade with high management tended to have the lowest yield losses

(Fig 2). These results reinforce the idea that diversified shade systems can help to regulate P&D (Fig 1). These findings become important knowledge for the development of agroecosystems that are capable of balancing high yields and reduce the impacts of P&D (Avelino *et al*., 2011).

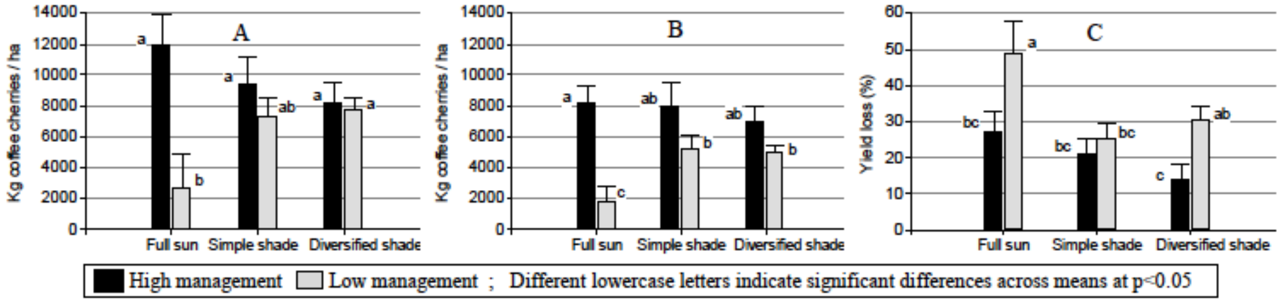
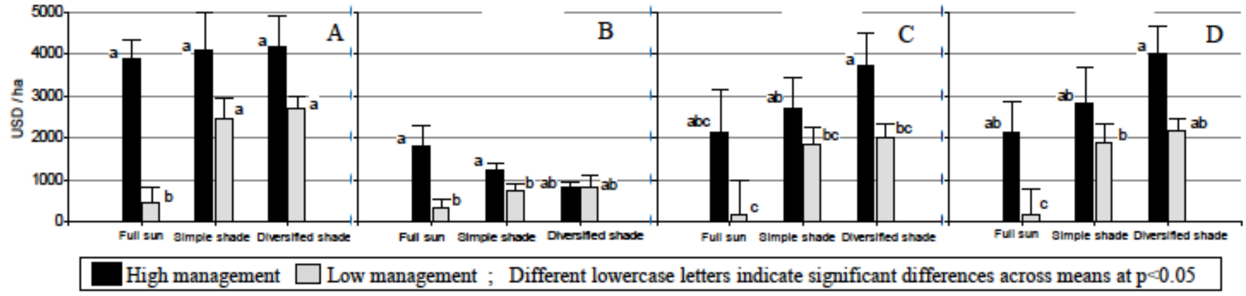


Fig. 2.A) Attainable yields, B) Actual yields, and C) Yield losses of coffee, according to shade and management.

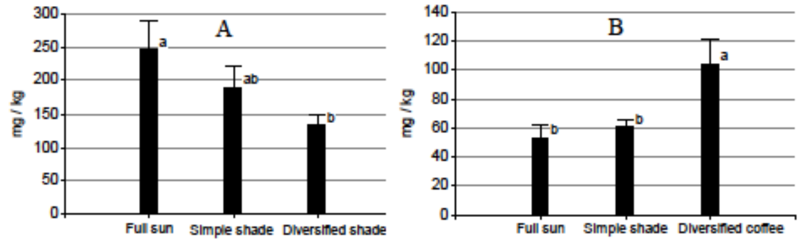
Only high coffee yields would not always be the best for farmer households. Cash costs of coffee in full sun were high and therefore its cash flow tended to be lower than in agroforestry systems. Besides, the agroforestry products of shade canopies increased even more the cash flow, the domestic consumption, and therefore, the family benefit (Fig. 3).

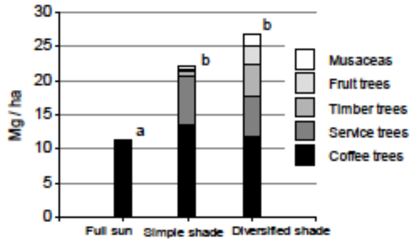


Cash flow = Gross incomes – Cash costs; Family benefit = Cash Flow + value of domestic consumption of agroforestry products

Fig. 3.A) Gross income, B) Cash costs,C) Cash Flow, and D) Family Benefit,according to shade and management.

The sole effect of shade was the most important on soil and carbon. Most elements of soil fertility were better in coffee under diversified shade, as in the case of acidity and potassium (Fig. 4), two key indicators of soil quality. Finally, agroforestry systems had at least double the above-ground carbon compare to coffee in full sun (Fig. 5).





Different lowercase letters indicate significant differences across means at p<0.05

Fig 4.A) Acidity, and B) Potassium in soil. **Fig. 5.Above-ground biomass carbon.**

4 Conclusions

The provision of ES varies across different types of coffee agroecosystems. The best ES are provided by coffee agroforestry systems. Coffee farming systems should be designed with the inclusion of productive shade canopies and managed with constant cropping practices, trying to reduce as much as possible the cash costs for a higher family benefit; being also the best alternative to reduce yield losses.

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Evaluation and design of multispecies cropping systems with perennials: are current methods applicable?

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1 Introduction

Mixing simultaneous crops, including perennials is repeatedly mentioned as a way towards ecological intensification in agricultural fields (Malézieux *et al.*, 2009). Research on these systems has developed recently and show that this mixing is not a silver bullet: practices have to be adapted locally in order to build on synergies and minimize tradeoffs between diverging functions, productions and services. For example, the introduction of shade trees in coffee plantations has contrasting effects on disease regulation, depending on the location, on the disease considered, or even on the epidemiological stage of the disease (Bedimo *et al.,* 2012). The same difficulties arise when considering the use efficiency of water or of nutrients. These requirements for local adaptations make the outscaling of innovations relatively difficult: the same cover crop in vineyard can have positive outcome on grape production in a location, and a negative outcome in another one, due to climatic or soil differences (Ripoche *et al.*, 2010).
Moreover, these systems usually rely on various products that enter into different value chains and are delivered at different time scales; the systems, due to the inclusion of perennials, have to be planned on the long term, with low transformability; as they are supposed to provide services as well as goods, their evaluation is complex, relying on multiple indicators.
Methods for cropping system evaluation and design have been developed for annual systems principally. Do they apply to cropping systems with perennials, are adaptation required or do we need to develop new methods?

2 Existing methods and their applicability to multispecies cropping systems with perennials

We discuss the applicability to these systems of common methods developed for the design of simple and annual cropping systems, based on several temperate and tropical case studies (Table 1).

Table 1: case studies selected for each method

Method used for the design / Systems	Prototyping	Participatory diagnosis of current systems	Modelling/simulations
Tropical Agroforestry	Design of two long term coffee agroforestry experiments with experts (Haggar et al., 2011)	Design of agroforestry systems based on the study of trade offs between Ecosystem Services, (Notaro*et al.,* this congress),	Modeling for the design of coffee based agroforestry systems, (Meylan et al., 2014)
Temperate agroforestry	Design of pesticide-free agroforestry system without pesticides with experts (Grandgirard et al., 2014)	*Commercial agroforestry systems in temperate regions are too scarce to allow for meaningful diagnosis*	Virtual experiments to identify optimal tree density and organization in the field (Talbot, 2011)
Mediterranean grapevine	A prototyping method for the re-design of intensive perennial systems: the case of vineyards in France (Metral*et al.*, this congress)		Cropping system design for including cover crop in vineyards (Ripoche et al., 2010)

A first approach is prototyping, based on the integration of general and local knowledge to elaborate hypotheses on the factors influencing the performances to be improved and build solutions according to these hypotheses (Lançon *et al.*, 2007). These methods apply well to complex systems, as the expert knowledge mobilized is often integrative, as shown in vineyards (Metral *et al.*, this congress) or in trees/arable crops systems (Castel *et al.*, 2013; Grandgirard *et al.*, 2014) in France. However, the evaluation and iterative design improvement of the resulting prototypes is problematic, as it relies on long lasting experimentation with results only validated locally (Stamps and Linit, 1999). Some experiments have been set, both in tropical regions and in EU and the US, which design were usually decided following this method. Few of them have already produced the expected results (Haggar *et al.*, 2011). The timing of the iterative adjustment of prototypes is always problematic in these perennial systems.

A second approach is based on diagnosis of existing cropping systems. The objective is to identify and rank environment and cropping system variables related to performance variation, and then to identify leeways and stepwise improvements through participatory research (Doré *et al.,* 1997). Many experiences of complex cropping system design rely on related methods. However this method requires an important number of commercial fields, implemented since long time enough, which might result difficult particularly in case of poorly disseminated complex systems. This is particularly true in vineyards in Europe, where monocropping has been the rule, particularly with the advent of mechanization. It is still very common in tropical agroforestry, where research has followed, rather than preceded, these practices. Millions of hectares of coffee or cocoa plantation are managed as agroforestry systems, and the potential of these methods for innovation is great (Notaro *et al.*, this congress).

The third set of methods relies on simulations with numerical models, to evaluate or design new combinations of practices that better fulfill a limited number of objectives. This method allows the exploration of very numerous solutions to select those that satisfy best the criteria; it can be used with stakeholders (Martin *et al.*, 2013). Models simulating multiple species and perennial cropping system are relatively scarce. Moreover, these models have a narrow validity domain: for example, they rely on strong hypotheses on soil exploration by the roots of mixed species, which can be hardly transposed to new environmental conditions. When used in collaboration with farmers, these models have proved very useful to explore scenarios and trigger new, more precise questions and hypotheses from participants (Meylan *et al.*, 2014). The recent uptake in silvoarable temperate agroforestry systems (STAFS) (about 3000 ha planted each year in France since 2012) was stimulated by the publicity about some key features of STAFS that were NOT measured on the field, but produced by simulating STAFS with process-based numerical models (i.e. high Land Equivalent Ratio (Talbot 2011); deep nitrate capture (Adriannarisoa *et al.*, 2015); good light transmission (Molto and Dupraz, 2014); enhanced resilience to extreme weather event (Schuller *et al*., 2015)). Waiting for field experiments to deliver the same outputs would have required decades. Nevertheless, there is a need to refine and validate the modelling tools that were used in order to avoid stakeholders to take wrong decisions for wrong reasons

3 Conclusions

We conclude that the existing methods are applicable to multispecies cropping systems with perennials. However, the particular features of these cropping systems highlight the drawbacks of each of them. Therefore, combining these approaches, where and when it is possible, should be preferred. Whatever the method, evaluation of the new systems requires new indicators development, to account for the multiple productions with very different timescales and serving varying objectives. Development of simple and effective sets of indicators adapted to these systems is a powerful tool to boost the design realm, for practitioners and researchers alike.

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Design of Agroforestry systems with coffee is facilitated by the description of relationships between Ecosystem Services provided

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1 Introduction

Ecosystem services (ES) have been defined as "conditions and process whereby the ecosystem sustains the primary human needs" (Daily, 1997). Cropping system do not provide only agricultural products, but also a range of services and disservices to the society. A way to achieve agroecological intensification of cropping systems could be reached by optimizing the ES they provide (Doré, 2011). Our study focused on coffee agroforestry systems that are supposed to provide a bigger ES panel in comparison with monospecific cropping systems (De Beenhouwer, 2013). The specific and structural complexity of these systems makes this optimization a methodological challenge. Our aim was to propose pathways for an agroecological intensification of theses cropping systems by studying the determinants of the provision of ES and the relationships between them. Four ES have been considered, coffee production, tree biodiversity, carbon sequestration into the aboveground biomass and quality of output water from coffee agroecosystems. We bore a specific interest to coffee production because economically is the most important service for growers, the 3 other services being more environmental and thus important for the cropping system sustainability but not for producer livelihoods. Several steps were necessary in order to reach the objectives: (i) understanding and quantifying ES determinants (ii) assessing the links between ES (independence, facilitation or trade-off) (iii) identifying cropping systems and innovating cropping practices that optimized the delivery of these four ES.

2 Materials and Methods

The study was done in Nicaragua, municipality of Tuma-La Dalia, 40 km north of the regional capital Matagalpa. A first survey was carried on 82 coffee producers selected by snowball sampling from April to June 2014. It enabled the determination of services related to water quality and coffee production at farm scale (by interview) and to tree biodiversity and carbon sequestration measured in a 20x50 m^2 plot in a representative coffee plantation. To better assess the determinant of coffee production, a second survey was led with 27 farmers, part of the 82 initial sample, from July to October 2014: we measured the main state variables of the system in 3 repetitions in the 20x50 m^2 plot and led thorough interviews about cropping practices with the producers.
The service of Water Quality - WQ - (score without unity) has been constructed based on doses of active ingredients of pesticides applied, and from the active molecule properties of the pesticides (IUPAC, the Pesticide Properties DataBase – PPDB – 2013). Tree biodiversity - Sh - (without unity) and carbon sequestration - C seq - (t of C) services have been applied for the shade trees of the agroforestry systems and calculated respectively with the index of Shannon (1948) and with an allometric equation from Chave et al. (2005). The service of coffee yield ($kg.ha^{-1}$) has been first picked up from the interview (data for 2013) and then field estimated (2014).

3 Results – Discussion

There was no connection between tree biodiversity and carbon sequestration (Fig. 1). Carbon sequestration was much more strongly related to tree diameter -and, to a lesser extent, to wood density- than to the number of trees. We found weak but significant correlation between coffee yield and water quality (negative, p-value = 0.015) (Fig. 2). The more pesticides are applied, the higher is coffee yield. But yield was not correlated with tree biodiversity nor with carbon sequestration (Fig. 2). Agronomic diagnosis enabled to know that coffee yield was highly and negatively correlated to shade density, to fongal disease and to weed pressure and positively correlated to soil pH.
Based on the quantification of the four ES, we separated by cluster analysis two types: one, smaller -9 coffee plantation among the 27- where high quantities of ES were provided, and the other one –the 18 coffee plantation remaining where provision was lower (Table 1). The mean values obtained for the 9 selected growers can be used as goals to reach for agroecological intensification. Disease, soil pH and nitrogen are statistically different, and also shade and weeds of the agroforestry coffee based system. To reduce shade, more time for pruning shade tress will be necessary. This would allow a faster weed development, and thus to mitigate it, producers will have to increase density of coffee plantation or

spend more time for mechanical weeding. To minimize weeds and fungal disease, the use of environmental friendly and efficient pesticide (identified during our study) could be a solution. Soil nitrogen and pH are important for coffee production and are as well correlated with the density of leguminous tree. Many Fabaceae trees contribute to maintaining a good level of soil Nitrogen but at the same time acidify the soil (Moura, 2015). Therefore to optimize the soil parameters it is necessary to find a good leguminous density, around 50 trees.ha^{-1}. Besides biodiversity seems to have a role to obtain this high joint provision of ES, except water quality service, and a more regular renewal of coffee plantation should allow better production.

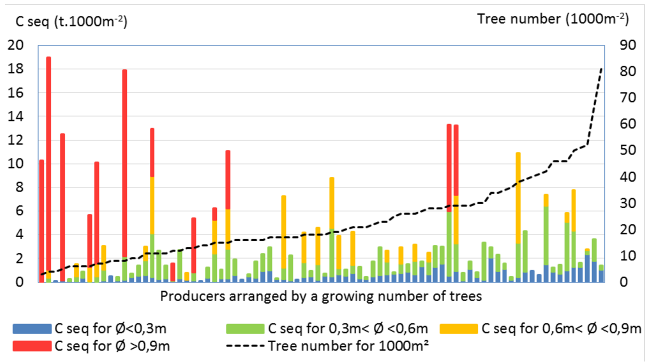

Fig. 1. Example of C seq to understand the determinants for the provision of this service. Ø means tree diameter.

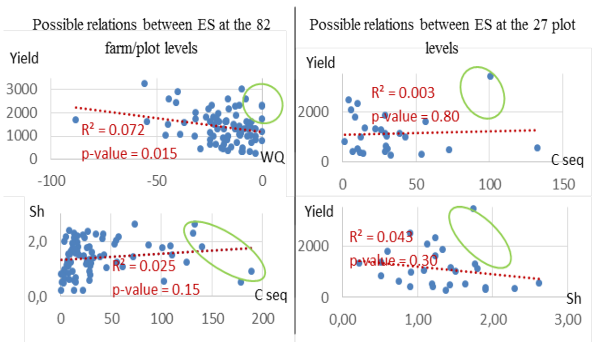

Fig. 2. Feasible relations between ES with the correlation coefficient (R-squared) and the p-value indicating the curve significance. Green ellipses shows where we should find trade-offs or win-win situations.

	Comparison element	Means of the 9 producers selected	Means of the other 18 producers	T-test
ES	Coffee yield(kg.ha^{-1})	2318 ±602	774 ±412	*
	WQ (index)	45.4 ±4.7	39.5 ±11.3	*
	C seq (t.ha^{-1})	40.4 ±45.6	27.8 ±19.1	
	Sh (index)	1.47 ±0.69	1.22 ±0.47	
State variables of agroforestry systems	Disease (% affected leaves)	0.08 ±0.13	0.30 ±0.34	***
	Shade (% plot covered by tree shade)	41.4 ±15.2	52 ±11.7	*
	Weeds (% ground plot covered)	21 ±14.6	30.4 ±16.2	*
	pH	6.23 ±0.44	5.79 ±0.25	***
	N soil (mg/L of nitrogen in the soil)	0.31 ±0.06	0.22 ±0.09	***
	Organic matter (% soil)	4.74 ±0.55	4.53 ±0.77	
Managing practices and shade tree choices	Nitrogen fertilization (kg.ha^{-1})	44.4 ±48.1	26.9 ±40.1	
	Pruning time of shade trees (days.ha^{-1})	4.1 ±3.1	5.1 ±3.8	
	Number of tree species (/1000m²)	9.5 ±6.1	5.9 ±2.7	*
	Number of fruit trees (/ha)	260 ±210	150 ±160	
	Number of firewood/timber trees (/ha)	70 ±25	50 ±70	
	Number of Fabaceae trees (/ha)	50 ±70	140 ±90	***
	Coffee age	8.4 ±5.1	14.6 ±13.6	*
	Density of coffee plantation	4940 ±1425	4720 ±1233	

Table 1. Comparisons of ES values, state variables of agroforestry systems and managing practices means between a group of 9 producers with high ES provision and the others (group of 18 producers). Student test was running to bring out the significant differences. Code signification, p-value: <0.05 "***", <0.15 "*"

4 Conclusion

This method permit to provide some pathways for designing agroforestry system in accordance with agroecological intensification trying to optimize the provision of several ES. We identified the action leverage, in other words state variables and managing practices to change in the coffee based agroforestry. However, we did not assess the feasibility for the producer to implement those modifications that would probably take more time than conventional management.

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What is the multifunctionalityof the mango orchards in Senegal?

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1 Introduction

Since forty years, the Senegal mango production has been developed to supply both the national and international markets. Around100,000 tons are yearly produced from quite diverse orchards. Some functions of the mango orchards dedicated to the fruit production marketing, are analyzed. The subject is the mango orchard rooted in a territory (Rapey *et al.*, 2004). The functions are defined with respect to user expectations. Various users exist: farmers, breeders, walkers, inhabitants, local representatives, territory administrator. The functions that are defined at the orchard level, involve different stakeholders. They go beyond the fruit production functions. The objective is to compare the functions of four types of orchards, resulting from a survey on orchards design and management.

2 Materials and Methods

The choice of the functions. A typology based on agronomic data (42 variables) classified 64 mango-based orchards in Niayes area. Four categories were obtained: (1) No-input mango diversified orchards ;(2) Low-input mango orchards; (3) Medium-input citrus predominant orchards; (4) Medium-input large mango or citrus predominant orchards (Grechi *et al.*, 2013).
The functions identified from literature and expert opinion are in three types:
-Productive functions: creating income from fruit production, maintaining employment in the area, land markers, increasing assets, other economic production within the perimeter of the orchard (hedges, grazing, market gardening).
-Social functions: wooded savannah landscape, tourism, maintaining employment on farms on a human scale, use of local variety.
-Environmental functions: storage of carbon in the soil (soil cover by trees, hedge, fertilization), plant biodiversity and fauna, cultivated biodiversity (other crops, plant diversity in hedges), pesticides pollution of water and soil, water depletion, creation of humid zones.
These functions can be negative or positive in relation to the stakeholders and the duration that are concerned.

The selected indicators. For each of the functions, we have selected some variables coming from the survey already done. They are used as indicators of the different functions and sub-functions. 13 indicators have been chosen, based on the author's experiences.

Productive functions: There was no yield data in that survey. We assumed that all the orchards have a fruit production. Four indicators characterize four sub-functions of productions other than fruits in the orchards: "pasture" that means that the orchard is used for pasture during some part of the year; "other crop": there are some crops grown between the line of the fruit trees; "hedge": the trees and shrubs in the hedges produced some fruits, leaves for medicinal uses and food, as well as wood for fire or building. An indicator "concrete block wall" is related to the land property, and consequently to the financial land valorization.

Social functions: three indicators are identified in relation with three sub-functions of the orchards; the landscape indicator is the ratio "hedges/acreage": the higher is the ratio, the higher is the percentage of hedges in the landscape with esthetic and walk values; "acreage" of the orchards in relation with the fact that the orchards should remain at a human scale; percentage of local mango varieties in the orchard "local varieties" in contrast to export varieties.

Agro-environmental functions: Six indicators have been chosen in relation with three sub-functions: the capacities of the orchards to maintain biodiversity, the soil protection and the water protection. The diversities in the "hedges species" around the orchard and the diversity of the fruit trees "species" in the orchards will provide some trends for the biodiversity. The soil protection is characterized by "fertilization" based on the hypothesis that fertilization will improve the storage of carbon in the soil. No difference has been done in this indicator between mineral fertilizers and animal manure. The second indicator is the "cover" of the soil by the canopy. The higher is the "cover", the higher is the protection of the soil. The relations with the water protection will be estimated by two indicators: the "irrigation" describing mainly the level of the irrigation in the orchards and the "pesticides" indicating also the level of pesticides use in the orchards. High irrigation and high pesticides application cause a low protection of the water.

The individual values from the previous survey are transformed by arithmetic operations and then added together to give "synthetic indicators" of same order.

3 Results – Discussion

Synthetic indicators of the productive, social and agro-environmental functions are gathered for the four types of orchards in the table 1.

Table 1. Synthetic indicators of functions for the 4 types of orchards in Niayes areas

Functions	Productive	Social	Agro-environmental
(1)No-input mango diversified orchards	9,4	6,1	15,1
(2)Low-input mangoorchards	11,0	5,9	13,0
(3)Medium-input citrus-predominant orchards	13,0	7,8	12,1
(4)Medium-input large mango or citrus predominant orchards	10,2	5,3	8,4

The table 1 puts in evidence that the functions of the different types of orchards seem intuitively in accordance with the expected results for social and agro-environmental functions, although a low number of indicators are used compared to the 42 indicators of the IDEA method (Villain *et al.* 2008). Agro-environmental functions are lower in the large orchards mainly focus on export production. But the type (3) orchard provides more productive and social functions that the types (1), (2), (4). The results of the productive functions raise the questions about the measurements of the yields and other productive sub-functions in spite of the lack of yields.

4 Conclusions

It seems possible to re-analyze an agronomic survey in a multifunctional approach which allows to better characterize the asset of orchards in a rural area.

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Mapping spatial distribution of Cocoa Swollen Shoot Disease for effective rehabilitation strategies in infected areas

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1 Introduction

Cocoa Swollen Shoot Virus (CSSV) is a semi-persistent virus transmitted to cocoa plants by mealybugs (Fig.1B) (Dufour, 1988; Lot *et al.*, 1991). CSSV disease evolves slowly and gradually through the plot (Oro *et al.*, 2012; Castel *et al.*, 1980; Partiot *et al.*, 1978). The symptoms of most virulent isolates are characterized by intense red coloration along the secondary veins and limb on young leaves (Fig. 1A), discoloration on adult leaves, swelling of stems and branches (Fig.1C) and stunted pods**.** This disease is endemic in major cocoa production regions of Cote d'Ivoire where it represents the main threats for cocoa production in the country (Kouakou *et al.*, 2012).

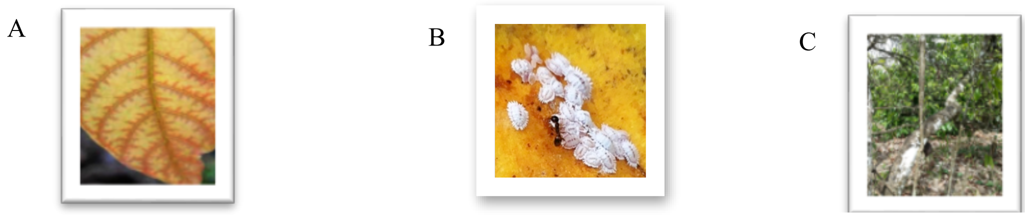

Fig. 1. Symptoms and vector of Swollen shoot Disease: (A): intense red coloration along the secondary veins and limb on young leaves, (B): mealybugs colony on mature pod, (C): swelling of stems.

In 2009, more than 12% of cocoa areas in Côte d'Ivoire were affected by disease (Anonym, 2009), but this figure seems to have increased given the damage observed in major production areas such as Soubré. CSSV disease is currently a major challenge for developing cocoa farms regeneration strategies, because there is no information system capable to update producers on disease prevalence**.** Hence, the implementation of the spatial distribution of CSSV at different scales is necessary for efficient monitoring of the disease and development of rehabilitation strategies. However, little data exists locally to accurately inform stakeholders on the prevalence the disease. Therefore our investigations aimed at supplying the stakeholders with evidence-based information on the prevalence of CSSV in main cocoa production areas in Côte d'Ivoire; the Nawa region.

2 Materials and Methods

Data collection

This study was conducted in the Nawa region located in the South- West of Côte d'Ivoire. This region is recognized as the leading cocoa producing area. Data were collected in two sentinel sites (Petit-Bondoukou and Koda), based on LDSF method (Land Degradation Monitoring Framework). Next, Field Survey Units have been defined as blocks of 10 x 10 km i.e. 10'000 ha and each of them has been installed in two sites of the Nawa region. 160 sample plots; each covering a circle of 50 m radius (7850 m^2) were randomly designed in each site. Data recorded include: Presence or Absence of CSSV outbreaks, Number of outbreaks, size of outbreaks and spectra data of outbreaks, which delimit the CSSV focus. The geographical coordinates of each plot were recorded to identify the spatial distribution. The number of cocoa trees was also counted for planting density estimation.

Spatial distribution and mapping

Data relating to presence or absence of CSSV disease at each plot were analyzed with statistical logiciel "R". Data were represented in an orthonormal with abscissa X, longitude and ordinate Y, latitude to produce spatial distribution maps for Petit Bondoukou and Koda. These maps have observed a large spatial variability of CSSV disease between the two sites. To better understand this spatial variability, we studied the correlation between "Short cocoa tree density» or "Great cocoa tree density" for both sites and areas affected by CSSV. The results were represented as boxplot. The chi-square test was applied to areas affected by CSSV and cocoa trees density to determine if there is a significant difference firstly between infected areas and short cacao tree density and secondly between infected areas and great cocoa trees. That as well for Petit Bondoukou site and for Koda site.

3 Results – Discussions

Disease spatial distribution maps

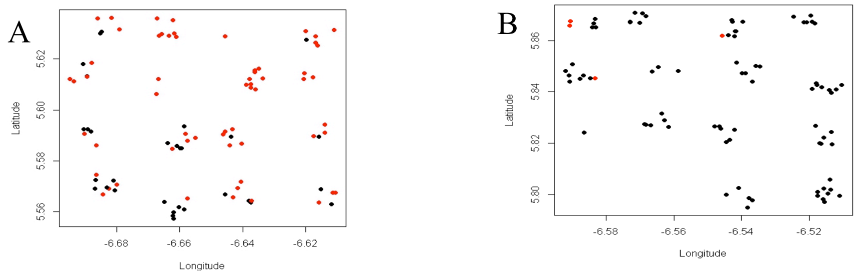

Fig. 2. CSSV distribution maps in both A: Petit Bondoukou (PBON) and B: Koda with red dots: presence of CSSV and black dots: no CSSV infection.

There is large variability of CSSV spatial distribution between Koda and Petit Bondoukou. This variability is expressed by 63% of disease presence in Petit Bondoukou plots (Fig. 2A) against 3% in Koda plots (Fig. 2B). CSSV infection seems to increase with both Longitude and Latitude coordinates. Heterogeneous data distributions have been observed between both Cocoa tree density and CSSV occupied area analyzed parameters (Fig. 3). However cocoa density trees parameter is normally distributed after data normalization around 0.5).

Rate in cocoa short and great tree evaluating CSSV propagation

Fig. 3. Boxplot shows the tree distribution (short and great trees) between both Petit Bondoukou and KODA sites.

Boxplot of short and great tree distribution in both Koda and Petit Bondoukou sites showed a significant difference between these two analyzed parameters. Furthermore, in Koda a consistent number of short tree have been observed with respect to Petit Bondoukou (Fig. 3). In this case the heterogeneity of the cocoa trees within the two considered sites is strongly evidenced by the statistical Chisq test from R software (p-value < 2.2e-16). This statistical analysis suggests that the high presence of short cocoa tree in the KODA with respect to those of Petit Bondoukou, could explain the difference in CSSV infection between the two under-analyzed sites. The Chisq test suggest that CSSV presence and/or absent in both Koda and Petit Bondoukou site, depend on the rate of short cocoa trees. Knowledge on the spatial variability can help design rehabilitation strategies in infected areas. Indeed, the use of full replantation technique and barrier trees are recommended in highly infected areas while grafting techniques on mature orchards are recommended in low disease prevalence areas.

4 Conclusions

The results presented in this work are partial and give but gives good prospects for understanding the spatial variability of the disease between Koda and Petit Bondoukou sites. This variability is related to the strong presence of short cocoa trees at Koda unlike Petit Bondoukou where there is only great cocoa trees.

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SYSTEMIC ANALYSIS OF A TEMPERATE FOREST GARDEN: A CONTRIBUTION TO COMPLEX AGROSYSTEMS STUDY

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1 Introduction

Forest gardens often described as permaculture systems are agrosystems that intimately mix a large number of trees and annual plants species on a small surface. Mainly studied in the tropics and almost unknown in temperate climates [1], they are today proposed as models of a sustainable agriculture although there is few quantitative data about their functioning, efficiency and sustainability (Torquebiau, 1992; Kumar & Nair 2004). The potentialities and principles of these gardens could be used as inspiration to design and improve agroforestry systems in farm conditions. Thus, questions arise about the biophysical functioning of such agrosystems and as a first step about the proper methods that should be used to study them. The objective of this paper is to present the systemic analysis of a temperate forest garden and discuss the interest of this method to study such complex agrosystems.

2 Materials and Methods

The studied garden is located in Belgium and has been cultivated on 2000m^2 for 40 years. This agrosystem is cultivated as subsitence and pedagogic farming with extreme diversity and density. A close garden with similar area (6000 m^2) and age (28 years) was used as a control to compare the measurements. It is cultivated with more classical techniques with lower plant density and diversity and in the objective of producing food.
The first step in our analysis was to define the conceptual model of the agrosystem in order to select process and variables to be further analyzed. We used the conceptualisation protocol of Lamanda *et al.* (2012) which allowed to identify the key sub-systems and their interactions. The active environment included physical input and labor as well as climate constraints. The passive environment included vegetable, fruit, wood and wild plant production, efficiency indicators and ecological services. This conceptual model then helped to analyse emergent properties of the system with five types of variables: the agrosystem performance, the structure of the plant stand, the animal biodiversity, the tree root distribution and soil characteristics driving key biophysical processes of the agrosystem (Altieri,1999; Fernandest & Nair, 1986).
The agrosystems performances were measured with efficiency indicators. The list of inputs and outputs was first established through interviews of the gardeners and observation of the garden. We took into account any exchange of the agrosystem with its environment. Then the quantity of inputs and outputs was evaluated when possible.
The structure of the garden was described with the biological composition and the organization of the three dimensions: horizontal, vertical and chronological. Shannon and Simpson indexes were calculated to evaluate structural complexity (Ngo Bieng, 2007). We determined the tree density and defined the interface index as the length of the imaginary contact line between trees and vegetables divided by the surface cultivated with vegetables (Pasquier, 2014).
Animal biodiversity was studied with three sampling methods. Aerian arthropods were caught with a yellow trap, and crawling arthropods with a Barber trap. Traps contents were collected every five days. We also used a earthworms catching protocol. We repeated this sampling procedure three times in the forest garden as well as in a control garden and a nearby grassland. An analysis of variance was done to compare abundance and diversity of the samples.
An auger was used to sample tree roots in different soil layers and at different distances from the fruit tree hedge in the forest garden and in the control garden (Fernandest & Nair,1986). An analysis of variance was used to study the influence of tree density, depth and distance from the fruit tree hedge on the biomass of roots.
Soil characteristics driving biophysical functioning of the agrosystem were also measured in the first soil layer (0-30cm): soil texture, organic matter content, bulk density, water infiltration rate and biological activity through soil respiration.

3 Results and discussion

A complete quantification of inputs and outputs appeared impossible in such an agrosystem but we found low levels of inputs for a significant level of production. The study of N cycle in the forest garden revealed a diversity of small N inputs including atmospheric deposition, human urine, neighboring lawn cuttings and chickens feeding. Specific

practices were highlighted that are not documented in the scientific literature such as tree disease management by ground deposition of infected tree shouts. Summer pruning of the fruit trees was a key practice in the agrosystem management influencing light catchment by tree strata, organic matter cycling and tree disease management.
Indicators of species diversity as well as of structural complexity like the Shannon and Simpson indexes (Table 1) showed results similar to tropical forest gardens.

Table 1. Different structure indexes

Species diversity			Structural complexity		
	Forest garden	**Control garden**		**Forest garden**	**Control garden**
Tree species	71 (1237*)	33	Shannon tree	3,252	2,598
Vegetable species	57	43 (149*)	Simpson tree	0,701	0,115
Wild plants	53 (28 edible)	25 (+24 ornamental plant species)	Tree density	1,14	0,64
Total species	181	125	Interface index ($m.m^{-2}$)	0,88	0,35

* number of varietes

The vertical organization showed five strata. The dwarfing rootstocks enabled the creation of an intermediate strata between tall trees and shrubs. The garden was organized following a north-south axis. Vegetables were associated to dwarf trees and shrubs in the southern part of the garden and tall trees protected the garden from the wind in the northern part. Wild plants were harvested with a low level of management. Insect diversity was higher in the two gardens than in the grassland (Table 2). In the forest garden we found much more earth worms and we trapped isopods and carabidaes which were absent in the control garden.

Table 2. Animal biodiversity indexes

	Forest garden	**Control garden**	**Grassland**
Mean of insect morphotypes number	15,7	17	10,7 *
Total isopods trapped	119 *	1	0
Total carabidaes trapped	10 *	1	1
Mean trapped earthworms	44,7 *	6,3	-

(* indicates a significant difference from the numbers in the same line)

The tree root distribution study showed a high root biomass in the soil of the forest garden (not shown). The pattern of root biomass distribution from the tree hedge, was different in the two gardens. This would deserve further research and suggest the role of rootstock vigor and shoot pruning in the management of root competition between trees and vegetables. The forest garden had a high content of organic matter which was linked to a low bulk density and a high water content (table 3). These findings are consistent with our knowledge of the benefits of agroforestry and no tillage practices [2,6].

Table 3. Soil characteristics

	Forest garden	**Control garden**
Organic matter content (%)	15,6	5,5
Bulk density ($g.cm^{-3}$)	0,84	1,14
Water content ($g.g^{-1}$)	0,52	0,23

4 Conclusions

Putting back the above results in the conceptual model allowed to analyze the emergent properties of the system related to productivity, efficiency and resilience, in the perspective of designing commercial cropping systems which combine fruit trees and vegetables. The efficiency of forest gardens remains to be evaluated using methods of systematic measurement of inputs and outputs. Despite this lack of quantitative data, many research hypothesis were highlighted such as favorable forest garden micro-climate, the effects of plant nutrition, microorganisms and summer pruning on plant health and production as well as the nutritional quality of shaded vegetables. Structural indicators like the interface index will be useful to define agrosystem simplification thresholds concerning biodiversity and structure when extending the principles of forest gardens to design cropping systems in farm conditions.

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"Cropping the roots" of agroforestry systems: applying moderate water stress and water competition at plantation to increase tree root biomass

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1 Introduction

Agroforestry systems performances and stability rely on reduced competition for soil resources between trees and the intercrop. A management strategy at plantation could hence be designed to shape root systems, so that crop roots forage the top soil horizon and tree roots forage deeper horizons. We hypothesize that root growth can be favored by applying a moderate water stress that limits tree shoot growth while maintaining net carbon assimilation (Li *et al.*, 1989; Pellegrino *et al.*, 2006) in order to allocate more carbon to the roots. We therefore hypothesized that such type of soil water deficit should increase root biomass and if combined with a shallow-rooted intercrop stimulate this additional tree root growth in deeper horizons. Therefore, our study aims to investigate the effects of a moderate water stress and intercrop competition on net photosynthesis and carbon allocation to root and shoot compartments, of peach trees intercropped with a grass cover (continuous under the trees) during the first growing season after plantation.

2 Materials and Methods

A 2000m^2 drip-irrigated peach tree orchard with 475 one-year old trees was planted in January 2014 on a clay-loam soil in Southern France with three water treatment replicated three times in a Latin square design: (i) a well irrigated with a canvas soil-cover control treatment (T1), a moderately stressed with a canvas soil-cover treatment (T2) and (ii) a moderately stressed treatment intercropped with a grass cover crop (T3). Soil water potential within the tree root zone was monitored every two days with tensiometers (3 replicates per treatment) and readings at 40cm depth were used to keep soil water status in T1 between 0 and -200hPa, and between -400 and -600hPa in T2 and T3, which is for T2 and T3 sufficient to limit shoot growth without impacting net photosynthesis (Pellegrino *et al.*, 2005). Net photosynthesis was monitored three times with a portable Licor 6200, and pre-dawn leaf water potential twice during the growing season with a pressure chamber. Total root and shoot biomass were weighed at the end of the root growth season on three trees per treatment. Effect of water treatment on these variables was tested with one way Anova.

3 Results – Discussion

Soil water potential (SWP) from the beginning of the fast-growing shoot phase (2014/06/01) to the stopping of irrigation (2014/09/05) indicates that in T1, water status was on average kept at -241± 263 hPa, in T2 at -405± 342 and in T3 at -372± 288 hPa (mean values± standard deviation). This corresponds to our target range only for T2 due to soil heterogeneity (in T3 two tensiometers mean values out of three fall within the range, in T1 one out of three) and some unavoidable variability of SWP in such type of irrigation management in field conditions, as can be seen in Fig. 1, A.

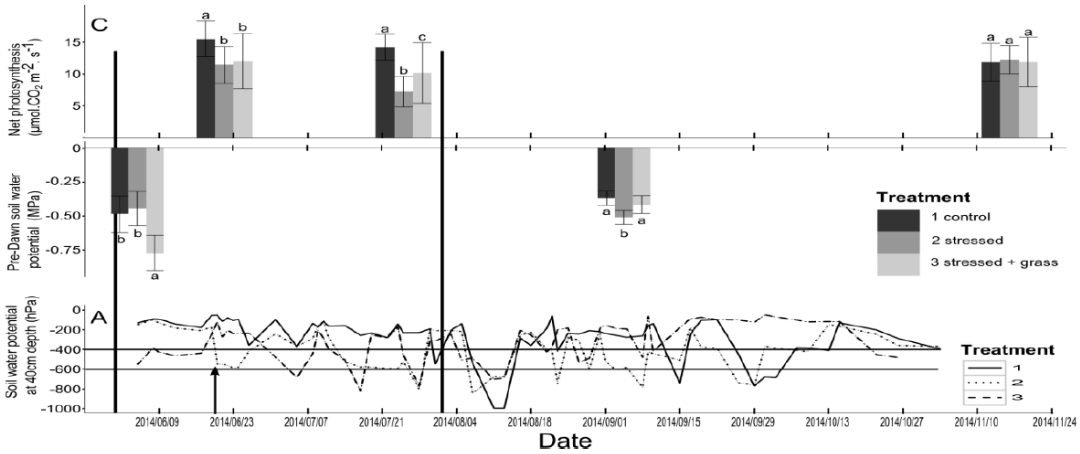

Figure 1: A: soil water potential at 40cm depth (hPa) mean values (n=3), B: pre-dawn water potential (Pa) mean values (n=12) ± standard deviation and C: Net photosynthesis (µmol CO_2.m^{-2}.s^{-1}) mean values (n=6) ± standard deviation per treatment. Figures followed by different letters are significantly different at P<0.05 according to Tukey test. Verticals bars delineate the fast-growing shoot phase and black arrow is the date of T2 soil-cover removal.

Indeed, pre-dawn water potential (Fig. 1, B) show that only T3 was stressed at the beginning of the fast-growing shoot phase (2014/06/05), due to the weed control canvas sheet used on T2 which prevented soil evaporation. Soil was then uncovered in T2 leading SWP to decrease and reach the target level of stress after 12 days (vertical arrow on figure 1, C). On the other hand at the end of the summer (early September), T3 was above the target SWP due to an excessive supply of water. The target levels of soil water deficit was therefore hard to maintain for each treatment during all the crop cycle but were achieved for most of the period and/or in most parts of the orchard.
By the end of June, net photosynthesis in T2 and T3 decreased in comparison with the control (T1), showing that water stress was sub-optimal in T2 and T3 (Fig. 1, C). At the end of July, i.e. at the maximum of the fast-growing shoot phase, net photosynthesis was lower in T2 than in T3. One explanation could be that trees in T2 having been stressed later than trees in T3, they had time to develop a higher leaf area (data not shown) and therefore a higher transpiration making it more difficult to maintain SWP in the target range. By the end of the growing season and after the stopping of irrigation, net photosynthesis was identical for all treatments.
Final tree biomass (Root+Shoot biomass) was significantly lower in T3 compared to T1 and T2 (Fig. 2) which is consistent with an earlier soil water deficit reducing plant photosynthesis. T3 also had a significantly higher Root/Shoot ratio than T1 and T2, whereas T2 was not significantly different from T1. Our first hypothesis was that water stress would increase Root biomass without decreasing net photosynthesis and hence total biomass. We therefore expected both T2 and T3 to have a higher Root/Shoot ratio that T1 but with an equal total biomass. This is the case for T3, but not T2, certainly due to an inappropriate timing and level of water stress. T2 was stressed later than T3, which allowed trees to produce more biomass before net photosynthesis decreased, but certainly too hard at a time where its water demand was high due to its high leaf area. Our second hypothesis was that water stress and competition with a herbaceous plant would force tree roots to growth at depth. We expected T3 roots to be hende found at depth, which is not the case (figure 3). The reason is that T3 was stressed too early and too hard, which hindered leaf development and hence carbon fixation, leading to dwarf trees with not enough carbon resource to allow sufficient root and shoot growth.

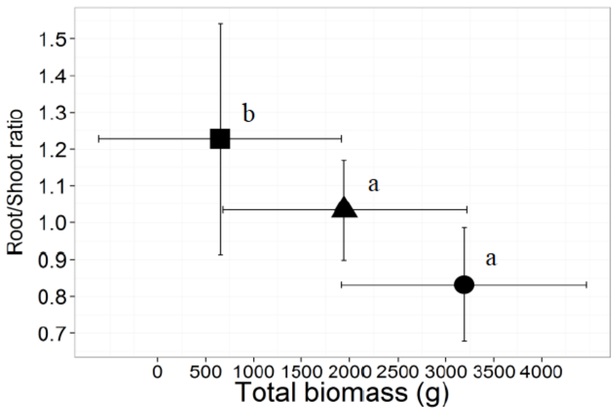

Figure 2: Root/Shoot ratio vs total biomass mean value (n=3) ± standard deviation per treatment at the end of the root growing season.

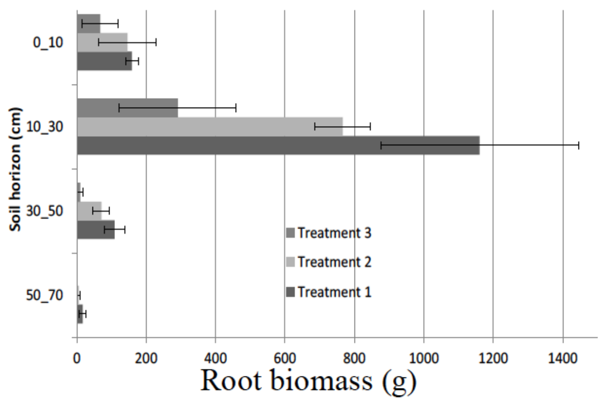

Figure 3: Root biomass mean value (n=3) ± standard deviation per soil horizon and per treatment at the end of the root growing season.

4 Conclusions

Our results show that photosynthesis, a physiological process thought to be the last to be impacted by water stress (Pellegrino *et al.*, 2006), is actually impacted by a moderate stress within the range of tensiometers readings. This means that tensiometers are appropriate tools to apply such a moderate stress, even though it is still difficult to steer water stress with them in field conditions. It also means that in order to test our hypothesis that root growth can be favored by applying a moderate water stress, we need to lower our water stress target range, in order not to decrease net photosynthesis. We also need to apply this water stress later during the growing season so that trees can develop a sufficient leaf area to assimilate enough carbon to support differential root growth.

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New agro-ecologic paradigm for little farming exploitations to obtain alimentary sovereignty

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1 Introduction

To face to the failure of intensive monocultural systems, because of soil degradation and pollution and (micro) biodiversity destruction, in tropical to sahelian zones, we propose a new agro-forestry ecologic paradigm. This concept refers to traditional practices and techniques that mimic the most natural functions. These new systems are based on the ecological intensification provided by the innovative rational multi-stratified multi-specific croppings according to climate change, pedoclimatic conditions, and socio-economic variations. For these systems the ecological performance results from the free Eco-Systemic Services. The approach down-top-down-top was taken with farmers to understand and to improve them by some innovations. The multi-species and multi-stratified systems designed to support productivity in the long term have been widely used in traditional agricultures in the entire world.

2 Materials and Methods

The study of these agro-ecologic systems began in the sixties by surveys among peasants and simultaneously y agronomical trials. The typology of different traditional systems and numerous trials were made in different pedoclimatic conditions. The combinations can be described in many seven main types: decay, relay, sequential, mixed cropping, row intercropping, strip intercropping, and mosaic intercropping. From European to Tropical pedo-climates the Density Equivalent Ratio (1) varies from 1 to 9 which improves the Land Equivalent Ratio (2) from 1 to 3 without trees. The concept of Eco-Systemic Services (ESS), a process whereby agricultural ecosystems produce benefits for society, is introduced by the Millenium Ecosystem Assessment (MEA-2005). These different services supply some agro-forestry ecologic conditions which contribute to increase yields.

3 Results – Discussion

3.1. Surveys

In the Sudano-Sahelian zone, the BIOSOL project initiated au Burkina Faso in 2012, in tree pedoclimatic conditions, has verified that in the Sudanese zone (Orodara) there remains about 43% of mixed cropping whereas in the Sudano-Sahelian zone (Baraniand Sampiéri) this fraction has diminished a lot. Bi (39%) and three (61%) species (cereals-cereals or cereal-leguminous) mixed croppings still remain surrounded or not by hedges and some tree parks have been maintained. 56 types of cultural successions in mono and associated cropping have been monitored.
Tests and trials on cultural associations were implemented in peasant fields in Sudan-Sahelian zones. These trials were carried out on cultural density, fertilization and the struggle against weeds, pests and diseases.
In the Equatorial zone, in West Cameroon, it appeared that the peasants vary qualitatively (species and varieties) and quantitatively (density) the associations according to the eco-systemic potential, social traditions, family food preferences, the distance from local markets and both national and global economic variations.

3.2. Trials

The different studied services are Supporting, Regulating , Provisioning and Socio-Cultural.

3.2.1. Supporting services

Cultural associations were found to favor the fertilization and the conservation/transfer of fertility thus resulting in the economy of fertilisers. The increase of N supply is the result of N leaching reduction. Coffee-Erythrina association reduces N leaching from 14 to 20 NO_3-N mg/NL in comparison to conventional monoculture. Cassava-maize association reduces nutrients leaching in the order of 20-30 units of NPK due to greater association efficiency. This was due to the good Root Equivalent Ratio (RER>1)(3). In the tropical zone, in Cameroon, the Maize-Colocasia-Xanthosoma intercropping system with 50 NPK units brings a LER (2) median de 1.76 (0.76 to 2.44) for trials in 5 sites with very different pedoclimatic conditions. In peasants and research fields, the calculations give a NPK Efficiency (Yield/NPK Unity) Equivalent Ratio (4) more large. These NPK efficiency Equivalent Ratio reached 5 (NP) to 4 (K) with the yield maximum for each systems (50 U for intercropping and 100 U for pure crops). For the intercropping

system, the NPK reduction was for maize 50% of N and 25% for each tubercle, 40% of P and 30% for each tubercle and 30% of K and 35.5% for each tubercle respectively.
For 2 plants, the NEfER was 3.53 (Maize-Sojabean) and 2.36 (Maize-Bean) whereasPEfERwas1.45 (Maize-Sojabean) and 1.93 (Maize-Bean). NPK application of imbalanced or excessive application or because of bad climate led to declining nutrients-use efficiency making fertilizer consumption uneconomical and producing adverse effects on both atmosphere and groundwater.
An economy of water was also found in the Sahelo-Sudanese zone (Senegal at Louga and Bambey), as for the millet-Cowpea intercropping the grains-LER = 1.20 was obtained (5 years of drought with 4randomised replications). The calculated Water Use Efficiency (Yield/AET) Equivalent Ratio (4) equals 2.

3.2.2. Regulating services:
Protection against runoff, erosion and crusting is improved together with pest and diseases control. Inter/mixed cropping control disease and parasite and striga weed because of the pull-push effect, vertical/horizontal barrier, micro environment modification, and favor niches for parasite predators. Pisumsativum and Camelia sativa intercropping brings LER from 1.43 (2003) to 1.98 (2004) because the suppression of adventices. Intercropping increases bacterial and fungal biomass more than monocropping and thus maintains Arbuscular Mycorhyse. Weed stifting is also favored.

3.2.3. Provisioning services:
- Production of food
LERs vary with the number (2 to 12), DER (0.98 to 9) and the associated species from 0.98 (DER<1) to 3 (LER from 1.5 to 9). The important production of straw and tree leaves allow to maintain breeding whereas the culture's residues produce compost and hedges can be used to produceRamial Chipped Wood.

3.2.4. Socio-cultural and ecologic services, healthy food:
Because of the increasing potentially valuable of biomass intercropping allows better than monoculture to maintain or reintroduce breeding. The healthy soil delivers healthy food richer in proteins and vitamins to improve human health. Intercroppings produce more and require more staff thus curbing the exodus from the countryside:

4 Conclusions

The combination of both logical and strategic farmer knowledge and analytic and predictive researcher's knowledge offers a practical framework for the integration of farming practices in a perspective of sustainable improvement. This system supplies some results which are belonging to different socio and agro-forestry-ecological domains. These intercropping systems are implanted traditionally with trees and quick hedges. However to stop erosion due to hard deforestation and ploughing it is also necessary to implement quick hedges, zaï and stone diguettes too.

This new agro-forestry-ecological paradigm which associates much of different plants (trees, shrub, pasture, food/industrial plants…) and animals could ensure the peasants food security and sovereignty.

NB

1) Density Equivalent Ratio (DER) = (Density intercrop 1 / Density monocrop 1) + (Density intercrop 2 / Density monocrop 2) + (Density intercrop 3/Density monocrop 3) +….

2) Land Equivalent Ratio (LER) = (Yield intercrop 1 / Yield monocrop 1) + (Yield intercrop 2 / Yield monocrop 2) + (Yield intercrop 3/ Yield monocrop 3) +….

3) Root Equivalent Ratio (RER) = (Root Yield intercrop 1 /Root Yield monocrop 1) + (Root Yield intercrop 2 / Root Yield monocrop 2) + (Root Yield intercrop 3/ Root Yield monocrop 3) +….

4) NPK/Wu Efficiency Equivalent Ratio (NPK/Wu-EfER) = (NPK/Wu intercrop 1 /NPK/Wu monocrop 1) + (NPK/Wu intercrop 2 / NPK/Wu monocrop 2) + (NPK/Wu intercrop 3/ NPK/Wu monocrop 3) +….

W6. Pathways for sustainable intensification of African agriculture?

Chair: Ken Giller, WUR
Co-chairs: Philippe Lecomte, CIRAD
Liang Weili, Hebei Agricultural University

INTEGRATING THE WOMEN'S LABOR INVESTMENT INTO THE PERFORMANCE ASSESSMENT OF OX-DRAWN COTTON PRODUCTION IN CÔTE D'IVOIRE

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1 Introduction

Cotton production in Francophone African countries has been considered as one of the few success stories (Gabre-Madhin and Haggblade 2003) lying greatly on the development of ox-drawn mechanization (Campagne and Raymond 1994) which remains somehow labor intensive. Women do contribute to the labor mobilized in cotton production in Africa, but their role was only coped with in a few qualitative analyses, having highlighted that cotton development had implied more women's involvement in cotton fields (Peltre-Wurtz and Steck 1991), up to reduce their capacity to conduct their own fields (Bassett 1988).
This communication is a first study attempting to quantitatively assess the impact of women in cotton production performance. It explicitly takes into account the extent of polygamy of farm heads –for its direct implication on women's availability and that of their offspring for field works.

2 Materials and Methods

This communication is based on a study conducted in 2013 in Northern Cote d'Ivoire through a one-way survey along a sample of 223 farmers in a major cotton producing province ("Département de Korhogo") represented by four of its counties ("Arrondissement").
Given the fact that most farmers were illiterate and no written records were kept at the farmers' level, the survey was conducted by enumerators calling upon farmers' memories. It was not realistic to ambition capturing perfectly the absolute values of time allocation, but the gap calculated for two labor investments (e.g. in distinct types of fields or in distinct periods) could be quite liable.
In each sampled farm, farm heads (males) were interviewed to capture the farmers' characteristics (age, education level), the farm features (size, ox-drawn equipment…) as well as production and costs. When dealing with the composition of families, the involvement of family members in field activities and their possible responsibility in managing plots for their own account were recorded. Women were interviewed in addition to capture their own assets (notably mobile phones and bicycles) and to address factors that could potentially impact their labor contribution in the fields of their husbands: size of their cultivated lands, time spent daily in their fields and in those of their husbands, and the number of days in ten-day period they were allowed to work in their own fields. Women were also asked whether their husband should keep on growing cotton, their opinion was interpreted as reluctance to cotton production in case of negative or absence of answers.
In data processing, descriptive analysis was complemented by multivariate regressions encompassing independent variables related distinctly to characteristics of farm heads, farms and women.

3 Results and discussion

There were more polygamous farm heads than monogamous, although only one fourth of them had more than two wives. The more farm heads had wives, bigger were their families, higher was the number of family members in fields, greater was their frequency to have at least two complete sets of ox-drawn equipment as well as were the cultivated and cotton areas. In terms of production performance indicators, either technical (farm cotton production, yield) or financial ones (gross income or surplus), superiority was found only for farms having more than two wives, while no difference was observed between farms having one and two wives, respectively. These results confirm and are more precise about the positive relationship observed formerly between cotton development and women, as above mentioned.
With regard to women, they kept on having land cultivated for their own. Furthermore, lower was the number of wives within a farm holding, bigger was the size of land women could manage for their own, and higher was the frequency they had a bicycle if not a cell phone. However, regardless of the number of women within a farm, the time women had to dedicate daily to the plots of their husbands far exceeded that allocated to their own plots. Hence, women lacked more time than land to produce for their own.
In multivariate regressions, the significant influence was only found for a relatively small number of variables either for

technical performance indicators or financial ones, likely because of the limited size of the study sample.
The influence of the number of wives was confirmed for technical performance indicators. The absence of effect of input intensification could be related to the little variation between farms in this intensification. With regard to the financial performance indicators, the influence of the number of wives vanished if not reversed somehow. The women's reluctance to see their husbands engaged in cotton production could be a reason. Allowing more days to women to go and care for their plots –for short duration− seemed to be positive.

Table 1. Farm characteristics and performance according to the number of wives of the farm heads (the presentation of a few variables is omitted for lack of place)

	Number of wives of the farm head			Total	p value
	1	2	> 2		
Number of farms	90	96	37	223	
Age of farm heads	39,4	41,2	41,9	40,6	0,242
% of illiterate farm heads	84,3%	73,7%	88,2%	80,2%	0,070
Number of family members	6,5 c	10,0 b	13,8 a	9,2	< 0,0001
Number of family members in fields	5,3 c	7,0 b	8,1 a	6,5	< 0,0001
Degree of implementation of ox-drawn agriculture					
% of farms with one complete equipement set[1]	15,6%	18,8%	5,4%	15,2%	0,158
% of farms with at least two complete equipment sets[2]	10,0%	19,8%	37,8%	18,8%	0,001
Total cultivated area, ha	18,9 b	20,6 b	31,9 a	21,8	0,000
Cotton area, ha	3,8 c	5,5 b	8,5 c	5,3	< 0,0001
Few characteristics of women in farm					
Area of women's land, ha	3,4 a	3,2 a	2,1 b	3,1	0,018
Hours per day in husband's field	5,8	5,8	6,0	5,8	0,619
Hours per day in her fields	1,1	0,9	0,7	0,9	0,285
% women with cell phones	42,2%	31,3%	37,8%	36,8%	0,297
% women with bicycles	44,4%	29,2%	16,2%	33,2%	0,005
Cotton performance					
Seedcotton yield, $kg ha^{-1}$	1118 b	1200 b	1873 a	1 285	0,010
Gross income after payment of inputs, $FCFA ha^{-1}$	157835 b	160612 b	339614 a	190 775	0,017
Non-input cash expenses, $FCFA\ ha^{-1}$	16988 b	20361 ab	25137 a	19 820	0,050
cost of occasional labour, $FCFA\ ha^{-1}$	9069 a	12645 a	15247 a	11 653	0,041
Gross surplus, $FCFA\ ha^{-1}$	140638 b	139444 b	314477 a	170 513	0,027

[1]At least two oxen and a plough; [2] At least four oxen and two ploughs. Different letters are attached to means when different

Table 2. Multivariate regressions of technical and financial performance indicators (the presentation of integrated independent but non-significant variables is omitted for lack of place)

Independent variables	Farm cotton production, kg		Yield, $kg.ha^{-1}$		Gross margin, CFA per ha		Gross margin, CFA per ha and family labour	
	Coef.	p value	Coef.	p value	Coef.	p value	Coef.	p value
Zonal effect relatively to Mankono county								
Boundiali county	-0,085	0,469	-0,018	0,886	0,031	0,022	-0,199	0,032
Ferke county	-0,079	0,436	-0,031	0,772	0,043	0,000	-0,240	0,003
Korhogo county	-0,067	0,564	-0,015	0,905	0,030	0,024	-0,201	0,030
Effects related to the farm and its head								
Head's education [1]	0,078	0,285	0,033	0,671	-0,019	0,036	-0,065	0,302
Nomber of ox-drawn ploughs	0,281	0,000	0,119	0,149	-0,003	0,738	0,118	0,081
Effect of the number of wives relatively to more than two								
Only one wife	-0,349	0,001	-0,280	0,016	0,025	0,068	0,318	0,001
Two wives	-0,319	0,003	-0,272	0,016	0,006	0,653	0,095	0,299
Effects related to women's features in farms								
Having enough days in their fields [3]	-0,011	0,872	0,009	0,902	0,019	0,030	0,239	0,000
Reluctance to their husband's cotton [4]	-0,051	0,581	-0,063	0,526	-0,041	< 0,0001	-0,043	0,551
Performance and costs								
Yield, kg/ha					0,994	< 0,0001	0,446	< 0,0001
Probability > F value	0,000		0,391		< 0,0001		< 0,0001	

[1] Having been to school [2] Having cattle of at least 15 heads [3] Women declaring having at least 5 days out of ten to work in their own fields
[4] Reluctance interpreted through their absence of answer to the question whetheer their husband should grow cotton

4 Conclusions

Women's labor contribution is real and its influence to cotton production could be quantitatively appraised even through a one-way survey. The technical performance is under influence of the number of wives within a farm holding but the financial performance depends more on factors of good will from women which could nevertheless be captured.

Acknowledgements. The paper is based on a study conducted in the framework of the project "AFINE" (Activités agricoles des femmes dans leur intégration à l'exploitation et la sécurité alimentaire des zones cotonnières) funded by the West African Economic and Monetary Union (UEMOA)

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The risk of declines in soil fertility and crop productivity due to decreased livestock presence in agropastoral zones of West Africa

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1 Introduction

In West Africa, food security and living standards improvement are still major issues in rural areas. Until the 20th century, the main feature of agricultural systems in semi-arid and sub-humid areas was livestock, crop and tree integration. At landscape level, livestock traditionally drove nutrient transfers from rangelands to croplands (Fig. 1). These transfers were essentials for making crop productions sustainable (Dugué, 1998; Manlay *et al.*, 2004; Schlecht *et al.*, 2004). Sincemid-1900's the traditional crop-livestock systems are impacted by climate change, population growth and resulting land use change. Cropland extension was done at the expense of range lands leading to a decrease in biomass available for livestock (Lericollais, 1999). Livestock are consequently relegated to areas with low population densities and to sylvo-pastoral regions, i.e. arid areas were climatic constraints are too limiting for crop activities.

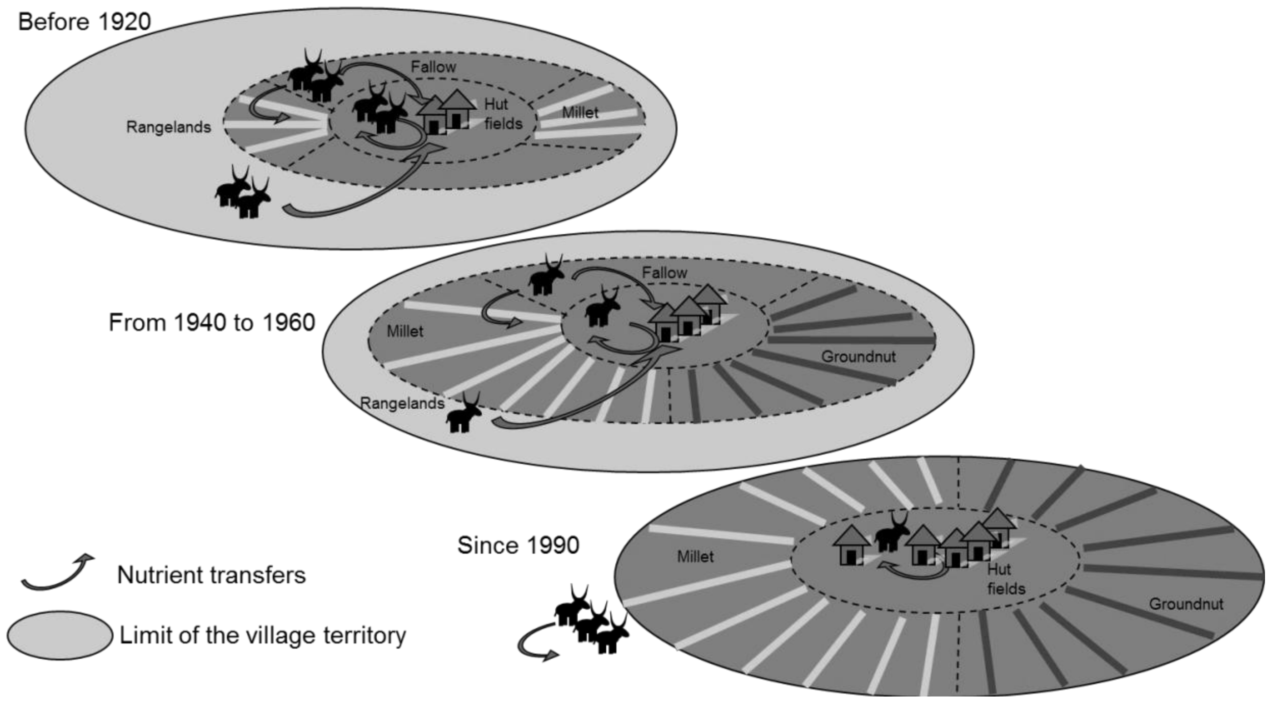

Fig. 1. Land-use change and dynamic of livestock-based nutrient transfers in village territories in semi-arid and sub-humid areas of West Africa during the 20th century

These dynamics emphasized tensions around biomasses (crop residues, manure) and led to the decline in wooded parkland and soil fertility. Increase in food demand, from cities in particular, emphasized the exports of agricultural products from rural areas to cities (cereals, hay, meat, etc.). While mineral fertilizers are poorly used, these dynamics are resulting in a negative nutrient balance that questions the sustainability of the resulting farming systems (Smaling *et al.*, 1997; Sanchez, 2002). The growing demand in livestock products in West Africa cities also represents an attractive market that may support the development of intensive livestock systems not any more based on free grazing but where animals are kept in-barns and fed with byproducts of the local agroindustry as feed concentrates. This study examines whether the reintroduction of livestock in landscapes affects the functioning and performances of agricultural territories.

2 Materials and Methods

The study focused on two villages within the groundnut basin of Senegal that adopted contrasting agricultural strategies; the first one kept a relatively traditional system based on livestock free-grazing (Diohine), while the second developed a system based on livestock fattening (Barry Sine).
Partial nitrogen (N) balances at plot, household and village levels were the indicators used to assess the sustainability of observed agricultural systems. The balances were built on a systematic inventory of biomass flows based on household survey: 44 households and 420 plots in Diohine and 74 households and 620 plots in Bary Sine.

3 Results – Discussion

Household scale nitrogen balances (13 $kgN.ha^{-1}$ for Diohine, 25 $kgN.ha^{-1}$ for Barry Sine) and village scale's ones (9 $kgN.ha^{-1}$ for Diohine, 25 $kgN.ha^{-1}$ for Barry Sine) demonstrate that Barry Sine village is more sustainable in terms of soil fertility maintenance (Table 1). Its higher nitrogen balances are mainly due to a larger use of manure (on average 1.83 $kgN.ha^{-1}$ in Diohine, 2.86 $kgN.ha^{-1}$ in Barry Sine). The introduction of the livestock fattening activity in farming systems improves animal presence at landscape level (0.96 $TLU.ha^{-1}$ in Diohine, 2.31 $TLU.ha^{-1}$ in Barry Sine), and provides an additional nitrogen input in the agro-ecosystem through imported concentrate feeds (3.14 $kgN.ha^{-1}$ in Diohine, 17.6 $kgN.ha^{-1}$in Barry Sine). The cash-flow generated by the selling of fattened animals gives farmers better access to mineral fertilizers. An equivalent of 1 $kgN.ha^{-1}$is used on average in Diohine, versus 6 $kgN.ha^{-1}$ in Barry Sine.

Table 1. Main village characteristics and performances for the 2012-2013 campaign

Village	**Human population density** (inhabitants.km^{-2})	**Livestock stocking rate** ($UBT.ha^{-1}$)	**Crop grain productivity** ($kgDM.ha^{-1}$)	**Crop residues productivity** ($kgDM.ha^{-1}$)	**Livestock productivity** ($kgLW.ha^{-1}$)	**Nitrogen Balance** ($kgN.ha^{-1}$)	**Nitrogen use efficiency** (dmnl)
Diohine	180	0.96	400	2070	25	8.5	0.15
Bary Sine	320	2.31	510	3150	213	24.9	0.64

Livestock reintroduction in villages improve N use efficiency at both household and village scales (0.15 in Diohine, 0.64 in Barry Sine). However similar plot scale nitrogen balances (-20 $kgN.ha^{-1}$ in Diohine, -23 $kgN.ha^{-1}$ in Barry Sine) point out that Barry Sine's livestock fattening manure management is not optimal. There is still room for progress in N use efficiency through the improvement of manure management (urine collection via straw bedding, better manure transport facilities, covered manure heaps, in-soil manure incorporation), especially in Barry Sine where most of the manure is managed contrary to Diohine where most of the manure is directly deposited on-fields (Audouin, 2014).

4 Conclusions

Livestock was a strong driver of nutrient transfers from rangelands to croplands at landscape level and an essential component of sustainable soil fertility management in traditional crop-livestock systems based on free grazing. Due to growing population in rural areas, land use change results in a significant reduction of rangelands to the profit of croplands. The gain of such an expansion in terms of staple crop production is not evident because livestock stocking rate in villages is negatively affected resulting in a reduction of manure available for crop fertilization. To counter the resulting unbalance in nutrients, this study shows that livestock can be reintroduced in crop-livestock landscapes via the promotion of fattening livestock systems. Livestock intensification is also the opportunity to indirectly intensify cropping systems and then feed more people in rural areas. This new livestock system also revolutionizes the manure management system. The "animal driven" system is replaced by a "human driven" system including manure collection, storage and spreading. Farmers are requiring new knowledge and new equipment to entirely benefit from the larger manure available. New manure management systems aiming nutrient conservation along the biomass recycling have also to be designed to improve the nutrient use efficiency and the productivity of the new farming systems generated.

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Soil nutrient balance, economic performance and scenarios for closing nutrient gaps in heterogeneous smallholder farm systems in south-western Burkina Faso

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1 Introduction

Cobo *et al.* (2010) reviewed nutrient balance studies in Sub-Saharan Africa, which showed widespread nutrient mining. Most of these studies' findings revealed large negative balances, raising the issue of the sustainability of land management practices in Sub-Saharan African farming systems. It is hard to find studies that focused on the soil sub-component nutrient balance for different farming systems. Furthermore, the relationship between soil nutrient balance and a farm's economic performance needs to be investigated. This may help improve the efficiency of policy intervention, as well as contribute to the body of knowledge for farm design. This study's main objectives were to analyse the soil nutrient balances of different farm types and their linkage with farm economic performances and to evaluate scenarios for replenishing soil nutrients in smallholder farms.

2 Materials and Methods

The study was conducted in Ioba Province in the southwest region of Burkina Faso, where Thiombiano and Le (submitted) identified five main types of agricultural livelihood systems (hereafter referred to as farm types): i) farm type I – better-off, cotton-and livestock-based farms; ii) farm type II – better-off, non-farm activities preference farms, iii) farm type III – pro-poor, labourless and landless farms; iv) farm type IV – medium-income, labour-rich, marketable food crop-oriented and educated farms and v) farm type V – poor, insecure land-tenure, livestock-based farms. By using the Nutrient Monitoring (NUTMON) Framework (De Jager *et al.,* 1998), 15 farms representing the five farm types (three replications per type) were monitored during a full year for cropping, livestock and off-farm activities and related nutrient flows. Soil nutrient (nitrogen, phosphorus and potassium [N, P and K]) balances were calculated for the whole farm system and the soil subsystem. The relational soil nutrient balance-economic performance was investigated for the five farm types by using two dimensional diagrams. We evaluated three management scenarios for replenishing soil nutrients. The business-as-usual (BAU) scenario represents the actual practices. The intensification of mineral fertiliser use (IMF) scenario involves the increasing use of mineral fertilisers for replenishing soil nutrients. The recycling crop residues (RCR) scenario replenishes soil nutrients through enhancing the use of crop residues for fertilising crops.

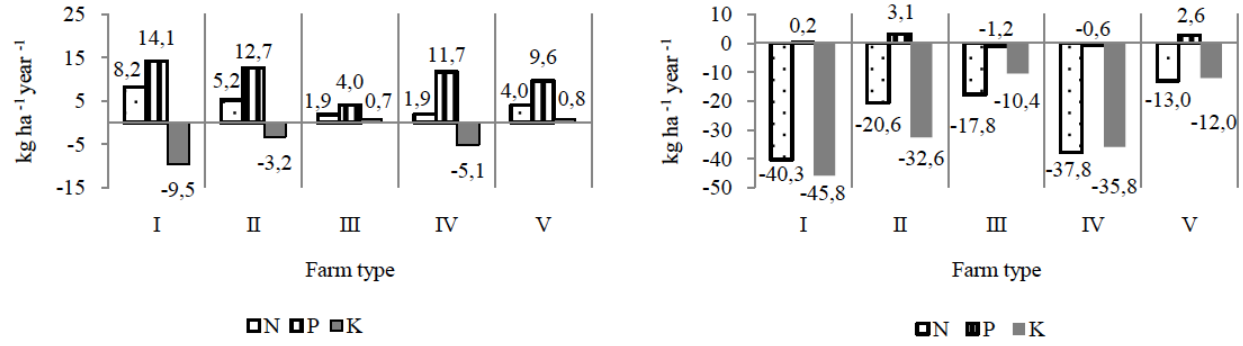
3 Results and Discussion

Nutrient balance analyses revealed heterogeneity across farm types (Fig. 1). The whole farm's full nutrient balance showed positive N and P balances for all farm types, with the lowest values for the pro-poor farm type (III). The K balance was negative for the better-off farm types (I and II) and the middle-class farm type (IV). The soil subsystem nutrient balance showed large, negative N and K balances, mainly for better-off farms. These results imply that better-off farms draw their wealth from farm nutrient mining, as observed by Van Der Pol (1992) in northern Mali. Crop and crop residues removal and erosion were the main sources of nutrient depletion. Crop and crop residues removal, and erosion were the main sources of nutrient depletion. Potassium appears to be limiting for wealthy farmings systems which exhibit negative whole farm full nutrient balance for that nutrient only. The large negative soil subsystem nutrient balances with positive farm full nutrient balances indicates inefficient nutrient resources management within the farming system resulting in nutrient accumulation in livestock production subsystem (unused manure).

The results showed that the middle-class farm type (IV) had the highest crop gross margin per cultivated land unit, while the poor farm type (V) had the lowest crop revenue per land unit. The analysis of the relational soil nutrient balance and crop gross margin per land unit revealed two main cases (Fig. 2).

In the first case, farms with a negative soil nutrient balance and a low margin comprised pro-poor, poor and off-farm preference farm types (III, V and II, respectively). They invested less in soil nutrients, due mainly to insufficient resources for poor and pro-poor farms and to the livelihood strategy of off-farm preference farms. Pro-poor and poor farms were likely in a poverty-soil nutrient depletion trap. Low productivity drives poverty, which in return, aggravates nutrient mining. Farms need to recycle locally available resources (crop residues and animal manure) and use soil conservation techniques, as well as N-fixing crops. The owners of the off-farm preference farm type may need training on sustainable soil nutrient management to leverage their incentive to invest in soil fertility.

Farms with a negative soil nutrient balance and a better margin, consisting of better-off cotton-based and middle-class farm types (I and IV), were found in the second case. These farms invested better in soil nutrients but still insufficiently. They would face depleted soil nutrient stock in the future, lose their profitability and become problematic. These farms need to combine mineral fertiliser use and organic fertiliser, which reinforce soil organic matter and fertility. They should also invest in soil conservation practices, as well as in livestock-agriculture integration.



b-Whole farm full nutrient balances**a**-Farm soil subsystem nutrient balances
Fig. 1. Farm nutrient balances

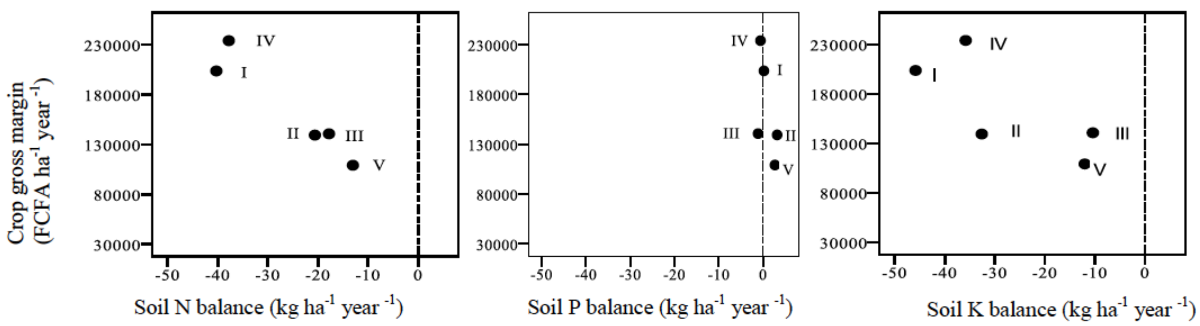


Fig. 2. Farm soil nutrient balance versus crop gross margin

The scenario analysis showed that farms could hardly afford reversing the trend of the nutrient depletion observed in the BAU scenario. In the IMF scenario, farmers should reinvest 72% of the crop gross margin per unit of cultivated land. This seems unaffordable, given that nearly 44% of households in the region live under the poverty line at US$217/person/year (Institut National de la Statistique et de la Démographie [INSD], 2010). Fully recycling crop residues under the RCR scenario improves nutrient balance by 40–90%. However, farmers have to face the labour constraints observed for many farm types and make trade-offs between competing uses of crop residues. Livestock-agriculture integration seems the best option for farmers to maintain productive and sustainable farms.

4 Conclusions

The study confirmed the findings of past research that drew attention to the alarming soil depletion in Sub-Saharan Africa. By investigating soil nutrient balance and farm economic performance, the study showed the nutrient mining-poverty trap in smallholder farms. The scenario analysis indicated that removing the observed nutrient gaps by increasing the use of chemical fertilizers would be costly and inefficient for farmers. Policy interventions and farm design should focus on the subsidiary linkages between livestock and crop production.

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Pathways for the sustainable intensification of agriculture

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1 Introduction

Sustainable development is at the top of the most challenging tasks facing humanity, and agriculture, being the largest business in the world, has a key role to play. The largest potential for the sustainable development of agriculture exists in parts of the world where most of the population is involved in small scale farming (up to 90%), and where the demand for food and levels of poverty are the largest i.e. Sub Saharan Africa. However, given the large diversity of agro-ecological, socio-economic and market conditions smarter approaches are required to guide investments and interventions that bridge the gap between present and achievable levels of farm production. Here we combined data from a household survey (n=672) and a dynamic and functional whole farm model (APSFarm-LivSim) to describe likely pathways of agriculture intensification across four agro-ecologies in Ethiopia. Intensification pathways were defined in terms of the effects of increasing on-farm investments on the reduction of down side risk for food security i.e. the likelihood of not attaining the household energy requirements; as a function of the household potential for intensification i.e. difference between present and achievable levels of production of maize, sorghum, beans, teff and livestock products (Fig. 1).

2 Materials and Methods

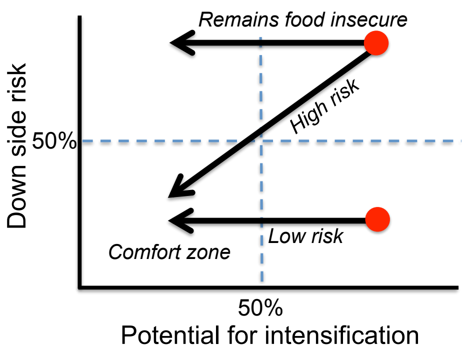

Fig. 1. Hypothesised framework for the analysis of pathways for the intensification of agriculture for househols having contrasting intensification trajectories i.e. housholds that after intensification are likely to remain food insecure; households exposed to a high risk pathway to reduce food production gaps; and households exposed to low risks as they reduce production gaps and move towards the "confort" zone i.e. low chance of being food insecure after the intensification potential has been significanly reduced.The baseline situation, before intensification, is represented in the graph by the red circles.

We used data from an extensive and homogeneous household survey collected by the SIMLESA program (http://aciar.gov.au/page/simlesa-program), across four contrasting agro-ecologies in Ethiopia. The survey data was used to parameterise a whole farm simulation model i.e. APSFarm-LivSim. The model was used to describe the existing diversity in pathways for intensification (Fig. 1) by simulating all the farms in the survey (n=672). The LivSim model (Rufino et al., 2009) was linked to the APSFarm model (Rodriguez et al., 2011), and; used to study the relationship between the chance of not meeting household energy requirements as levels of productivity of maize, sorghum, teff, beans and livestock increases. Each of the 672 households were simulated using climate records from the MarkSim V2 model (http://www.ccafs-climate.org/pattern_scaling/) i.e. 99 years, baseline 2013, for nine sites associated to the four agro-ecological regions present in the survey i.e. Adami Tulu, Meskan, Bako Tibe, Mesrak Nadawacho, Dugda, Pawe, Gubuesyo, Shalla, and Hawasa Zurya.

3 Results - Discussion

Based on total on-farm energy production, intensification of agriculture is likely to meet the energy requirements of more than 60% of the surveyed farmers in Ethiopia (Fig. 2). Different success rates can be expected in different regions. The Sub-humid region appears to be the most challenging (only 49% food secured) while the Humid regions the most promising (68% food secured). Identifying low risk and high-risk pathways is also likely to help better target interventions in regions where the likelihood of farmers not meeting household requirements is high. Livestock keeping, and technology adoption were associated to the low risk pathway, while households remaining food insecure had larger proportion of the farm income from off-farm sources.

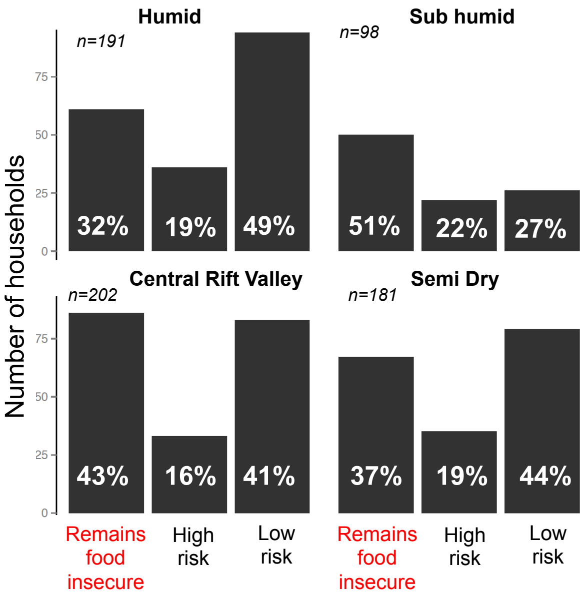

Fig. 2. Proportion of households across the four studied regions that fall within each of the the proposed pathways for intensification in Figure 1, i.e. households that are likely to remain food insecure after the intensification took place; households that are exposed to high risk during the intensification process; and households that can be intensified at a low risk.

Summary of pathway groups characteristics

	Remains food insecure	High risk	Low risk
Humid			
Farm size(ha)	2	2	3
TLUs	34	38	49
Manure (t/ha)	1432	1734	1013
Fertilisers (kg/ha)	96	85	86
Tecnology factor	26	27	29
Household size	5	6	7
Experience in maize	16	18	19
Distance to seed markets	35	38	35
Off farm income (%)	23	19	17
% produce sold	12	18	27
CRV			
Farm size(ha)	1	2	2
TLUs	6	7	14
Manure (t/ha)	1561	496	565
Fertilisers (kg/ha)	23	29	34
Tecnology factor	25	28	31
Household size	7	7	7
Experience in maize	24	18	18
Distance to seed markets	42	53	65
Off farm income (%)	43	37	29
% produce sold	16	17	19
Sub humid			
Farm size(ha)	3	3	3
TLUs	6	3	4
Manure (t/ha)	1804	2903	2376
Fertilisers (kg/ha)	35	22	22
Tecnology factor	32	30	32
Household size	5	4	4
Experience in maize	17	16	13
Distance to seed markets	57	78	65
Off farm income (%)	25	26	32
% produce sold	19	16	18
Semi dry			
Farm size(ha)	2	2	2
TLUs	10	18	16
Manure (t/ha)	2097	1798	1692
Fertilisers (kg/ha)	64	71	66
Tecnology factor	36	36	37
Household size	8	7	7
Experience in maize	22	20	22
Distance to seed markets	58	57	65
Off farm income (%)	15	23	22
% produce sold	14	20	14

Table 1. Table of mean values of main characteristics of the households in the Humid, Sub humid, Central Rift Valley, and Semi dry regions of Ethiopia, within each of the identified pathway paths.

4 Conclusions

Ignoring the contribution from off-farm income, significant sections of the population are likely to remain food insecure after intensification in the Central Rift Valley and Sub Humid regions. Low risk household usually have larger number of livestock (tropical livestock units, TLU), and have adopted a larger number of improved technologies. Households that are likely to remain food insecure showed larger proportion of their income originating from off-farm sources.

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Tailoring cropping systems to variable climate, diverse farms and landscapes

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1 Introduction

Soil fertility depletion and climatic volatility are the major biophysical barriers confronting small scale farmers in Africa (e.g. Smaling *et al.*, 1997; Challinor *et al.*, 2007). On the other hand, African farming systems and landscapes are highly heterogeneous creating complex socio-ecological environments characterised by wide differences in farmers' resource endowments and the use of such resources (van Wijk *et al.*, 2009). Although a basket of possible technologies is available, poor resource endowments and seed and fertilizer costs limit the options available for farmers to improve their circumstances. Predictive crop modelling may help to explore the *ex ante* effects of an array of intensification options and answer most of the 'what if' questions (Jones *et al.*, 2003). Participatory modelling with farmers provides for integrative analysis and development of alternatives for increased productivity and sustainability, at both the cropping and farming systems levels. Thus a comprehensive farm design has to take into account climatic variability and change, diverse farms (household priorities and production objectives), and a landscape consisting of fields of different soil fertility status. The objective of this study was to assess the potential of conventional tillage and conservation agriculture to offset the effects of climate variability and change on crop productivity across farms of different resource endowment. This interactive analysis at multi-scales allows the identification of cropping systems that are suitable to farmers' conditions, increase productivity and offer possible adaptation strategies to climate variability and change.

2 Materials and Methods

The modelling approach used historical as well as generated future climatic data, farm and field typologies from a case study site in Monze, Zambia to explore the trajectories of current and alternative cropping systems. Climatic data was input into the Agricultural Production Systems Simulator (APSIM), version 7.6 with management scenarios derived from different farm typologies created by classifying farmers based on resource ownership and production orientation. The model was described in detail by Keating *et al.* (2003). APSIM is a process-based model developed to simulate biophysical processes in farming systems in response to management decisions as well as climatic perturbations (Keating *et al.*, 2003). In this study the APSIM model was used to simulate the productivity of maize under conventional and conservation agriculture options with different scenarios of future climate change generated using global circulation models (GCMs). APSIM was calibrated and evaluated using data derived from a long-term agronomic experiment at Monze in Zambia. Future climate change met files were generated by an ensemble of 17 global circulation models (GCMs) using two extreme emission scenarios: (a) the low emission scenario - Representative Concentration Pathway (RCP2.6), and (b) the high emission scenario - Representative Concentration Pathway (RCP8.5). The weather files were generated and downscaled using MarkSim web version for IPCC AR5 data (CMIP5) (Jones & Thornton, 2000). To assess effects of climate change, the 2013/14 cropping season was taken as base and compared with the future season of 2049/50.

3 Results - Discussion

Future (2049/50) projected climate for Monze showed no significant change in solar radiation, but higher total season rainfall compared with current climatic conditions. There was an increase in both minimum (+1°C) and maximum (+1.5 °C) temperatures for the two emission scenarios. However, the ensemble of models showed high variability indicating an uncertainty in future climate prediction. Farmer classification revealed four broad farm types (F1-F4) which confirmed the existence of heterogeneity across farms with fertiliser use ranging from 0 kg ha^{-1} to 100 kg ha^{-1} per year. Livestock ownership and land cultivated also differed greatly across the farms (2.5 - 4.3 ha yr^{-1}). Consequently these differences had a significant effect on crop productivity (Fig. 1). There was a direct relationship between resource ownership and crop productivity for both climate change scenarios. Farm type two (F2) who did not own cattle and did not afford fertiliser achieved the least yield that contrasted sharply with that from F4 farmers who owned the most livestock and applied the largest fertiliser of about 100 kg ha^{-1}. Simulated crop yield results showed that the advantage of CA in the future will be for the low emission scenario only (Fig. 1). This is because of the projected increase in rainfall in combination with the moisture conservation effects through crop residues retention that may lead to waterlogging (Araya and Stroosnijder, 2010).

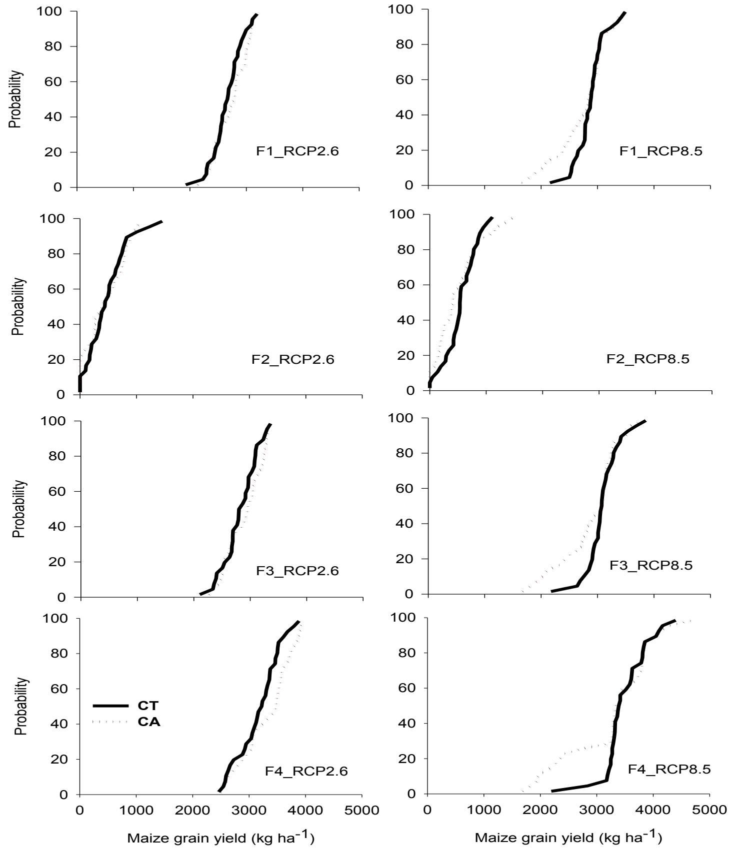

Fig. 1. Maize yield probability distribution for conventional tillage (CT) and conservation agriculture (CA) with projected future climate (RCP2.6 and RCP8.5) for the four farm types (F1-F4).

4 Conclusions

CA has potential to mitigate against moisture stress but may depress yields when moisture is abundant. There is need to understand better the impact of a combined increase in both temperature and rainfall as the the impact of this two variables has been assessed when temperature is predicted to increase and rainfall to decrease. Historical data shows that cropping seasons are starting late which reduces significantly the planting window i.e. the option of staggering planting dates to deal with climatic uncertainties may not be viable in the future.

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Socio-ecological conditions for food security in African drylands: A quantitative and spatially-explicit typology to facilitate learning

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1 Introduction,

Food production is key to achieving food security in African drylands. Agricultural productivity is however limited due to low and variable water supply and soil fertility. In addition, climate variability, inequitable trade conditions and social exclusion frequently exacerbate the already pronounced constraints on agricultural productivity. Vulnerability is employed in this study as a concept to capture the relation between socio-ecological systems and perturbations impacting upon them. The diverse and heterogeneous conditions that shape a system's vulnerability in various locations challenge policy-making for improved food security given that decisions are usually taken at a higher than local level. To facilitate learning, the aim of this study is to identify quantitative and spatially-explicit patterns of vulnerability to global change considering farmers' and pastoralists' livelihoods in African drylands. The typology explicitly incorporates malnutrition as cause and consequence of vulnerability.

2 Materials and Methods

This study employed cluster-based pattern recognition relying on well-defined and formalised mechanisms that generate vulnerability (Sietz *et al.* 2010; Kok *et al.*, 2015). We quantitatively indicated the most relevant environmental and socio-economic properties of the dryland systems at a sub-national resolution including water availability, soil erosion sensitivity, agropotential, child malnutrition, income, population density, urban population share, distance to markets and governance with reference to the early 2000s. After indicator normalisation, cluster analysis was performed in the nine-dimensional data space using a sequence of clust and k-means algorithms. Based on stochastic initialisation, we calculated the reproducibility of partitions for a pre-given number of clusters to determine stable partitions.

3 Results – Discussion

Clustering revealed nine vulnerability patterns with distinct and transparent indicator combinations (Fig. 1A; for their spatial distribution see Fig. 1B). Seven clusters are characterised by high levels of malnutrition while only two clusters show low malnutrition levels.

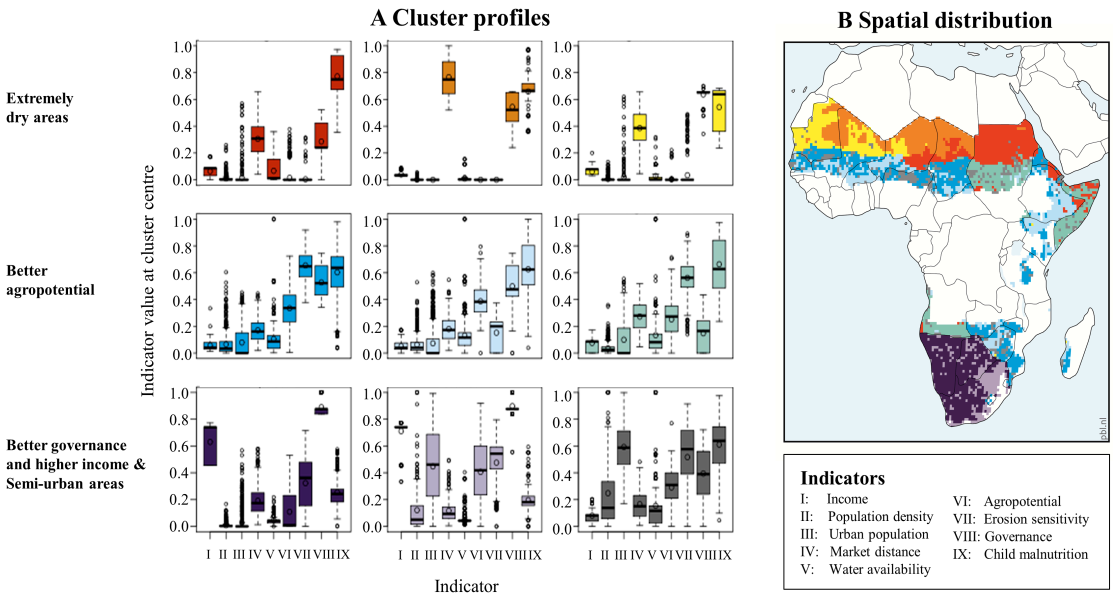

Fig. 1. Typology of vulnerability: Cluster profiles showing indicator combinations at cluster centres (1A) and spatial distribution (1B) (Note 1A: Box boundaries = 25th and 75th percentiles; whiskers = 5th and 95th percentiles; circle inside the box = mean value; bold line = median value; dots = outliers).

The clusters in *extremely dry areas* (red, orange and yellow clusters) describe most resource-constrained situations, both in terms of natural resource quality and income, medium to very high malnutrition and low levels of governance. In clusters with *better agropotential* (dark blue, light blue and turquoise clusters), the somewhat better natural resource endowment and market access do not translate in improved wellbeing indicated by very low income and medium malnutrition. Comparable to rural areas, *semi-urban areas* are also characterised by very low income and high malnutrition, though better market access (grey cluster). In contrast, clusters with *better governance and higher income* (dark purple and light purple clusters) depict situations with lowest vulnerability and better food security.
To ground-truth our results, we used independent case studies to confirm cluster-specific mechanisms and their spatial distribution. For example, Northern Afar region in Ethiopia may serve as an example to illustrate specific processes indicated by the red cluster (Fig. 1). Recurrent droughts, food shortages and political conflicts are among the major causes of food insecurity in Northern Afar. However, pastoralists in this region have frequently been excluded from development programmes as compared to other pastoral groups in Ethiopia (Tesfay & Tafere, 2004). Government support in this remote and very sparsely populated region remains largely ineffective partly as a result of centralised, top-down approaches in project planning and implementation.
Overall, indicator combinations given by the clusters provide valuable insights into entry points for vulnerability reduction which should be reflected in policies and intervention efforts. For example, combined efforts to increase income and reduce malnutrition are required in the majority of clusters. But simultaneous enhancement of market access is most relevant in the orange cluster, governance improvement is essential in the turquoise cluster and tapping the potential of existing agropotential and better water availability is very important in the light blue cluster. Assuming that intervention options are transferable among similar socio-ecological systems, strategies such as food storage and livelihood diversification that were successful in one location are expected to reduce vulnerability and subsequently food insecurity in other locations categorised in the same cluster.

4 Conclusions

The cluster-based typology enables policy-makers to evaluate key inter-linkages between vulnerability and food security based on similarities among African drylands. It allows the essence of these inter-linkages to be grasped beyond individual cases, while at the same time representing spatial and functional heterogeneity at an aggregate level. Besides regional comparison, similarities support the identification of key entry points for managing transitions towards improved food security and may facilitate the transfer of successful strategies. Based on typical combinations and manageable number of key indicators, our findings enable new insights into the prioritisation of intervention efforts and related monitoring efforts.

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Improving the productive performance of family farms in Senegalese rural area

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1 Introduction

Despite the Millennium Development Goals, food security and poverty remain unavoidable challenges for the world in general and Africa in particular. However, a dynamic agricultural sector is expected to implicitly reduce poverty and food insecurity. In Senegal, growth in the agricultural sector is generally very beneficial to the poor in that it mobilizes the major endowments of underprivileged populations, and makes dynamic economy in rural areas. Moreover, given the growing nutritional needs of a population of over 13 million rising to over 19 million in 2030 and 26 million in 2050 according to the low population projections assumptions (AFD, 2013), increasing agricultural production sounds like an inescapable challenge.
Like other developing countries, Senegalese agriculture suffers mainly from low productivity. Indeed, less than half of the workforce, employed in industry and services, accounts for over 80% of GDP, while agriculture which occupies more than half of the labor force represents only 7.6% of GDP (ANSD, 2013). However, in recent years many initiatives have been taken by the government to make agriculture the engine of growth. In this context, why does the productive performance still low in Senegal? What are the drivers affecting this productive performance? Identifying the factors determining the productive performance instructs judgment and should allow to know the best farming system to improve farmer's productivity and reduce poverty and food insecurity. The overall objective of this study is to analyze the productive performance of farms in Senegalese rural area. It will first calculate the efficiency scores for each farm of the sample before identifying its determinants.

2 Materials and Methods

This study was conducted in the Senegal River Valley which is one of the six agro-ecological zones of Senegal with 240,000 ha of cultivable land (8% of total arable land of the country). Sampling conducted in this study has identified three zones: Matam Bakel and Kidira. The selected sampling plan was to choose three rural communities by zone, and then 40 households by rural community. At the end, 360 farms was interviewed for this study.
The productive performance of farms is analyzed through two stages. In the first stage, the efficiency scores will be calculated with the non-parametric approach Data Envelopment Analysis (DEA) for each farm. An advantage of DEA approach is that it allows the estimation of multi-input and multi-output models. Thus, the production of maize, sorghum, millet, groundnuts, cowpeas and rice are used as output. For inputs, the total area of the farm (in hectare), the labor force evaluated through the FAO weights, the capital which consists of amortization of agricultural machinery and equipment, the amount of seed used per hectare are used to calculate efficiency scores (Djimasra, 2009; Abatania *et al.*, 2012; Fasasi, 2007).
In the second step, the proportional nature of the efficiency scores has led to the exploration of fractional response models (Papke and Wooldridge, 1976; Ramalho *et al.*, 2011; Suhyeon, 2014), which include the generalized linear model and calls for the choice of a functional family for the distribution of errors, the binomial distribution in the study and a mathematical function for the transformation of the dependent variable called "link function", the logit distribution. The efficiency scores are thus regressed on a set of socio-economic variables assumed to explain the productive performance including age, sex, type of instruction, the first activity of the household head, the use of external labor, the household size, the existence of emigration in the household, the total number of fields, the location of the farm, irrigation, the existence of non-farm income, access to credit and herd size.

3 Discussions

The DEA model can simultaneously calculate total technical efficiency and its components that are pure and scale efficiencies (Coelli, 1998). A farm would be technically efficient if compared to other farms, it uses the least input for a given level of production when returns to scale are constant. The results show that with a more efficient utilization of production factors, a discount of 55.9% could be done on the inputs, while maintaining the production at the same level. The scale efficiency show that farms could reduce on average cultivated area by 20%, while maintaining the same level of production. The 12 family farms operating at optimum level have an average area of 1.25 ha. The pure efficiency reflects the best practices in terms of input management when it is assumed that the returns to scale are variable. Thus, in a short-term perspective, a reduction of 46.6% production factors is possible, while maintaining the same level of

production. This hypothesis reflects the production conditions of our study area, thus pure efficiency was chosen for estimating the generalized linear model.
The estimation of generalized linear model shows that agriculture and livestock activities are relatively complementary as the productive performance increases with the size of the herd. This result seems logical in view of cultural practices in the area where the use of organic manure from the animals is very common. Also, animals are used for traction by more than 80% of farms (ISRA / BAME, 2013). In addition, Gueye and Dièye (2002) noted the importance of agro-pastoral systems in Senegalese agriculture due to agricultural origin of most of the animal and plant production. In the Upper and Middle Senegal River Valley, access to credit impacts strongly the productive performance of farms. Indeed, the more farms have access to credit, the more efficient they are. These credits, which may take the form of credit campaign, allow producers to adjust inputs problems especially seeds and fertilizer. It is also noted, unfortunately, that the percentage of farmers that have access to credit remains low. In our sample, only 20% of farmers have access to credit. Thus, credit access facilitation policies through public instruments should improve the productive performance of the Senegalese agriculture. Furthermore farms where farming is considered as the main activity are the best performing. Yet the possession of several fields has no impact on productive efficiency. This result calls for better targeting of agricultural promotion policies.
The results show also that farms where the household head has been at the French schools are more efficient. Indeed, the school helps develop cognitive abilities that can help them to better respect the technical procedures and integrate new technologies. Also, farms headed by men are more effective than those led by women. Similarly, the experience gained through the age acts positively on productive efficiency. However, non-farm income and revenues from transfers have no impact on the productive efficiency. Likewise, the household size does not impact the performance of farms because of the lack of interest generated by agriculture among youth. Thus, there is increasing substitution of family labor by external labor, which does not affect the productive performance. Also, during the raining season, because of the availability of water, irrigation is not decisive in achieving a high level of efficiency.

4 Conclusions

In a context of resource scarcity, efficiency in the allocation of inputs becomes necessary to improve the productivity of family farms in the middle and upper Senegal River Valley. Indeed, family farms could increase their productivity simply by making a better allocation of land, water, human and financial resources. To improve the performance of farms, the production system combining agriculture and livestock should be promoted by policy makers as the herd ownership positively affects the efficiency.

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Emerging farms in Northern Cameroon: an economic and social change towards high agricultural productivity?

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1 Introduction

Sub-Saharan family farms have often been described as structures with low production means explaining their weak economic performance (Mbétid-Bessane *et al.*, 2006), and also their difficulties to innovate. In their diversity, some more efficient farms qualified as emerging were identified by the Cotton Development Company in Cameroon (SODECOTON) as being capable of cultivating more than five hectares of cotton, allowing individual marketing of their production and inputs. Fifteen years ago, these farms were rare (less than one per thousand farms). In 2014, over 4,000 emerging farms were counted (2% of all farms), growing 13% of the cotton area in North Cameroun. How these farms come to such results, and are they more likely to implement technical innovations, are questions whose answers may allow addressing in a targeted way the development of agriculture in northern Cameroon. A survey was conducted in 2014 on these farms, aiming to (i) characterize their structure, (ii) understand how their management could explain their results, and (iii) whether specific supports would improve the sustainability and efficiency of their production system.

2 Materials and Methods

Using the 2013 census (by SODECOTON) of 3,532 emerging farms in the administrative regions of North and Far North of Cameroon, a survey was conducted in 2014 with a single pass questionnaire among 45 of them located in the SODECOTON area of Ngong, in a SODECOTON area where they were particularly numerous. The questionnaire included closed and semi-open questions and had to be administered in less than one and a half hour. The results were compared with the average data of farms, using various reports and published work (Mbétid-Bessane & Havard, 2013; Bourou *et al.*, 2006).

3 Results – Discussion

3.1 Structure of emerging farms

The number of families dependent was more important than in the average of farms in the region (table 1). Immediate family was large, but collateral and permanent hired labor was found as well. It should be noted that 91% of school-age children were actually attending school, girls and boys as well. The number of equipment in animal traction and cattle existing was also more important.

Table 1. Structure of emerging farms

	Number of family dependents	Number of working age people	Number of draught animal full equipments	Tropical Livestock Units existing
Emerging farms	16.2	5.1	1.8	11.3
Regional average	5.1	2.9	0.26	1.5

3.2 Cropping Systems

Emerging farms have grown twice more surfaces per capita than the regional average for comparable crop rotation (Fig.1). They were not only the largest farms in the region but also functioned differently. To achieve this, they relied heavily on external hired labor: on average 522 working days for the 2014 crop year. The crops were also cultivated in an intensive way: the doses of fertilizers applied (in a localized manner) on cotton were close to the recommendations (while besides, the half dose is usually used, often deposited on the surface without being covered), and the recommended doses were exceeded in the cultivation of maize. All cultivated areas were treated with herbicide at least once, sometimes twice. Nearly all farms have used organic manure. Three-quarters had trees plantations. To raise their animals, almost all producers have made fodder reserves and resorted to buying food supplements. Half of the farms have made forage (forage sorghum).

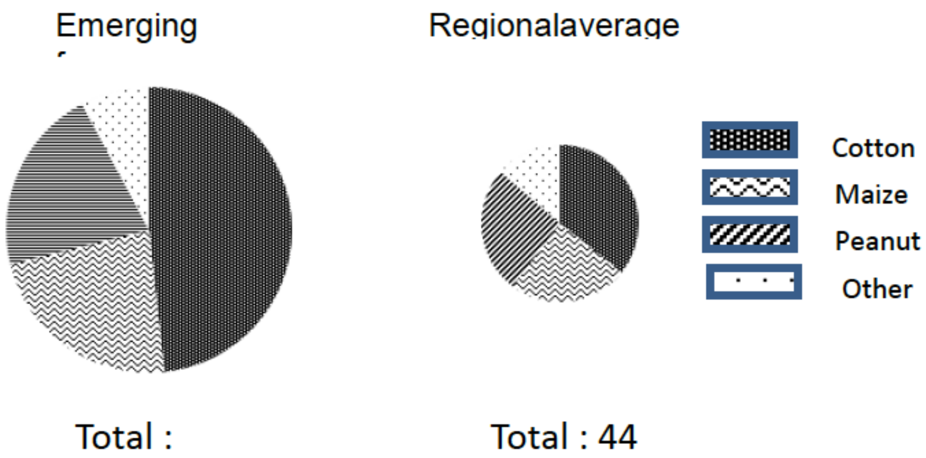

Fig.1. Emerging farms acreage per capita

3.3 Economic Approach

The survey does not establish a complete operating account, but some data can be calculated. While inputs for cotton production are subject to a seasonal credit campaign, inputs for food crops and hired labor payment are to be settled in cash. So, emerging farms spent an average of 854,000 FCFA (Table 2) during the crop year and before harvest. This high flow capacity, rare in African family farming, allowed them to set up their crop system. Note that the sale of cotton covered virtually all cropping costs, and its fixed price was an insurance to recover all of the expenses. The farms also produced food surpluses. These farms are similar to the entrepreneurial farms described by Bosc*et al.*, 2014.

Table 2. Some emerging farms costs and products data of crops in FCFA, for the crop year 2014

›st of food inputs (cash)	Cost of hired labor (cash)	Cost of cotton inputs (on credit)	Total cropping costs	›tton Product, 2013 crop year (for 30 farms)
427,000	427,000	1,045,000	1,898,000	1,797,000

3.4 Social environment of the production

In a region where land insecurity reigns, these farms reported being safe on 69% of their cultivated plots in average. They were confident that over half of their plots, they had the exclusive right of the profits on wood products. The heads of these farms often had traditional or economic titles (village or district chiefs, group delegates), but so far the ownership of all of these farms was in general in no way linked to traditional hierarchy.

4 Conclusions

These farms are emerging, firstly because they are becoming more and more numerous, and secondly because they put in place a system of intensive and efficient crops through a controlled economic management. The economic area and the social environment of these farms are conducive to the adoption of technical alternatives that have had little success elsewhere. Measures to limit the negative impact of the systematic use of herbicides, improving the quantity and quality of organic fertilizers produced on the farm, the establishment of an integrated fertility management for farms, are examples of targeted support that are likely to bring good results with these farms. This study also shows segregation of the farms with the poorest selling their labor and sometimes their inputs to the more efficient ones.

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A GxExM approach to manage climate risks in rainfed maize cropping systems

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1 Introduction

Recent maize yield gains have been achieved by increasing plant population densities using crowding tolerant hybrids in high-input high-output cropping systems. However, the high cost of maize seed relative to alternative cereals such as sorghum limits the inclusion of maize in large-scale high-input commercial rainfed systems. The costs are also prohibitive for low-input and low-output rainfed smallholder farming of Africa.
Technologies that reduce maize establishment costs such as using prolific maize hybrids i.e. hybrids that set more than one cob per plant on the main culm, grown at lower plant populations, have the potential to reduce risk and provide incentives for the sustainable intensification of agriculture. Prolific hybrids that can yield up to 10 Mg ha^{-1} of grain under optimal conditions when sown at population densities lower than 3 plants m^{-2}. These materials are currently available in both Australia and Sub Saharan Africa.
Here we used data sets from field trials in Africa and in Australia together with a cropping systems simulator (APSIM) to evaluate the influence of maize population densities and hybrid phenotypes (i.e. different degrees and types of prolificity) across recommendation domains both in eastern and southern Africa on yield and yield stability.

2 Materials and Methods

A total of 158 three-way-cross maize hybrids were evaluated in 48 locations across southern Africa in 2013-2014. Each trial consisted of 2-3 replicates sown at 2.7, 5.3 or 7.9 plants m^{-2}. All trials were managed with best practice agronomy for conventional tillage at each site including optimal fertiliser application and weed control. The crop water supply demand ratio was simulated for check hybrids to characterise the environment using APSIM. This model was parameterised based on locally measured soil properties and cultivar specific inputs for widely grown early to mid duration hybrids. Data points for analysis of the plant growth rate and kernel number relationship were extracted from published literature with the WebPlotDigitizer (http://arohatgi.info/WebPlotDigitizer/).

3 Results – Discussion

Prolific hybrids were generally high yielding across all sites and population densities in the 2013-2014 cropping season (Fig. 1). Prolificity was not associated with yield gains in the more favourable maize cropping environments of Argentina (Echarte *et al.* 2013). However, the influence of prolificity on long-term grain yields across productivity gradients and contrasting rainfall environments is untested.
The prolific phenotype can be predicted from the plant growth rate during critical period bracketing silking (PGRs), but the degree of prolificity or propensity for prolificity varies between hybrids. Secondary cobs only develop when resource availability supports PGRs between 3.6 and 6.0 g $plant^{-1}$ day^{-1}depending on the hybrid (Fig. 2; Lizaso *et al.* 2011). Different combinations of thermal time calculations, critical period durations or growth rate methodologies were used to obtain the data presented in Figure 2. The APSIM model also predicts kernel number based on the plant growth rate during a different critical period starting 130 and ending 260 growing degree days before and after anthesis, respectively. Despite the inconsistent methodologies, base PGRs for kernel development on the primary and secondary cob (hybrid dependant) are consistent across all studies. The critical period for prolificity and kernel number determination occurs during the linear growth phase of the maize crop, therefore slight changes in the critical period definition are unlikely to influence predictions.
Crop simulation can be used to identify the management by environment combinations that favour prolific hybrids as determined by the frequency distribution of PGRs that are greater than critical thresholds. Further simulations can then be used to compare long-term yields of non-prolific and prolific maize hybrids grown under optimal management across environmental gradients.

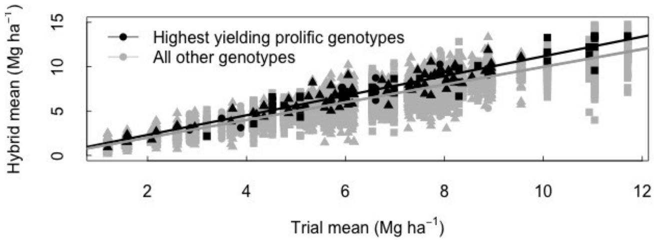

Fig. 1. Grain yield of the 5 highest yielding and highly prolific hybrids (y = 1.107x + 0.099, R^2 = 0.89, P< 0.001) and all other hybrids verses trial means. The 5 hybrids with the highest relative yield anomaly that also developed greater than 1.4 cobs per plant averaged across all sites were identified at a population density of 2.7 plants m^{-2}. Circle, triangle and square shaped symbols identify population densities of 2.7, 5.3 and 7.9 plants m^{-2}, respectively.

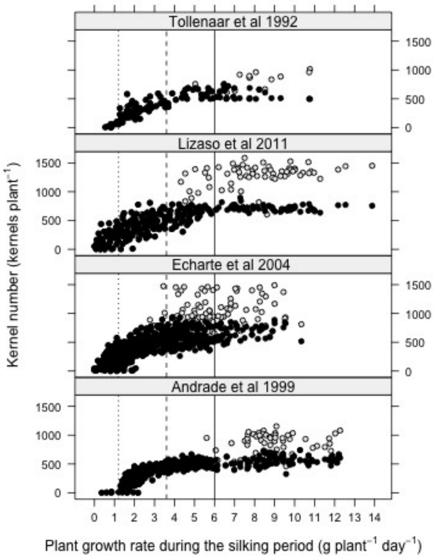

Fig. 2. Primary cob (●) and total including secondary cob (○) kernels verses growth rate on an individual plant basis. Dotted line defines the base plant growth rate for kernel development on the primary cob and below which baron cobs occur. Dashed and solid vertical lines show the base growth rate for secondary cob development as defined by Lizaso *et al*. 2011 and Tollenaar *et al.* 1992, respectively.

4 Conclusions

Results demonstrate that the high yielding prolific maize hybrids are potentially suitable for environments with yield potentials from 1-to-12 Mg ha^{-1}. The propensity for prolificity is hybrid dependant, but can be predicted from simulations of PGRs. Research continues to explore (i) the environment and management combinations that support expression of the prolificity phenotype, (ii) the degrees of prolificity available in current maize hybrids, and (iii) the influence of this technology on water and nitrogen demand patterns.

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Combined and targeted application of crop residues and cattle manure increases maize productivity in a crop-livestock farming system on granitic sandy soils of Zimbabwe

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1 Introduction

Granitic sandy soils of low pH and poor inherent fertility constitute about two thirds of Zimbabwe's arable land area (Anderson *et al.*, 1993). These soils are characterized by low clay, organic carbon and nutrient, content. They also are prone to degradation due to excessive soil loss and run-off caused by poor soil management practices (Vogel *et al.*, 1994). Various technologies including integrated soil fertility management (Zingore *et al.*, 2011) and conservation agriculture (CA) technologies (Thierfelder *et al.*, 2014) have been tested to rehabilitate these soils. . Use of cattle manure in such systems has been found to significantly improve crop productivity (Rusinamhodzi *et al.*, 2013). Hence the dwindling cattle numbers due to poor pastures imply farmers need to use manure resources more efficiently. CA systems, recommended as a strategy for sustainable intensification involving reduced soil disturbance, crop rotations and provision of a permanent soil cover using crop residues, have also been the major focus of agricultural research in southern Africa in the last decade. One of the major challenges of practising CA has been the scarcity of mulch emanating from the conflict between use of maize crop residues as feed for cattle during the dry winter months and as mulch in crops (Rufino *et al.*, 2011). This study investigated the combined effects of maize residue and cattle manure application on maize yields under CA. It also sought to understand the potential impact of such management options on food security in Goromonzi and Murehwa districts, Zimbabwe.

2 Materials and Methods

The study was conducted on a sandy soil, 30 km north of Harare, Zimbabwe over four cropping seasons (2010/2011-2013/2014). CA treatments with 0, 3 and 5 t ha^{-1} surface applied maize residues, were tested with and without 5 t ha^{-1} cattle manure applied in basins (15 cm diameter × 15 cm deep) laid out in a split plot experimental design with residue application as the main treatments and fertility management regimes as sub-plots. All treatments received 250kg ha^{-1} basal fertilizer (7% N:14% P_2O_5:7% K_2O) and top dressing (200 kg ha^{-1}ammonium nitrate (34.5%N). Manure was applied annually as subtreatments from 2010/2011 at a rate of 5000 kg ha^{-1} at 225g per station (22 222 stations ha^{-1} and spacing of 0.9 × 0.5 m). A hybrid maize variety was planted annually at the onset of the rainy season. Results from this experiment were then used to assess the potential impact of the adoption of such technologies on food security in Goromonzi and Murehwa districts using local demographic data from baseline studies.

3 Results and Discussion

Maize yields generally increased with time (Fig. 1). Analysed over the four years, significant interactions on maize grain yields were observed between maize residue application rate and fertility management ($p<0.007$) as well as between fertility management and cropping year ($p<0.001$). Thus time (year) influenced the applied manure effectiveness and linear regression analysis of yield results, showed highly significant ($p<0.001$) difference in responses over time between manured and non-manured treatments, irrespective of maize residue rates applied. Manure application thus resulted in a steeper slope (3.36) of the yield-time linear relationship compared with non-manured systems (1.65)suggesting that manure application will be beneficial in the long-term (Fig. 2), an effect attributed to the observed increase in soil phosphorus content and micronutrients, as well as improved physical conditions of the soil. However, linear regression analysis showed no apparent differences in yields between the two fertility levels with increase in maize residue application rates. The margin of differences in yields with or without manure progressively widened over time (Fig. 1). Thus in 2013/2014, the application of 3 t ha^{-1} maize residues without manure, depressed yields by 1.0 t ha^{-1} (36% reduction) but increased yield by 1.6 t ha^{-1} (56%) when manure was applied. When the mulch rate was increased to 5 t ha^{-1} and combined with manure, a yield increase of 2.2 t ha^{-1} (77%) was observed relative to no residues without manure, whereas a marginal yield increase of 0.5 t ha^{-1} was observed for a similar increase in mulching rates without manure. Thus the most recent results from this on-going experiment suggest that the that application of cattle manure at 5 t ha^{-1} combined with modest residue applications of 3t/ha could potentially increase yields by at least 60% (Figure 1). By inference, the judicious use of manure at 5 t ha^{-1} combined with residue application rates of 3 t ha^{-1}, and assuming a 60 % yield increase above current ones, the 44% cattle owning households in Goromonzi and Murehwa districts, could potentially benefit immensely and reduce food insecurity with an estimated mean 27% increase in mean district annual maize output based on the analysed sample ward demographics (Table 1). These preliminary results however, also suggest that farmers applying about 3 t ha^{-1} residues in CA without manure, may need to apply more fertilizer to offset the yield reduction attributed to nitrogen immobilization from maize residues. The need for integrated soil fertility management is apparent. Farmers often broadcast manure on small areas of e.g. 0.3 to 0.5 t ha^{-1} yr^{-1}, thus can achieve the modest targeted spot application rates and the benefits suggested in this study.

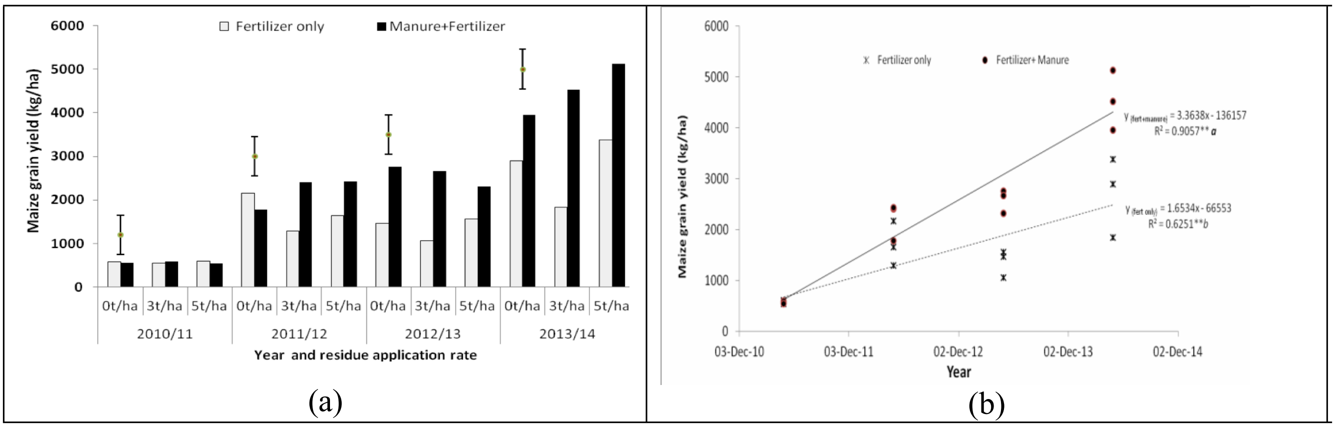

Fig. 1. (a) Residue application rates and soil fertility management and (b) Effects of manure application on maize yields at Domboshawa **Training Centre (DTC) (2010-14).**

N.B: error bars denote l.s.d$_{(0.05)}$*Residue rate*fertility* for comparing means within and across years.

Table 2. Estimated productivity changes with CA and manure application in Goromonzi and Murehwa districts of Zimbabwe.

Disttrict	% cattle ownership per hhd	Cultivated maize area (ha/hhd)	Current maize output (t/ hhd)	Expected maize output (t/hhd)	Expected mean increase in maize output per hhd
Goromonzi	40	0.591	0.56	0.89	
Murehwa	44	0.554	0.51	0.83	27%
Mean	42	0.573	0.53	0.86	

Current maize yield estimates= 0.94 t/ha: N.B A household of six requires 1.2 tmaize/yr

4 Conclusions

A combination of surface applied maize residues, inorganic fertiliser plus spot application of organic cattle manures, improves crop productivity in both short and long term and maybe sustainable in mixed crop–livestock systems of smallholder farmers if conflicts between multiple uses of crop residues can be reduced. Results support the need for integrated soil fertility management even in conservation agriculture systems. Adoption of such crop management strategies in similar agro-ecologies could potentially increase household maize output by 27 % thereby reducing food insecurity.

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Innovative participatory farming system design: combining on-farm crop/livestock trials with ex- ante trade-off analysis

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1 Introduction

In Southern Mali, farmers grow cotton for income generation, cereals for food self-sufficiency and keep livestock for draught power, milk, meat, manure, and buffer against risk. Due to increasing land and market pressure, farmers need to adapt to the decline of cotton sector (Coulibaly *et al.*, 2015) and decreasing fodder availability for livestock. This study presents an innovative approach to design adaptive farming systems based on participatory on-farm crop/livestock trials and ex-ante analysis, using farmers' input at every stage of the process.

2 Materials and Methods

An iterative learning cycle of testing and refining seven options for sustainable intensification was applied in the Koutiala district with farmers belonging to four farm types: High Resource Endowed farms with Large Herds (HRE- LH), High Resource Endowed farms (HRE), Medium Resource Endowed farms (MRE), and Low Resource Endowed farms (LRE). The options were co-designed by farmers and researchers and each contained two to four treatments. For maize, sorghum and groundnut, improved varieties combined with fertilizer and manure were compared with farmer practice. For soybean and two improved varieties of cowpea, inoculation (soybean) and addition of P (cowpea and soybean) was compared with a control with no input. Two other options included cereal/legume intercropping and stall feeding of lactating cows during the dry hot season. This basket of options was tested by 12, 121, and 132 farmers in 2012, 2013 and 2014 respectively in a total of 451 on-farm trials. Farmer practice for maize, sorghum and groundnut, and soybean and cowpea were assessed based on yield and gross margin (revenue-variable costs). Treatments with extra input (e.g. inoculation, addition of mineral fertiliser, cotton seed cake) were assessed based on yield increase, return to investment and probability to generate profit (based on spatial variability in trials). Participatory Analysis of Variance (PANOVA) of yields in trials was carried out and farmers were asked to indicate possible reasons for the yield differences observed in contrasting trials. After the field visits, a productivity and profitability analysis was discussed with 30 farmers who were asked to indicate options and specific treatments they preferred. Scenarios integrating these preferred options were designed with 12 farmers (three per farm type) during individual sessions and assessed with a simple farm trade-off analysis linking crop area and yields to total production and total income from crops and lactating cows. The trade-off analysis was refined based on farmers' feedback, measured yields and results from soil analyses. Yields were averaged per soil type and previous crop when there was a significant effect or averaged across soil type and previous crop when there was no significant effect. Cowpea fodder was assumed to be fed to lactating cows in the stall (for HRE-LH and HRE farms) and surplus sold. Using the current cropping pattern of 37 farms, we performed ex- ante trade-off analysis of the farmer-designed scenarios and assessed the effect on average food self-sufficiency and average increase in net cash income per farm type.

3 Results – Discussion

Average grain yields with farmer practice were 1.83, 1.03 and 0.54 t ha^{-1} with an average gross margin of 191, 244, 527 USD ha^{-1} $year^{-1}$ for maize, sorghum and groundnut respectively. Improved maize and sorghum varieties did not increase yields, while groundnut improved variety gave a 28% yield increase, a 1.46 return to investment and a 58% chance to generate profit. Soybean, cowpea grain variety and cowpea fodder variety with no inputs were more profitable (280, 311, 750 USD ha^{-1} $year^{-1}$ respectively), but yielded less grain (0.41, 0.23 and 0 t ha^{-1} respectively) compared to maize and sorghum with farmer practise. Addition of P did not increase cowpea grain yield but gave a 126% yield increase for soybean, with a 1.7 return to investment and a 49% chance to generate profit. Mixing cowpea with maize gave a 4 and 13% decrease in maize yield, a 7.4 and 16.3 return to investment with a 60% and 76% chance to generate profit for the cowpea grain and fodder variety respectively. During the PANOVA, farmers indicated that soil type and previous crop could explain spatial yield variability. This perception, substantiated with a statistical analysis of trial results, allowed for identification of specific niches for intensification: (i) on clay soils after cotton or maize, soybean was two times more profitable than sorghum (ii) on gravelly and sandy soils, cowpea grain variety was 2 and 1.4 times more profitable than sorghum respectively, (iii) after cotton or maize, there was no maize grain yield penalty due to the intercropping with cowpea. HRE-LH farmers preferred the maize/cowpea option, HRE farmers the cowpea fodder variety option, MRE farmers the maize option and LRE farmers the cowpea grain variety option (Table.1).

Table. 1. Percent farmers who chose the option (all treatments taken together).

farm type	n	maize	sorghum	maize/cowpe	sorghum/cowpea	cowpea grain	Cowpea fodder	Soybean
HRE-LH	7	57	14	71	0	43	57	43
HRE	12	50	50	33	8	50	67	42
MRE	6	83	17	17	0	50	50	33
LRE	5	80	60	20	0	100	0	40

Stall feeding of lactating cows showed a four-fold increase in total milk yield and a doubling of total manure production compared to the farmer practice of free grazing, with a 0.4 return to investment. During participatory scenario design, HRE-LH and HRE farmers wanted to evaluate the combination of maize/cowpea intercropping with stall feeding of cows. MRE farmers wanted to assess substitution of sorghum by soybean, while LRE farmers were interested in substitution of sorghum by cowpea grain variety.

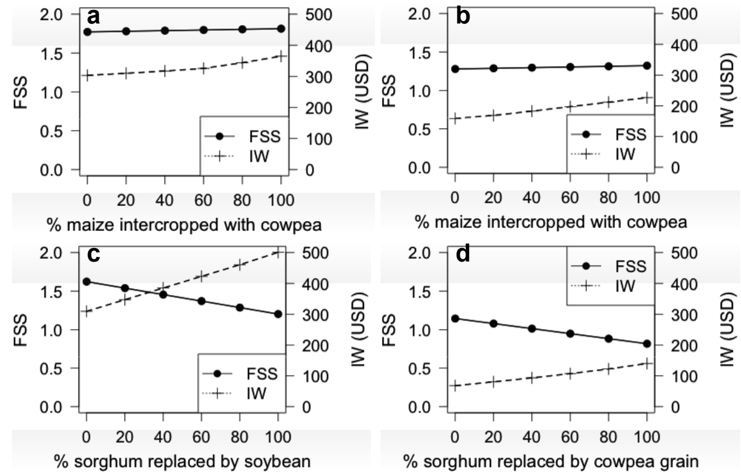

Fig. 1. Ex-ante trade-off analysis for HRE-LH farms (a), HRE farms (b), MRE farms (c) and LRE farms (c). FSS= household Food Self-Sufficiency, IW= net cash Income per Worker

Ex-ante trade-off analysis showed that for HRE-LH farms, intercropping with cowpea on 60% of the maize area after cotton would allow to feed all the lactating cows in the stable during the dry hot period (results not shown) without compromising household food self-sufficiency (Fig.1a). For HRE farms who keep less cattle, this percentage would be reduced to 30%. In those two scenarios, income increase would be limited (Fig.1a&b) as the extra milk barely offsets the cost of cotton seed cake to feed the cow. However, 2 and 0.3 t of extra manure would be produced by HRE-LH and HRE farms respectively, and better reproductive performance of the herd would be achieved in the long term (de Ridder *et al.*, 2015). Intercropping 100% of maize with cowpea and selling the fodder produced beyond cows need would lead to a 20 and 42% income increase for HRE-LH and HRE respectively. MRE farms replacing 50% of sorghum by soybean (on clay soils after cotton) would increase their income by 30% while maintaining food self-sufficiency (Fig.1c). LRE farms replacing 30% of sorghum by cowpea grain (on gravelly and sandy soils) and selling cowpea fodder would increase their net IW by 28% without compromising food self-sufficiency (Fig.1d).

4 Conclusions

The trust built through regular interactions between farmers and researchers, combined with reflective on-farm testing, participatory appraisal and participatory scenario design and analysis led to the identification of farm type-specific promising pathways to agro-ecological intensification. Farmers were enthusiastic about results of the scenarios and some farmers who did not participate in the research buy improved grain and fodder variety cowpea seeds. Other farmers expressed their interest to expand the area allocated to soybean. Our work highlights the value of designing adaptive farming systems based on participatory on-farm crop/livestock trials and ex-ante analysis, using farmers' input at every stage of the process.

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Ecosystem services for West African farming families: the role of woody shrub mulch

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1 Introduction

Woody vegetation in semi-arid West Africa provides ecosystem services that benefit local livelihoods through provision and regulation of natural resources (Sinare and Gordon, 2015). Use of traditional fallows to restore soil productive capacity via organic matter accruement has been compromised by population growth in West Africa and increased land degradation (Bonetti and Jouve, 1999). Continued crop cultivation and insufficient fallow periods have thus, led to severe soil organic matter depletion and subsequent soil degradation in semi-arid West Africa. This situation ultimately undermines food provision of local farm communities and may affect irreversibly ecosystem provision and regulation services within these landscapes. Improved use of local manure and compost as options to regenerate soils may be limited by availability (usually in homestead enclosures), transport constraints (dependent on donkey cart access and distance to fields), and labour requirements (harvest and application effort). As crop residues are vastly collected for livestock forage during the dry season, farming families in certain dryland areas are left with little sources of organic matter to regenerate soils. Innovative farmers in Burkina Faso have developed spatial and temporal shrub-crop arrangements by switching from a strategy of slash-and-burn to a strategy of slash-and-mulch to optimize services provided by *in situ* native woody shrub biomass (Félix, 2015). Increasingly, scientific evidence supports key roles that shrub vegetation types have in sustaining crop productivity and enhancing soil quality in the sub-region (Dossa *et al.*, 2013; Hernandez *et al.*, 2015; Lahmar *et al.*, 2012; Yélémou *et al.*, 2013). Event though woody shrub-based farming systems may have heterogeneous shrub densities, these provide soil water regulation services (Kizito *et al.*, 2007) and nutrient provision services through organic matter from branches and leaves (Ba *et al.*, 2014). In this context, if 100% available woody shrub biomass is the usual application by farmers as mulch, then two questions arise: (1) To what extent is crop productivity affected by *in situ* available mulch application? and (2) What is the effect of twice that dose of application on crop productivity?

2 Materials and Methods

Our study was located in Yilou, Burkina Faso (13°01' N, 01°32' W), where rainfall pattern is unimodal, with a rainy (and cropping) season usually occurring between June and September and total rainfall of 615 mm in 2013 and 653 mm in 2014. Eight on-farm plots of 300-900 m^2 were established in areas with homogeneous distribution of *Piliostigma reticulatum* DC. Hoscht shrub types, following a randomized complete block experimental setup (n=4 in 2013; n=8 in 2014, two of which were on the same piece of land as in 2013). These plots were divided in three equivalent sections where standing woody shrub biomass was cleared, weighed, and applied as three fresh mulch treatments: no mulch (M0), 100% standing biomass (M1; one-third), and 200% standing biomass (M2; two thirds). Mulch application rates varied among plots since total standing biomass was heterogeneous between plots (Fig. 1). Planting dates varied from mid-June to mid-July during both years; sorghum (0.80 x 0.40 m) was intercropped with cowpea (0.80 x 0.40 m) using reduced tillage techniques and fertilizer application 21 days after sowing at 100 kg.ha-1 NPK (23-10-5). Sorghum (grain, straw) and cowpea (grain) yields were measured on three 8 m^2 sized sub-plots per treatment at harvest (November 2013 and 2014). Two-sample inference Student paired *t*-test was conducted to analyse significance of treatment effects on crop yields.

3 Results - Discussion

Numerically, average results from 2013 and 2014 on-farm trials show that yields were highest when 200% biomass mulch (M2) was applied than with treatments of 100 (M1) and 0% (M0) available biomass application (Table 1). Highly significant statistical differences ($p<0.005$) were found for sorghum grain for treatment M2 compared to both M0 (73% yield increase) and M1 (35% yield increase). Significant statistical differences ($p<0.05$) were found for sorghum straw production for treatment M2 compared to M0 (50% increase) and M1 (24% increase). No statistical differences were perceived for cowpea production even though M2 presented 38% and 35% yield increases as compared to M0 and M1, respectively. Overall, these results evidence that woody mulch may contribute to increased crop yields (M2>M1>M0) as related to enhanced soil water use efficiency and reduced water losses (Yélémou *et al.*, 2014). Moreover, the contribution of biological activity (*i.e.* termites, fungi, bacteria) to enhance soil productive capacity and nutrient retention as drivers for chemical soil fertility increases may be evoked (Diedhiou-Sall *et al.*, 2013) and should be explored in further studies.

Table 1. Average yield results ($kg.ha^{-1}$) from 2013 and 2014 and yield differences amongst treatments for on-farm trials with mulch applications of 0, 100, and 200% available woody shrub (*Piliostigma*) biomass in Yilou, Burkina Faso

	Sorghum grain (n=12)	Sorghum straw (n=9)	Cowpea (n=10)
Treatment M0 (0% biomass)	526.4 (222.7) ^{a}	1124.9 (465.2) ^{a}	376.1 (341.5) ^{a}
Treatment M1 (100% biomass)	674.8 (321.7) ^{a}	1353.7 (566.3) ^{a}	384.0 (243.3) ^{a}
Treatment M2 (200% biomass)	912.0 (361.3) ^{b}	1688.9 (664.5) ^{b}	519.8 (397.0) ^{a}
Difference M1 - M0	148.4 (362.0)	228.8 (588.7)	7.9 (197.8)
Difference M2 - M1	** 237.2 (187.9)	* 335.2 (426.3)	135.7 (218.3)
Difference M2 - M0	** 385.6 (370.1)	* 564.0 (728.1)	143.7 (348.3)

Values are shown as Means (S.D.); Means within the same column followed by the same letter are not statistically different; (*) indicates differences are significant at $p<0.05$ and (**) indicates differences are significant at $p<0.005$, following two-samples paired Student *t*-test

Plotting sorghum grain yield increase (%) in function of actual *Piliostigma* dry matter application reveals increased yields with higher application of standing woody biomass availability and variability of crop response to mulching between fields (Fig. 1). These results suggest that there are no linear responses of sorghum to mulching with shrub branches and leaves and that increased crop productivity varies according to soil texture and landscape location (data not shown).

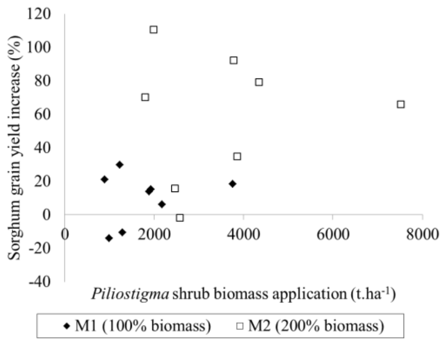

Fig. 1. Sorghum grain yield increase (%) as a function of *Piliostigma* shrub mulch application (n=8, 2014 yield data).

4 Conclusions

Woody shrub mulch, based on above-ground *Piliostigma* biomass, at rates corresponding to *in situ* availability, had clear positive effects on crop productivity. Doubling mulch application rates revealed increased crop production as compared to no mulch and 100% mulch application. However, recommendations for optimal application rates to return highest benefits, in form of ecosystem provisioning services to farming families, requires further study and context adaptation, especially in regards to soil type. Agroecosystem services to dryland farming systems through shrub vegetation types should be further explored, both on farmer fields and experimental stations across West Africa.

Acknowledgements. This research is part of a collaborative effort for the Woody Amendments for Sudano-Sahelian Agroecosystems (WASSA) project, funded by the European Union (ERA-ARD-II). Authors are grateful to farming families of Yilou and field technicians, Oumarou and Zérôme.

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Climate Change Impacts and Food Production in Sub Saharan Africa

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1 Introduction

The agricultural sector (in the broad sense, including forestry, animal production, aquaculture, etc.) represents the dominant part of the economy in most countries and provides the majority of employments and livelihoods. Agriculture has and according to most observers, will continue to have a central role to play in the development process of the African continent. As the global population continues to grow, diet changes associated with rising incomes drive greater demand for food and other agricultural products, while global food systems are increasingly threatened by land degradation, climate change and other stressors. Ultimately, climate change is about human acting in socio-ecological settings in which biophysical, socio-cultural, economic, institutional, political and legal mechanism operate. Agriculture must change to meet both rising demand and become ecologically sustainable. Approaches with the potential for informing and guiding policy and practices are imperative. One of these approaches is Ecosystem-based adaptation (EbA), which provides flexible, cost effective, and broadly applicable alternatives for building robust food systems on less inputs and reducing the impacts of climate change. Practices such as agro-forestry, buffer strips, on-site water conservation, use of native species, etc., have demonstrated that ecological based approaches can provide just one right framework for catalyzing transformative change on a larger scale. If the critical impacts of climate change are not addressed, the impact on ecosystem will be numerous, placing added pressure on already limited land space and natural resources. This paper provides a short description of the potential influence of climate change, variability on food systems and local adaptation strategies as it affects food production.

2 Materials and Methods

Adaptation strategies that can be implemented during droughts serve as a foundation for planning response to future climate change. Climate change is already affecting the livelihoods of West African smallholder farmers who rely on rain-fed agricultural techniques, and it is expected to make food shortages more acute as the region's Population continues to grow. Farmers in the region are trying to cope with irregular rainfall, flooding and degraded soil and we must recognize the potential to reduce some of the effects of climate variability and change. With the shift towards sustainable development goals (SDG) to replace the Millennium Development Goals (MDGs) after 2015, approaches that severe multiple purpose and provide cross-cutting benefits are highly needed in Africa and elsewhere. For example, achieving food security is unmanageable without adaptation to climate change measures and practices that not only support farmers in producing enough food to meet people's nutritional needs, but that also preserve ecosystems from degradation. The infusion of the indigenous knowledge and the scientific views and cross-cutting initiatives at the local and national levels has led to restoration of both terrestrial and marine/aquatic species. A range of specific techniques were adopted to enhance climate change adaptation, among these Payment for Ecosystem services (PES), preservation and promotion of indigenous species and sustainable harvesting practices, afforestation and mangrove rehabilitation, water system rehabilitation (including reservoirs, wastewater reuse, and early maturing and drought resistant crop adaptation were among the most successful projects implemented.

3 Discussion

As the global Population climbs steadily towards 9billion, natural systems that support us all may not be able to withstand the pressure that this growth exerts. Water scarcity, land degradation and the loss of natural (ecosystem) services we all depend on, point to fundamental problems caused by unsustainable development. The direct causes of inadequate food access are poverty, environmental stressors and conflict. Catastrophes like floods, earthquakes, drought and conflict in vulnerable countries force the poor to abandon their homes and livelihoods, creating even more victims of hunger. It is in this complex system that disasters emerge and that society has to cope with. Human and food security within the context of climate change remains relatively under explored. It has now been widely established that the pervasive societal emphasis on the modes and volume of food production in developing countries has been detrimental to resolving problems relating to food distribution, affordability and accessibility. The singular focus on production has consequently amplified food insecurity in many parts of the world. Agriculture must change to meet both rising demand and become ecologically sustainable. Agriculture has significant linkages to poverty and hunger, nutrition and health, peace and security and preserving the world's natural resources. Variability in climatic conditions has been argued to be a stumbling block to food security in most developing countries and especially in Sub-Saharan Africa. This is because, Sub-Saharan Africa already experiences high temperatures and low (and highly variable) precipitation; second, because the economies are high dependent on agriculture and; third, because there is low adoption of modern technology. Extreme poverty, hunger and undernourishment can be eradicated by 2030 while protecting and even reversing harm to natural resources, despite the challenges of climate change and weather extremes.

4 Conclusions

Further, the search for synergies should intensify as governments at different levels (International, national and local) engage private and citizen groups to identify opportunities for resource optimization through efficient use of environmental and budgetary resources. How equipped is the scientific community to capture changes in human behaviour (such as cropping practices), analyze their impact on bio-physical processes and build capacity of governments to predict and respond to environmental shocks and stresses (examples: decline in soil fertility and air quality. We must also realize that smallholder farmers play a key role when it comes to ensuring food for all and climate change and hence need our help. A more integrated approach is needed which recognizes the impacts of; and relationship between agriculture and other development activities. By neglecting the management of natural resources, unsustainable pro-poor land and water allocations, which increase resource efficiency, our ability to as a global community to meet future food needs and address climate change may be compromised. With the anticipated impacts on coastal ecosystem, from climate change, it is vital that measures be put in place to ensure measures for resilience, to allow a system to absorb and recover from the effects of a hazardous event and maintain its essential functions and structures.

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Assessing soil water trajectories and WUE: A multi-year modeling approach to design resilient cereal-legume rotations in the dry areas

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1 Introduction

Cropping system simulation can address the complex and interactive nature of resilience and allows for biological (crop growth and development), physical (soil-water dynamics), chemical (soil carbon and N turnover), and management-related (e.g. crop choice, applications of nitrogen fertilizer, timing of sowing) aspects of resilience to be quantified. Soltani & Sinclair (2012) recently presented a non-calibrated, mechanistic, simple model, called Simple Simulation Model (SSM), which uses a generic approach for simulating the growth and yield of cereal and legume crops. The robustness of the legume and cereal versions of SSM has been demonstrated for a wide range of environments and various species including wheat (Soltani *et al*., 2013) and chickpea (Vadez *et al.* 2013). In cropping systems of the semi-arid Mediterranean region, variable and deficient rainfall and drought episodes are primary constraints to productivity. Under these conditions, maximizing water-use efficiency (WUE, defined as the ratio of yield per unit evapotranspiration) is critical. Hence the accurate prediction of soil-water dynamics and crop–water relations is required to identify management strategies that increase the use of scarce rainfall and its conversion into grain yield. We applied SSM to examine rotations including wheat and chickpea that are representative of rainfed environments of the southern and eastern Mediterranean.

2 Materials and Methods

Simulations were carried out for Tel Hadya, Syria. The site (36°01'N, 36°56'E; elevation 284 m) has a semi-arid Mediterranean climate. Firstly, SSM was parameterized to simulate the growth and development wheat and chickpea crops and the soil water dynamics as observed in experiments conducted in 1998/99 and 1999/2000 at Tel Hadya (Moeller *et al.* 2007). Secondly, data from a longer term two-course rotation experiment established in 1983 at Tel Hadya (Harris, 1990) were used to assess the ability of the model to simulate long-term soil water dynamics and crop productivity as observed under field conditions. In the rotation experiment, wheat (*Triticum turgidum ssp. durum*, cv. Cham3) was rotated with wheat, annual fallow, and chickpea (*Cicer arietinum,* cv. Ghab2), and crop productivity and the soil-water dynamics were quantified under different N fertilizer regimes from 1986 to 1998 (12 crop cycles). For the purpose of simulating successive rotational cycles, a new version of the model (SSM-Rotation) was designed. In SSM, the soil water status is calculated daily as the amount of transpirable soil water (ATSW) using the water balance equation for an expanding volume of soil, corresponding to the addition of the soil layer explored by roots on that given day. Finally, SSM-Rotation was applied to simulate a continuous 30-year period and compare three long-term rotations of Wheat-Fallow (used as reference), Wheat-Chickpea and Wheat-Wheat-Chickpea. Simulations were run with no nitrogen stress effect on wheat; chickpea is supposed to be self-sufficient in Nitrogen. The performance of rotations is discussed regarding yield, in-crop WUE (WUE1), and the WUE calculated over all cycles of the rotation (WUE2). For the sake of uniformity, the wheat yield equivalent (WYE) of chickpea was calculated as: WYE =Yield of Chickpea x (Price of Chickpea/Price of Wheat) (Chetty & Reddy, 1987).

3 Results - Discussion

Overall, the model was able to simulate wheat and chickpea yields, total biomass, and the soil water dynamics as reported for contrasting conditions in Moeller *et al.* (2007) (Fig.1 A-D). In addition, SSM-Rotation simulated the long-term soil-water dynamics in rotations with reasonable accuracy (Fig.1E). The predictive abilities of SSM-Rotation demonstrated here showed that the model is robust enough to be applied to explore indicators of cropping systems resilience such as WUE.

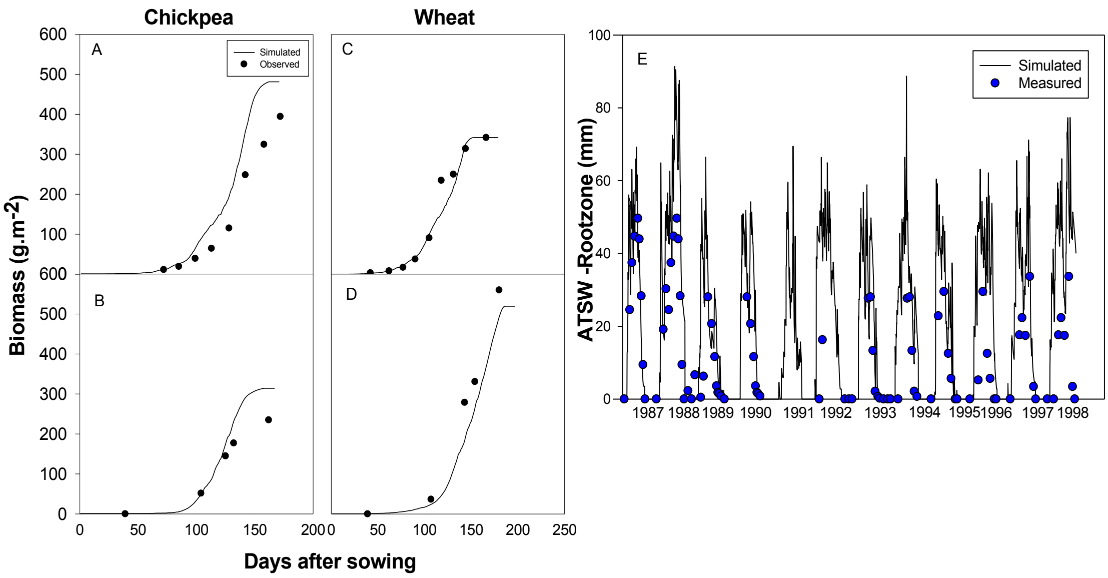

Fig. 1. (A-D) Simulated (curves) and measured (closed circles) of biomass chickpea and wheat grown at Tel Hadya: (A) rainfed chickpea, 1998-99, (B) irrigated chickpea, 1999-00, (C) rainfed wheat, 1998-99, with a nitrogen (N) fertilizer rate of 60 kg N.ha^{-1}, and (D) irrigated wheat, 1999-00, with a N fertilizer rate of 100 kg N.ha^{-1}. (E) Simulated (curves) and measured (closed blue circles) of actual transpirable soil water in the rootzone (ATSW-RZ) in a rainfed wheat–chickpea rotation without N fertilizer applications.

Although wheat WUE was increased in wheat/fallow rotation compared to diversified rotations, the total WUE of the rotation (WUE2, Table 1) was lower in the fallow rotation due to important evaporative losses during the fallow period. The 3 years wheat/wheat/chickpea rotation was the most productive and the most efficient regarding total water use (WUE2) as it combined i) a high proportion of high economic value wheat, ii) reduced evaporative losses due to ground cover every year.

Table 1. Simulated mean yield and WUE in three rotation schemes

Rotation scheme	Wheat yield (t.ha^{-1})	Chickpea yield (t.ha^{-1})	Wheat WUE	Chickpea WUE	WUE1 (in-crop)	WUE2 (over entire rotation)
Wheat/Chickpea	1.42	0.89	0.53	0.39	0.42	0.30
Wheat/Fallow	1.80	-	0.60	-	0.60	0.26
Wheat/Wheat/Chickpea	1.62	0.75	0.62	0.32	0.50	0.37

4 Conclusions

The overall performance of the model was sensible, providing sufficient confidence in the simulation capabilities of SSM-Rotation for subsequent scenario analyses. The analyses will be expanded to different crops (lentil, barley), sowing dates, N rates, and crop maturity types (short and long-season).

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Improving resource allocation in nitrogen constrained systems: acknowledging within and cross-farm variability effect on yield and NUE

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1 Introduction

Sowing multiple fields is a common risk management strategy, implemented by poor resourced smallholder farmers of Central Mozambique. This is done in an attempt to take advantage of the growing climatic and cross-field biophysical variability, i.e., soil types, soil water holding capacity and also natural and management induced soil fertility patterns. However, engaging in this extensive farming practice comes at a cost, mainly because of the poor resource allocation strategies and limited supportive services to assist smallholder farmer's decision making process. Nowadays with the increasing promotion of conservation agriculture among poor resourced smallholder farmers in Sub-Saharan Africa (Giller *et al.*, 2011) the resource allocation burden has increased specially with fertilizer use being increasingly advocated alongside, residues retention and legume incorporation. Therefore, finding best fit allocation strategies for crop residues and the limited amounts of nitrogen fertilisers across crops and fields within agro-ecologies, remains a question of research especially in the maize dominated cropping systems of central Mozambique. In this study we hypothesize that, there are site specific management practices and resource allocation strategies that are more likely to improve yields and increase resource utilization while helping farmers make an easy shift into more productive and labour saving farming systems.

2 Materials and Methods

To evaluate the effect of cross-farm variability on yields and NUE in rain fed N-constrained systems, maize and cowpea were grown as sole crops across three contrasting farming environments. The environments were represented by three soils of contrasting soil water holding capacities and starting soil-N, i.e. a fine sand (fSa) – with low starting N and low initial soil water, a sandy loam (SaL)- low starting N and high initial soil water, and a coarse sandy clay loamy (cSaCL) – with high starting N but low initial soil water. The crops were grown across two residue levels, 0 and 6t/ha, using giant thatching grass as an alternative to maize residues. Three levels of nitrogen application were used i.e. 0, 23 and 92 kg N/ha representing an unfertilized N-deficient (ND), limited N-application (LNA) and a non-limiting N-application (NLA) system. The soils fort he trials were selected from resource allocation maps developed by farmers during a two day participatory crop modelling workshop held in Macate (low rainfall) and Rotanda (High rainfall) during the 2013-14 cropping system.

3 Discussion

The response of maize and cowpea to high C/N ratio residues differed across, fields and levels of N-applied. In unfertilized N-deficient systems (ND), residue application significantly increased cowpea yields by 31.2% and 29.4% in the cSaCL and SaL in detriment of maize yield (Fig. 1). Although expected, no positive responses to residues were measured across all N-levels in the drier fSa. In maize, positive responses to high C/N residues were only measured under LNA and NLA in the wetter SaL and N-rich cSaCL. The poor maize response to residue application in ND systems suggests that, under this circumstances, the high C/N ratio crop residues would be better off if invested to improve the performance of the legume where short term benefits can be obtained. Here, residues a part from improving legume yields, they would also help build up soil organic matter and generate additional income for the households.

In terms of N-productivity, negative responses to N-application were measure in cowpea mainly resulting from poor N-translocation into grain above 23 kg N/ha. For maize however, contrarily to residues, significant responses to N-application were measured with increased N-application but responses differed across sites (figure 1). NUE have differed across sites and crops (Fig. 2). In maize, N-uptake and partitioning into grain yield was higher in the N-rich cSaCL and considerable wetter SaL where the good moisture regime appeared to compensate for the lower initial N content especially at high N application levels. In the N-rich cSaCL the low starting moisture content have undermined N-uptake and partitioning into grain specially when no residues where applied. Residue application was detrimental to increase N-responses in the N-rich cSaCL. Despite the measured differences in N-response, the best nitrogen use efficiency (NUE) for all tested fields, was measured under limited N-applications (Fig. 2). The poor response to high

N-applications can demonstrates that for this unreliable rainfall environments high inorganic N-application are agronomicaly risky (Sadras and Rodriguez, 2010) and unprofitable (Dimes, 2011) as no enough water is available for the crop to make a more effective use of the available N.

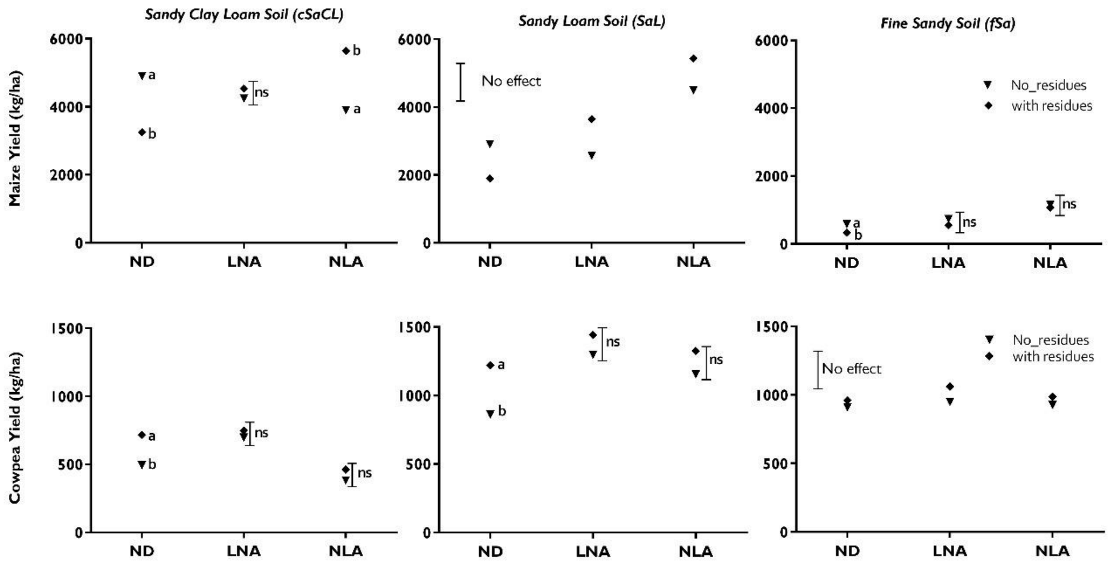

Fig. 1. Crop response to residue and fertilizer application across fields of contrasting water and starting nitrogen.

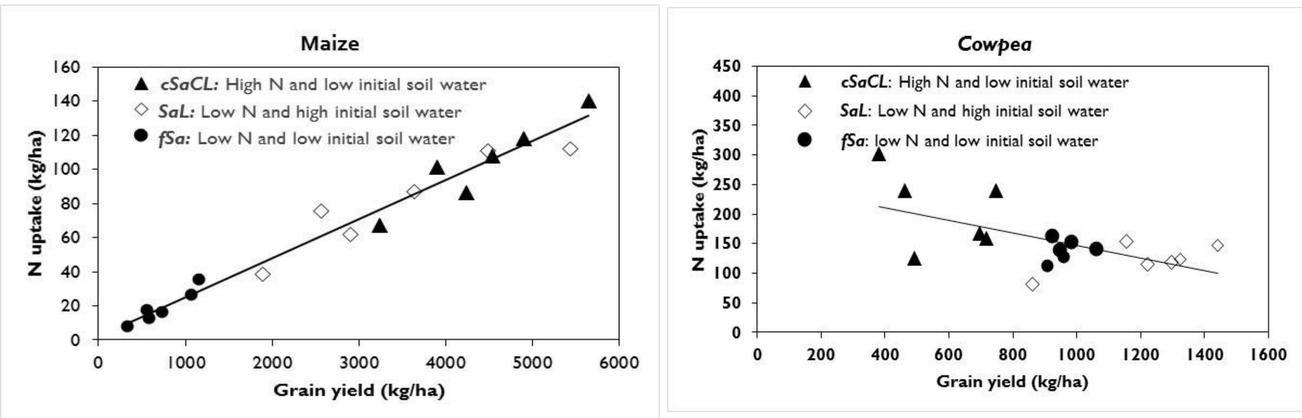

Fig. 2. Relation between N-application levels with maize NUpE and NUE across tested environments

4 Conclusions

Cowpea, positive response to high C/N ratio residues application in unfertilized ND systems, call for a shift in practice especially under N-deprived conservation agriculture, where this alternative resource allocation is more likely to help improve not only legume productivity but also the availability of nitrogen rich legume residues and consequently improve soil-N availability in the system. With regards to responses to N-application, despite significant crop yield increases being measured with increased N-application across tested farming environments, for the unreliable rainfall environments of Central Mozambique the best returns form N-application (NUE) are achieved with limited N-applications (LNA), except for wetter fields were despite decreasing NUpE if good soil moisture for N-translocation (NUtE) into grain is secured good NUE can be achieved at higher N-application rates. This results mean systems design and resource allocation in the region need to be tailored across-fields of contrasting moisture and N-levels within and across agro-ecologies so that farmers can improve their resource allocation and get the best returns out of their already limited resource pool.

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Application of farm typology to explore soil fertility variability and farm-specific nutrient management recommendations in smallholder farming systems in sub-Saharan Africa

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1 Introduction

Smallholder farms in sub-Saharan Africa (SSA) exhibit a high degree of soil fertility heterogeneity, and as consequence, crop productivity and crop yield response to applied nutrients varies considerably across fields (Zingore *et al.*, 2007; Titonell *et al.*, 2008). Sustainable crop production intensification in SSA will largely depend on the development of farm and field-specific nutrient management practices, rather than blanket recommendations across highly diverse farms. Farm typology is a useful tool to explore the wide diversity among smallholder farms to improve targeting of crop production intensification strategies (Chikowo *et al.*, 2014). Key studies on smallholder farm typologies have shown consistent patterns of differences in soil fertility between farm categories, mainly associated with access and use of nutrient resources. Despite advances in the understanding of farm-level soil fertility and socio-economic heterogeneity, there remain major knowledge gaps in integrating available information to develop simple decision support tools that can be used to evaluate the agronomic and economic impacts of nutrient management practices at farm scale. Improved understanding of the interaction between farmers' access to resources, soil types, management history and seasonal rainfall variability on maize productivity and economic viability of various soil fertility management options is an important step to develop meaningful and flexible recommendations that allow farmers to use scarce fertilizer and organic resources effectively.

2 Materials and Methods

We used the Nutrient Expert for Hybrid Maize (NE) model to explore the potential impact of various options for maize production intensification for various categories of farmers in Siaya, Western Kenya, and Wedza, Eastern Zimbabwe. Farm types generated from past studies were used as a basis for development of farm-specific maize production intensification nutrient management strategies. NE applies the site-specific nutrient management concepts to develop field- and farm-specific strategies to manage fertilizer N, P, and K. Determination of N, P, and K fertilizer requirement for a given field by NE is based on the relationship between the soil nutrient supply potential and the balanced uptake of nutrients at harvest and grain yield, which are predicted using the quantitative evaluation of the fertility of tropical soils (QUEFTS) model (Smaling and Janssen, 1993).

3 Results – Discussion

Resource-endowed farmers have access to large quantities of manure and mineral fertilizers, which contribute to higher soil fertility and crop productivity on their farms. Resource-constrained households use little or no manure and mineral fertilizers, and have limited capacity to invest in labour-demanding soil fertility management technologies. These farmers often have to rely on off-farm opportunities for income that are largely limited to selling unskilled labour to their resource-endowed neighbours. The variability in management practices by farmers has resulted in three main soil fertility classes that can be used for targeting soil fertility management technologies, characterized by potential response to fertilizer application as: (i) low-responsive fertile fields; (ii) high-responsive infertile fields; (iii) poorly responsive degraded soils cultivated for many years with little or no nutrient additions.

Analysis of nutrient management options using NE at the two study sites showed that current maize productivity was strongly related to farm resources endowment and soil fertility, with high resource endowment (HRE) category farmers achieving >3 t ha^{-1} compared to about 2 $tha^{-1}$and 1 $tha^{-1}$for medium resource endowment (MRE) and low resource endowment farmers, respectively. Despite water limited yields of >6 t/ha, farm-specific attainable yields were highly variable, depending on soil constraints. In Wedza, NE analysis showed that MRE and HRE farms can at least double maize productivity and net profits by increasing fertilizer use by about 100 and 50% respectively.

Table 1. Analysis of the current maize production situation across farm types in Zimbabwe and Kenya

Site	Resource endowment	Soil fertility status	Farm size	N-P-K applied	Manure applied	Maize productivity	Gross margin	Net profit
			ha	Kg ha^{-1}	t ha^{-1}	t ha^{-1}	US$ farm^{-1}	US$ farm^{-1}
Wedza, Zimbabwe	Low	Low	1	27-7-4	0	0.8	68	-213
	Medium	Medium	2	54-14-7	2	1.9	512	-183
	High	High	3	80-20-10	7	4.0	1,674	1,299
Siaya, Kenya	Low	Low	0.2	21-3-0	0	1.4	59	47
	Medium	Medium	0.8	32-9-0	5	2.2	364	219
	High	High	1.6	80-58-0	6	3.4	1,172	448

In Siaya, there was scope for MRE and HRE to increase maize yields and net profits with optimal N and P fertilizer rates, and including application of K. However, NE results suggested the need to increase fertilizer use under low and moderate soil fertility conditions, but reduce fertilizer application in the fertile soils on HRE farms in Siaya. At the two study sites, the poor soil fertility conditions on the LRE led to very low attainable yields of <2.5 t/ha. Due to small farms sizes and poor soil fertility conditions, the capacity for self-sufficiency in maize production was low for the LRE, even with optimal nutrient management. The need for managing drought risk in Wedza necessitated options for reducing target yields and reducing fertilizer application rates. Application of manure, or retention of maize residues reduced fertilizer P and K requirements, but had no effects on N requirements. The analysis conducted using NE showed that socio-economic and soil fertility diversity between smallholder farms had profound effects on crop productivity and nutrient management recommendations to optimize yields and profits. Simple approaches that integrate scientific data for refinement of nutrient management practices to suit different types of farmers are essential for developing practical options for sustainable maize production intensification in heterogeneous smallholder farming systems. Additional efforts to build the capacity of extension to apply the NE guidelines and test nutrient management options in an iterative process with farmers is required for wide-scale validation and dissemination of site-specific nutrient management recommendations.

Site	Resource endowment	Soil fertility status	N-P-K applied	Maize productivity	Gross margin	Net profit
			Kg ha^{-1}	t ha^{-1}	US$ farm^{-1}	US$ farm^{-1}
Wedza, Zimbabwe	Low	Low	40-20-10	2.0	224	-61
	Medium	Medium	100-38-22	4.0	864	88
	High	High	120-63-32	7.0	4,743	3,172
Siaya, Kenya	Low	Low	58-25-20	2.5	96	82
	Medium	Medium	100-40-32	4.5	712	435
	High	High	50-32-23	6.5	2,467	1,652

4 Conclusions

Combining farm typology and the Nutrient Expert of Hybrid Maize model provided a practical framework for analysis of nutrient management options for maize production intensification under variable soil fertility conditions in smallholder farming systems in Zimbabwe and Kenya. The evaluation of current farmers management practices captured the opportunities and constraints that exit for farmers in different resources groups to improve crop productivity and income from maize production. Soil fertility conditions and current maize productivity was strongly influenced by access to land, manure and mineral fertilizers; resources that should be considered when developing strategies for maize production intensification.

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Bio-physical and Socio-economic Factors Influencing Farmers' Decisions on Whether to Intercrop or Sole Crop Maize in Ethiopia

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1 Introduction

Intercropping is a practice traditionally used by low input (low investment) low output (low productivity) small-scale farmers. For example maize intercropped with legume is commonly practiced by small scale farmers in both semi-arid and sub-humid agro-ecologies in Ethiopia. However, whether increases in the use of inputs would also require the replacement of intercropping systems by more sole cropping systems is not clear. As sustainable intensification practices and on-farm investment increases, driven by agriculture development programs, improved understanding of biophysical and socio-economic factors influencing farmers' preference of cropping system is required. The main aim of this study was therefore to answer what are the key drivers for farmers' choice of cropping in two environments of contrasting agro-ecological potential (i.e. rainfall) in Ethiopia.

2 Materials and methods

A total of 120 households were randomly selected from semi-arid and sub-humid agro-ecologies of Ethiopia in 2012. Sixty household heads were interviewed from each agro-ecology. Survey questions included questions related to available household resources, soil fertility, cropping systems and practices as well as farmer performance e.g. yields and incomes, and farmers' perception on intercropping and sole cropping. Soil samples were collected at 0-0.15m depth from three representative sites at each agro-ecology to understand the soil properties of the study sites. Descriptive analysis was used to compare household's characteristics within each agro-ecology. Independence sample t-tests were used to assess the difference between the two agro-ecologies. Household typologies were developed after identifying relevant variables from a principal component analysis that were used to cluster households into homogeneous groups. Similarity between each pair of individual households in cluster analysis was measured according to Euclidean distances and Ward's method (Hair *et al.*, 1998). One-way ANOVA was used to test the significant difference between the identified clusters of households. The decision on farmers' preference for each cropping system was further analysis using a Tobit regression model. All statistical analyses were carried out using SPSS and STATA.

3 Results – Discussion

Bio-physical (climate and soil) factors: The average in crop rainfall, the amount of fertilizer used for maize production and total soil N was significantly higher in sub-humid than in semi-arid environment while air and soil temperature, SOC, exchangeable K, exchangeable Ca and EC were significantly higher in semi-arid than in sub-humid of the survey areas. The average soil pH was found to be 5.9 in sub-humid while it was 7.2 in semi-arid. In contrast, the average tropical livestock unit and amount of manure used for haricot bean production as well as soil properties such as available soil P, CEC, exchangeable Mg and exchangeable Na were not significantly different between the study sites of semi-arid and sub-humid agro-ecologies.

Socio-economic factors: Average family size of sub-humid was significantly bigger than that of semi-arid. Older farmers and larger farm labour were reported in sub-humid than in semi-arid environment. Average household expenses in sub-humid was twice as high as in semi-arid environment.

In general, adopters of intercropping were 34% in semi-arid and 27% in sub-humid environments. Unlike to 60% of farmers were reported practicing intercropping in the semi-arid environment of Ethiopia (Katungi *et al.*, 2010), our result indicated that greater than 60% of farmers practice sole cropping in both semi-arid and sub-humid agro-ecologies.

Cluster analysis: Cluster analysis was separately computed for semi-arid and sub-humid environments. The analysis was performed using the loadings of principal component analysis. Farm types in general were clustered into three groups and the average values of biophysical and socio-economics indictors were used to describe each cluster type.

Cluster analysis for semi-arid: Households of cluster 1 use high amount of fertilizer to maximize their income from maize production. This farm type was made up of 22% of the total sample households and 38% of the cluster households were adopters of an intercropping system. In contrast, intercropping adopters of cluster 2 were 44% and this cluster comprises 42% of the total sample households. Households of cluster 2 use small amount of fertilizer for maize production. In addition their annual average income is very low ($ 1,641, for example in the year 2012). They satisfy their subsistence food requirement from the amount of maize produced during crop growing season as compared to cluster 1 and cluster 3. Farmers grouped under cluster 2 are regarded as resource poor small scale farmers and they usually practice intercropping system. The main distinguishing features of cluster 3 are large household size and large crop land. The household survey data showed that cluster 3 comprises 36% of the total sample households and only 18% of their total households in cluster 3 adopted intercropping. In addition, households of cluster 3 had larger livestock holdings. Farmers of cluster 3 use higher amount of DAP for maize production. Additionally, they produce haricot bean as a cash crop to generate better income. Households of this farm appeared to be richer and they prefer sole cropping system than clusters 1 and 2.

Cluster analysis for sub-humid: In sub-humid, 42% of cluster 1 households were adopters of intercropping systems. This farm was made up of 32% of the sample households. Cluster 1 represents households with low input low output small scale farming system. Framers of this cluster appeared to be very poor. For example the average crop land size of this cluster was found to be smaller (1.52 ha) as compared to average farm size of cluster 2 (3.44 ha) and cluster 3 (3.62 ha), indicating farmers with smaller farm size are more likely to be adopters of intercropping systems. This is consistent with findings of Iqbal *et al.* (2006) who found association between farm size and intercropping adopters. Similar to their counterpart cluster 2 of semi-arid environment, the households of cluster 1 use low fertilizer for crop production. In addition, household heads of cluster 1 were less educated and their average household income and expenses were less as compared to cluster 2 and cluster 3. Households of cluster 2 of sub-humid were older, mature and well experienced in farming. Their family size is larger and they have large farm size. This cluster represents 30% of the total sample households and only 22% were adopters of intercropping systems. Cluster 3 households are educated and owners of large farms and several livestock. Their land is very fertile and they also apply more fertilizer (urea, diammonium phosphate and manure) for crop production. This cluster was made up of 38% of the sample households and few farmers of this cluster adopted (17%) intercropping systems.

In general, cluster 1 of sub-humid and cluster 2 of semi-arid were low input small scale farmers and relatively many of their households were adopters of intercropping system than clusters 1 and 3 of semi-arid and 2 and 3 of sub-humid.

Factors affecting adoption of intercropping: Further analysis was undertaken using Tobit regression model to understand farmers' decisions to adopt intercropping system over the sole cropping. In general, adopters of intercropping in sub-humid were older and matured household heads. They also had more livestock population, whereas non-adopters of intercropping had larger families and more availability of labour in sub-humid environment. In semi-arid environment, non-adopters of intercropping had more availability of labour, and larger farms. This result appears to indicate that, irrespective of the agro-ecology, larger and richer farmers prefer to sole crop compared to poorer smaller farmers. Similar to our findings, survey results from India (Rajasekharan and Veeraputhran, 2002) and Kenya (Hassen, 1996) showed a negative relationship between farm size and adoption of intercropping practices. Households with larger crop land were less likely to adopt intercropping systems, which was in agreement with farmer's perception.

Farmer's perception on intercropping: Farmers in semi-arid were more optimistic than in sub-humid on the benefit of intercropping in terms of improving soil fertility, better use of resource, reducing unstable grain price, animal fodder, reducing crop failure due to climate risk, contributing to cash sale, improving crop yield, contributing to food security, reducing cost of fertilizer application, increasing soil organic carbon, reducing soil loss due to erosion, reducing weed competition, providing lodging resistant, and reducing insect pests and crop diseases.

4 Conclusion

The result of this study showed that farmer's choice to adopt intercropping system had an association with bio-physical and socio-economic factors. It has been shown that resource poor small scale farmers were more likely to adopt intercropping than resource rich farmers. In addition, farmers cropping in low soil fertility under low rainfall and high temperature conditions tend to intercrop than farmers in potential environment. In both agro-ecologies, households with larger farm size and more availability of labour were less likely to adopt intercropping system.

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Institutionalizing Systems Approaches for Improving Agricultural Livelihoods in an Arid Ecoregion of South Asia

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1 Introduction

The arid agro-ecosystems of South Asia are affected by severe resource degradation, low and unstable farm-based livelihoods and persistent poverty. In these environments, a major research program, the CGIAR Research Program (CRP) Dryland Systems, is underway that utilises multi-disciplinary and systems approaches that build on the indigenous coping and adaptation strategies. The objectives of this study were: to identify relatively homogeneous farm typologies among dryland farmers in the extensive to intensive agricultural systems of Indian Thar desert to target context specific technologies for increased impacts, and prioritize interventions across different farm typologies and facilitate appropriate institutional machenism for future trajectory development for resilience building and or intensification.

2 Materials and Methods

In a study based in Western Rajasthan in India, 250 farm households were randomly selected along the rainfall gradient (Jodhpur, Barmer, Jaisalmer districts) and surveyed using survey techniques and focussed group discussions (FGDs). Built farm-system typologies based on key livelihood assets that helps to explicitly understand the potential, expectation and the limitations of farms and thus develop a "recommendation domain", which can be defined as: "a group of farm-systems, relatively homogenous, with similar circumstances, and for which we can make more or less the same recommendation (Giller 2013). A multivariate approach was used to exploit the large number of recorded variables in the most efficient way. Statistical analysis was carried out by using Principal Component Analysis (PCA) and Cluster Analysis (CA) (Usai *et al.*, 2006; Rufino *et al.*, 2013; Riveriro *et al.*, 2013). Prior to building the farm typologies the major constraints to the farming systems for the each selected village were identified based on FGDs with farmers and stakeholders consultations. Corresponding possible interventions based on the available resources and technologies were identified during the multistakeholder Innovation Platform workshop. In the next stage, the major factors constraining agricultural production and farmers' livelihoods were prioritized for each farm typologies by using pairwise comparisons of different constraints with farmers (men and women) group. The corresponding interventions identified by the multistakeholders innovation platform and the farmers groups were also prioritized using the same method. Thereafter ex-ante assessment of priority options was carried out on farm typologies. Based on the above analysis the best fit options were assessed on-farm as components of the integrated agro-ecosystem, targeting resilience and intensification at different scales: field, farm and landscape. Enabling institutional mechanism, enhance stakeholders' capacity to innovate and strengthening value chains were the key components of the systems approach.

3 Discussion

The values of coefficient of variation (CV) in the crop yields and net returns per standard animal unit indicated very high variability across farm households during the same agricultural year; which was not related to landholding size. It indicates that there might be a number of livelihood assets other than landholding-size which could differentiate farm households in terms of their capacity to make proper use of resources to produce and to adopt new interventions and technologies. As part of characterization we looked at both the farm structure and function. The socially diverse and spatially heterogeneous households were grouped into four broad farm typologies based on multiple livelihood assets using multivariate analysis: 1) Rainfed extensive crop-livestock medium farms; 2) Semi-irrigated intensive diversified medium; 3) Rainfed extensive livestock off-farm income based small; 4) Irrigated semi-intensive off-farm income based small. For each typology, the common structures and functions were developed (Table 1) and constraints prioritized using participatory tools. The magnitude of most of the 32 livelihood assets was significantly different across the farm typologies underlining the need for such clustering. Based on ex-ante assessment and farmers' preferences for promising options/system components, potential interventions were prioritized and implemented in participatory mode engaging innovation platform and community. Farmers' perceptions of constraints and priorities for potential interventions differed across typologies. For example an ex-ante analysis of agro-silvi-horticulture systems demonstrated higher net-returns by 1.5 to 2 times in typology 2 and 4 and 2 to 4.5 times in typology 1 and 3.
Besides the typology specific-technical interventions which were implemented through >250 on-farm trials, other important system interventions are underway including: institutional mechanisms for managing natural resources base

(e.g. common property resources- pastures and water); value chain approaches for improving market access (fruits and medicinal plants) and information; the establishment of long term multi-institutional partnerships to influence policy and up-scaling. A village development committee facilitated to be evolved in each action village was involved in planning and implementing interventions as part of systems approach. At districts/region level, a multiple stakeholders Innovation platform contributed in planning of need based interventions and enhancing linkages and convergence for upscaling. All relevant actors; farmers, government departments, researchers, NGOs, industry and development institutions were appropriately involved for enhancing economic viability and resilience of the farming systems.

Table 1. Structural and functional characteristics of households under different farm typologies

Characteristics	Typology 1	Typology 2	Typology 3	Typology 4	Probability value
Structural characteristics					
–Landholding size cultivated, ha	6.2	6.0	3.3	3.2	0.0696[ns]
–Land labour ratio, ha per adult person	1.7	1.4	0.7	1.0	0.0417*
–Standard animal Units (SLU), No.	5.0	6.2	5.1	5.1	0.0112*
–Number of months own produce support farm family	5.4	10.4	3.8	5.9	<.0001**
–Number of crops grown	2	5	4	2	<.0001**
–% income from off/non-farm earnings	56	25	52	46	<.0001**
–Number of livelihood strategies	3.1	2.9	3.3	3.5	0.0423*
–Status of feed availability (months of sufficiency)	6	10	5	8	<.0001**
–Amount borrowed from bank/financial institutions, US$	313	3196	2999	853	<.0001**
–Average distance of input market, km	15	17	7	3	<.0001**
–Total investment in past 5 years, US$	319	7876	758	1324	<.0001**
–No. of times the farmers visit the extension officials/office	0.3	0.2	0.0	0.4	0.4623[ns]
–Women headed households (%)	14	0.0	17	0.0	0.0211*
–Households opt for out migration (%)	24	3	33	13	0.0121*
Functional characteristics					
–Manure Applied, Kg/ha	71	2035	297	122	<.0001**
–Quantity of Fertilizer-Urea used kg/ha	1	82	11	16	<.0001**
–Quantity of Fertilizer-DAP used kg/ha	1	65	7	17	<.0001**
–Access to bore-well for irrigation (% households)	14	94	15	0	<.0001**
–Access to khadins (% households)	28	0	0	0	<.0001**
–Access to canal for irrigation (% households)	4	0	0	100	<.0001**

Note: NS- Not significant at 0.05; * significant at 0.05 level; ** significant at 0.01 level

4 Conclusions

This paper aims to share the methods and processes of designing resilient farming systems to improve livelihoods under the drylands in South-Asia. Our analysis proved that the dryland smallholder farming systems in south Asia occur within diverse agro-ecological and socio-economic environments and develop different livelihood strategies driven by opportunities and constraints encountered. Multiple livelihood assets determine different land use patterns and agricultural management practices. Well-designed household survey on socio-economic and agro-ecological variables and statistical approach helped capture the diversity of livelihood assets to categorize households into homogenous farm typologies. The follow up FGDs with farmers were equally important to validate the farm typologies and prioritizing the constraints in each typology. The analysis makes a strong case for revisiting the method/ criteria for grouping the farmers for targeting technological and livelihood interventions in arid and semi-arid ecoregions of South Asia. Engaging the innovation platform for identification of possible options and their prioritization at district level; farmers for each farm typology, and ex-ante assessment of promising options led to the on-farm assessment of farm typology specific most appropriate interventions in the action villages. The institutional mechanism being experimented at village to regional level has strengthened the capacity of the community/stakeholders to improve the farming sysytems resilience and economic viability. An ex-post assessment will be undertaken in these communities to assess the impact. This study contributes to the understanding of how research for development through technology targeting for trajectory development can contribute towards stabilizing farm incomes, sustainable intensification and smoothening livelihood of resource poor farmers in vulnerable dry regions.

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What level of detail in input data and crop models is required for food production studies in West Africa?

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1 Introduction

Modeling agro-ecosystems aims at describing and understanding relevant plant processes and their interactions with abiotic and biotic factors and future behavior of the system. Crop models are common tools for this task but various uncertainties exist; in the model design and model parameters, and maybe even more important in input data. While one might argue that the higher the resolution of the model input the better and the less uncertain the model output, this might not be true as models are developed for different scales and the aggregation level of the model output differs.

2 Materials and Methods

We analyze the performance of the point-scale model APSIM and the global scale model LPJmL in the maize-growing areas of Burkina Faso. We test the models´ response to different levels of input information from little to detailed information on soil, climate and agricultural management and compare the models´ ability to represent the observed spatial and temporal variability in crop yields. We simulate grid-cell and national maize yields between 1961 and 2000 with APSIM and LPJmL. We compare simulated maize yields with different input data for climate, soil and sowing dates (Table 1). Up to eight combinations of different input settings are possible for the two crop models. Even though some settings might not be very practicable for an actual model application they represent the upper and lower level of information / resolution of input data available for the study area.

Table 1. The level of information in soil, climate and management data used in APSIM and LPJmL simulations.

Level of information	Climate	Soil	Management - Sowing Date
low	CRU TS3.0; Simple, grid-cell specific monthly climate data (Mitchell & Jones, 2005)	FAO/IIASA-v1.2; Multiple, grid-cell specific soils from global soil map (Nachtergaele *et al.*, 2012)	MIRCA2000; Single national sowing date from global crop calendar (Portmann *et al.*, 2010)
high	WFD; Grid-cell specific daily climate data (Weedon *et al.*, 2011)	AfSIS; Multiple, grid-cell specific soils from African soil database (Leenaars, 2012)	Variable; Multiple, grid-cell specific sowing date from a climatic rule based on rainfall (Dodd & Jolliffe, 2001)

3 Results – Discussion

We found that the level of information of different soil, climate and management data sets influences the simulated crop yields in both models. The uncertainty in input data propagates to uncertainty in simulated maize yields and production. The country's annual maize production of about 500,000 tones is underestimated by 1-17 % in LPJmL simulations, underestimated in most APSIM simulations by 3-46 % but overestimated by 15 % in APSIM simulations with daily climate, local soil information and variable sowing dates.

However, the difference between models can be larger than between input data in particular when assessing the spatial variability of crop yields (see how the points and triangles in Figure 1 group together). Further, the agreement between simulated and observed spatial variability is higher than between simulated and observed temporal variability (not shown) due to abrupt changes in national mean yields from 1987 to 1991 in Burkina Faso which cannot be explained by rainfall variability like in the previous decades and therefore cannot be simulated from the two crop models. The most accurate estimation of spatial variability in maize yields with APSIM is possible with daily climate information and uniform sowing dates i.e. with detailed information on climate data but little information on sowing dates (R=0.65) (WFD-MIRCA, Fig. 1). In contrast the most accurate estimation of spatial variability in maize yields with LPJmL is possible with monthly climate information and uniform sowing dates i.e. with little information on both, climate and sowing dates (R=0.80) (CRU-MIRCA, Fig. 1). APSIM and LPJmL tend to overestimate and underestimate, respectively the spatial variability of maize yields. Soil data that determines water holding capacities is less important for the skill of the two crop models to reproduce the observed spatial variability (see how simulations with different soils group together in Fig. 1) even though the spatial variation in the two soil data sets differs to a larger extent than the spatial variation in the two climate data sets and is of similar magnitude as in the two sowing date settings. However soil fertility levels and soil processes in the crop models such as NO3 leaching from the root zone are important and partly explain the deviations between both models and between simulations with monthly and climate data.

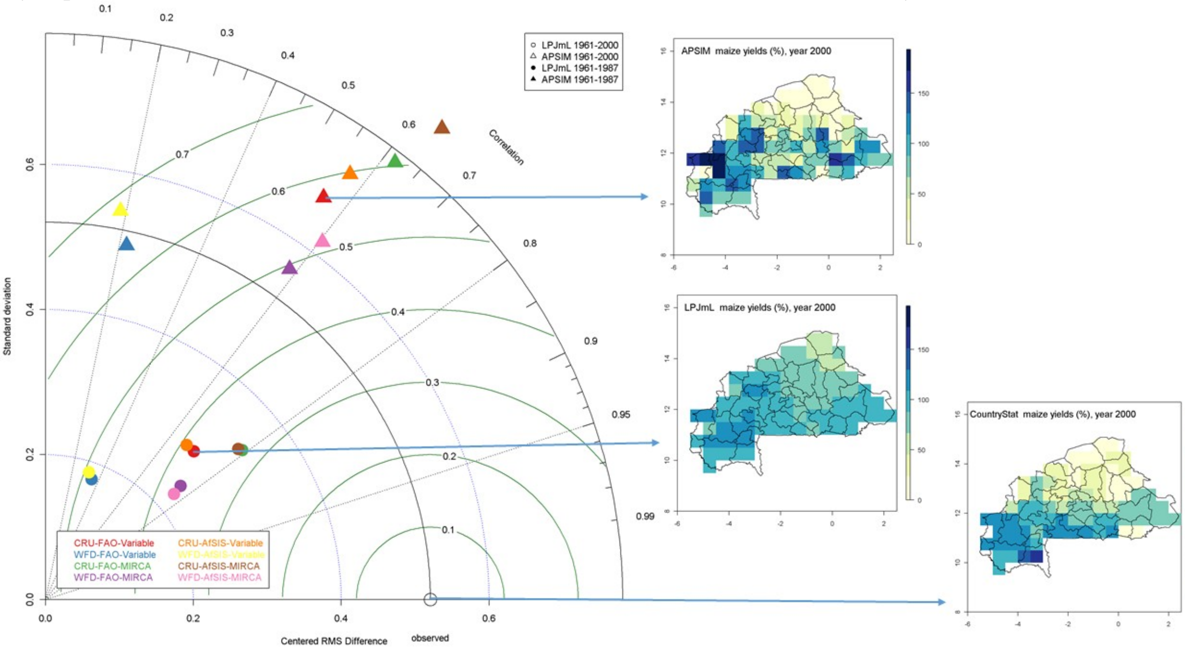

Fig. 1. Taylor diagram displaying a statistical comparison with observations of 16 model estimates (two crop models by eight input data sets) of grid-cell yields in 2000 (A). The closer the coloured symbols to the unfilled circle on the x-axes the higher the correlation and the smaller the root mean square error. The solid green and dotted blue contours indicate the centred root-mean-square (RMS) difference and the standard deviation. The three maps show the spatial pattern of observed and simulated grid-cell maize yields for one example input setting (please note that units in the maps are different from the units of the data used to plot the diagram).

Our results and conclusions are valid for the low-input agricultural systems in Burkina Faso and other parts of West Africa with low yield levels compared to other world regions and they depend on the limitations to crop growth specific to this study area. We expect changes in spatial and temporal variability with increasing yield levels which might lead to different conclusions on the ability of the two crop models to simulate observed yield levels.

4 Conclusions

The findings of our study highlight the importance of scale and model choice and show that the most detailed input data does not necessarily improve model performance. Further we inform about the magnitude of uncertainty in simulated maize yields and production arising from different input data and crop models which will assist identifying the level of detail in input data and interpretation of results in future modeling studies in West Africa.

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Participatory modelling of the trajectories of agro-sylvo-pastoral systems at landscape and community levels in West Africa – the case of Senegalese groundnut basin

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1 Introduction

West African populations are rapidly increasing and are becoming more urban (Ouedraogo, 2007). Due to improvement of living standards, consumption habits in this region are also evolving. The fast growing demand for livestock products creates an important gap between the supply and demand (Kamuanga *et al.*, 2008). Competition over resources increases due to rural population growth and the resulting cropland expansion (van Asselen & Verburg, 2013). Furthermore, the climate stays highly unpredictable with very high inter-annual variability. To predict the future of agrosystems in this context, it is important to identify the ecological and social drivers of their trajectories. The objective of this research is to explore the trajectories of agro-sylvo-pastoral systems at landscape and community levels through participatory modelling. The study area is located nearby Niakhar, in the Senegalese basin, which is an area that has been well-documented since 1960 (Lericollais, 1999; Audouin, 2014). The observed environmental changes are representative of the West African trends described above. Three villages in the area have been chosen for the analysis. These villages are exposed to similar constraints and pedo-climatic conditions but have different landscape structures and diverse combinations of household types. The hypothesis is that despite the contrasts and diversity of household's strategies certain ecological properties are conserved at the landscape level. These properties (plant and animal biodiversity, crop-livestock integration and spatial heterogeneity) are thought to increase the resilience of the whole socio-agro-ecosystem to climatic, pest and market hazards.

2 A role-playing game to define past and future village trajectories with farmers

Three different decision levels are classically distinguished in agronomy: the strategic, tactical and operational decision levels (Sebillote & Solers, 1988). Strategic decisions are define as those that guide the production system for numerous years by choosing production activities and productive resource allocation (human migrations, crop expansion, change in crop or livestock activities, etc.). Tactical decisions aim at managing the production system over seasons. Operational decisions use the resources allocated on a daily basis. Tactical and operational decisions can be observed on the basis of farm survey or on-farm immersions (Vayssières *et al.*, 2007). Strategic decisions are more difficult to apprehend due to their long term dimension and the fact that they depend on household and community levels. We consequently plan to use a role-playing game to capture farmer's strategic decisions and the resulting past and future village trajectories. The role-playing game combines a game-board and a simulation model, responding to each-other (Le Bars *et al.*, 2011; Matthews, 2006). Both represent a hypothetical village (Fig. 1). Farmers take strategic decisions during the game. Each playing round is a year. Farmers' strategic decisions are inputs for the computerized model which simulates the consequences of these strategic decisions on the performances of the different farm types and at the village level. Computerized model outputs are information provided to farmers at the end of each playing round. This information is used by farmers to adjust (or not) their strategies during the next playing round.

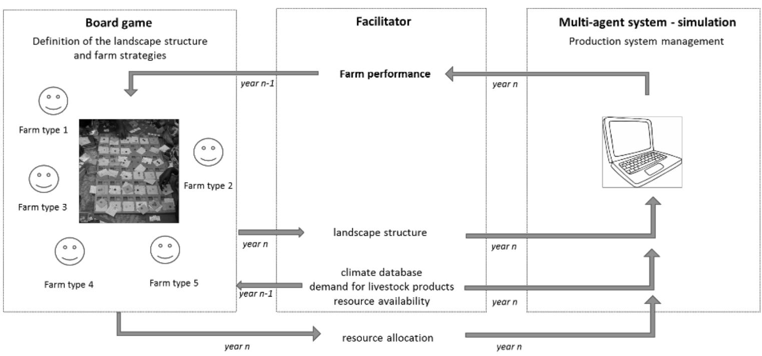

Fig. 1. Interactions between farmers and MAS during the role-playing game (arrows are information flows)

This sequence of role-playing and simulation is implemented for 10 to 50 rounds, i.e. 10 to 50 years. Played scenarios are based on real demographic, climatic and market series (from 1960 to 2015) or projections (2015 to 2050). Both strategic decisions taken by farmers while playing the game and resulting simulation are recorded, and used to describe and analyse village trajectories.

3 A multi-agent system to assess the resilience of socio-agro-ecosystems along their trajectories

The computerized model used for simulations in the role-playing game is a multi-agent-system (MAS). It represents the functioning of the socio-agro-ecosystem at landscape and community levels. Model inputs are of two types: i) parameters directly impacted by farmers' type and strategies (the landscape structure, the action plan and corresponding decision rules) and ii) environmental parameters (resource availability, unreliable weather and variations of demand for livestock products). The MAS integrates two systems in interaction: a decision system and a biophysical system (Fig. 2). The decision system represents farmers' tactical decisions, i.e. their action plan (one per farmer type) and its implementation. It defines the technical actions performed by farmers on plots and cattle over seasons. The biophysical system is essentially a stock-flow model. It represents the biomass productions and the organization of biomass flows through livestock, soil, rangelands, crops, and feed, forage and manure storage structures. The majority of these flows are defined by the technical actions decided by the decision system (e.g. crop manuring). Biomass flows are translated into nutrient, working-time and money flows to calculate different sustainability indicators at farm and landscape levels.

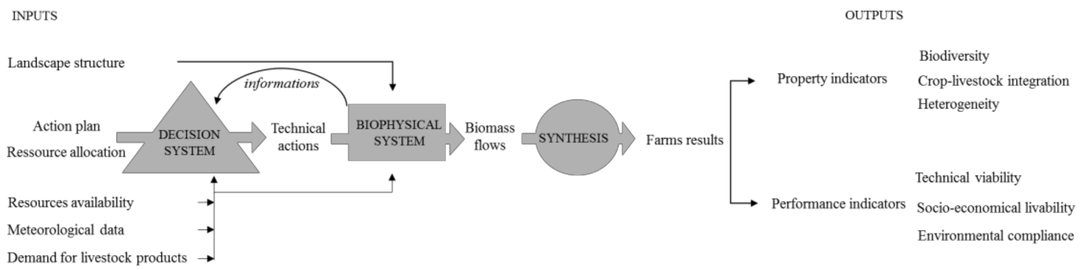

Fig. 2. Conceptual model of the MAS (adapted from Vayssières *et al.*, 2007)

Two types of output indicators are provided by the model: property and performance indicators. Property indicators are used by researchers to verify if some properties (biodiversity, integration and heterogeneity) are conserved over time to increase the resilience of the performances of the whole socio-agro-ecosystem. Three types of performances will be analyzed at landscape level: technical viability (crop and livestock production, workload), socio-economic livability (food self-sufficiency, gross margin) and environmental compliance (nitrogen balance, nitrogen use efficiency). Some of these performance indicators (productions, workload, food self-sufficiency and gross margin) are also the indicators that are provided to farmers at farm level during role-playing games.

4 Conclusions

In West Africa, the demographic, economic and environmental context is changing at a rapid pace, reorganizing rural territories. By using a participatory simulation, farmers are involved in exploring collectively past and future trajectories of agro-sylvo-pastoral systems at landscape and community levels. The proposed game links a board game and a multi-agent system. The role-playing game puts farmers in a position to choose activities and allocate resources on a yearly basis. The board is used to materialize these choices and the MAS provides information on their consequences on the year performances of farms and the whole territory. After N iterations, i.e. an N-years exploration, the dynamic of choices and their consequences can be recorded and considered as probable past or future trajectories.

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A more integrated approach for a diversity of intensification approaches and pathways to cope with the necessity of sustainable intensification of African agri-food systems: The IntensAfrica initiative: Position paper.

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Agriculture faces some unprecedented challenges at global level and in Europe but, for Africa, these challenges are particularly acute on several fronts. The agriculture sector (in the broad sense, including crops, animal production, forestry, aquaculture, etc.) represents the dominant part of the economy in most African countries and provides the majority of employments and livelihoods and hence will play a central role in the development of the continent. At the same time, African agriculture and its associated value chains are expected to contribute to local food and nutrition security, to preserve biodiversity, to provide work opportunities in rural areas, and to have a catalytic effect on the development of related economic sectors. As the African population will continue, in the midterm, to grow both in urban areas and in rural areas, African agriculture will be required to grow and evolve quickly, in particular to adapt to changes in demand. Beyond the expected surge in productivity, African producers will have to engage in a process of intensification in a sustainable way, which means increase of yield in a context of scarcity of natural resources and threats against fragile livelihoods while, at the same time, facing new constraints linked to climate change, competing energy chain values and dwindling natural resources.

In Africa (and in Europe as well), agricultural and food systems will face growing constraints: scarcity of natural resources, environmental degradation, increased energy and input costs, markets more opened to competition, higher vulnerability to various risks, price volatility, demographic changes and migration, etc. Furthermore, European agriculture is confronted with a “plateauing” of yields. Doubts are raised on the ability of such systems to further increase yield, while avoiding increased energy and input costs and negative environmental impacts. European agricultural practices are also often criticized for their consequences on water contamination and their significant contribution to greenhouse gas (GHG) emissions.

It is clear that current agricultural practices, with or without high levels of external inputs, often have negative impacts on the environment and the natural resource base. Effects may vary, from soil fertility degradation, loss of biodiversity and ecosystem functions, pollution of water sources, to emission of GHG, for instance. There is a growing consensus that the sustainability of agriculture needs to increase and that “business as usual” can no longer be considered as a sustainable option. However, there is still much debate about what should be done instead.

New approaches will be required since sustainable intensification is not only about higher outputs, but also about prudent and efficient use of resources, eco-system services, social and economic impacts, induced technological dependency, limits of natural and energetic resources, etc., all at different scales of time and space. New exciting avenues are offered by agro-ecological approaches based on the understanding and mobilization of agroecological processes like the optimization of available water and nutrients and the control of pests with limited use of fertilizers, pesticides and energy. These avenues need to be analyzed and compared, with the appropriate tools and metrics, in order to evaluate their performance and resource use efficiency as well as their sustainability. Comparative research is needed to fully unlock the potential and the limitations of this approach.
The socio-economic and biophysical environments are extremely diverse across Africa, resulting in very diverse farming systems and diets. As a consequence, the solutions aimed for need to be built and adapted to each local context, which means that no magical solution exists, and different pathways for sustainable intensification need to be developed. Despite the great importance of the local contexts, there is also evidence that improving some generic soil or ecophysiological functions1, either by practices or by crop breeding, could significantly alleviate the burden generated by the impact of intensified agriculture on natural resources, and would dramatically modify the long term natural resources balances.

Economic development has demonstrated the capacity of African farming systems to respond to emerging markets, nationally and internationally, but this often comes with considerable environmental or social costs, which appear poorly self-regulating. This highlights the importance of replacing the “business as usual” approach by tailor-made local adaptions – able to create and manage markets.

It is clear that current agricultural practices, with or without high levels of external inputs, often have negative impacts on the environment and the natural resource base. Effects may vary, from soil fertility degradation, loss of biodiversity

and ecosystem functions, pollution of water sources, to emission of GHG, for instance. There is a growing consensus that the sustainability of agriculture needs to increase and that "business as usual" can no longer be considered as a sustainable option. However, there is still much debate about what should be done instead.

Because of the diversity and the complexity of the situations, local innovation systems will play a crucial role to bring up new solutions, mingling all kinds of knowledge and achieving the desired impacts. The role of scientific research in these systems will be important but should be revisited, as S3A states, in multi-stakeholders partnerships. At the same time, scientific research must also be active in combining policies, science, market organization, etc. and involving not only producers but all the actors along the value chain, thus attracting expertise and capital into the agricultural sector.

Though the situation has improved in some countries in recent years, National Agricultural Research systems in Africa often have limited capacity, in human resources, research infrastructure and funding, to address all the challenges involved in sustainable intensification of the agro-food systems. International and European research organizations and research funding agencies are increasingly trying to invest in research for development programs in concerted action with their African partners. However, this external support often remains scattered, which hampers the impact of these efforts on the agricultural led development of Africa. There is a need to increase the African capacity in research for development and to harmonize the support from other partners to create a critical mass for addressing the challenge of sustainable agricultural intensification.

The overall objective of this initiative is only achievable through a concerted and persistent effort and IntensAfrica will be developed as a long term partnership between the two continents. It will contribute to the sustainable intensification for food and nutrition security and economic development by concentrating means on strategic issues of common interest and by creating a critical mass to address the complex issues related to the sustainable intensification pathways development. It will aim at bringing together and streamlining the wealth and diversity of existing partnerships and projects in different agroecological situations, socioeconomic contexts, and policy environments working on sustainable intensification already.

Ex-ante analysis of opportunities for the sustainable intensification of maize production in Mozambique

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1 Introduction

Farming systems of central Mozambique are dominated by small-scale maize (*Zea mays*) production (Cavane 2007). Despite high in-crop rainfall, production and N fertilizer use in the country are among the lowest in sub-Saharan Africa (FAOSTAT, 2015). A fundamental roadblock to increasing inputs and productivity is poor agronomic management (Xu *et al.* 2009). Without addressing this, increases in nitrogen fertilization are less likely to be profitable and may pose a risk to the resilience of smallholders. We refer to these improvements as 'feasible pathways' to sustainable intensification as they account for the capacity of farming communities to successfully adopt new management and technologies. This study aimed to determine how agronomic management may be improved, so that nitrogen use efficiency (NUE) and maize productivity are increased.

2 Materials and Methods

This study took place in Manica province of central-western Mozambique. Farmers (n=52) from three communities were surveyed to establish their input use, productivity and income levels (18 in Marera, and 17 in both Chinhamdombwe and Rotanda). These data were analysed to identify the poorest performing location and farms. The cropping systems model APSIM (Holzworth *et al.*, 2014) was then used in two exercises: 1) A sensitivity analysis to identify agronomic management contributing towards reported production variability; and 2) An estimation of the potential for three simple agronomic changes to increase productivity for the lowest performing farms (defined as the lowest yielding with no N input use from all three sites).
The APSIM model was parameterised for simulations using farm management described by the communities during two group workshops. Soil data from the Estação Agraria de Sussundenga was used along with farmer descriptions and data from the literature to parameterise APSIM's soil module. Meteorological data from Watching Force Data (Weedon *et al.*, 2011) was used for the sensitivity analysis, while observed data was used in the subsequent modelling activity. The sensitivity analysis explored the effect of soil fertility (initial N and organic carbon), agronomic practices (sowing density, sowing date and residue levels) and weed burden (weed density) on yield variability at all sites. The second modelling exercise ran simulations to identify the highest yielding agronomic management of sowing density, sowing date and row spacing at the poorest performing location to establish the potential for low performers to benefit from improved agronomy.

3 Results – Discussion

Maize production was low (mean yield across all three sites was 1033kg/ha^{-1}), as was N input use. Productivity, N input use and yield gaps between average and maximum yields varied with site (Table 1). Marera proved to be the lowest-yielding location as well as that with the lowest level of N use. Average maize yields in Marera were significantly lower than the other two sites. Farm income was lowest at Chinhamdombwe, and significantly higher in Rotanda compared with Marera.

Table 1. N input use and productivity of maize fields at each site; values shown ± standard error; lower case letters next to values indicate significant difference between sites ($P < 0.05$).

Site	N input (kg/ha^{-1})	Mean yield (kg/ha^{-1})	Maximum yield (kg/ha^{-1})	Farm income (US$)
Marera	0.79 ± 0.1	625^{a} ± 12	2700	175^{a} ± 49
Chinhamdombwe	16.1 ± 3.3	1537^{b} ± 27	3500	696^{b} ± 131
Rotanda	16.0 ± 5.9	1085^{b} ± 30	5400	26 ± 18

Results form the sensitivity analysis indicated that maize sowing density was highly influential in determining yield variability at all sites and particularly in Marera (Figure 1). Other agronomic factors affecting yields were residue levels and to a much lesser extent sowing date. Aside from agronomic management, varying soil fertility (represented by initial nitrogen and soil organic carbon) was able to simulate high levels of yield variability.

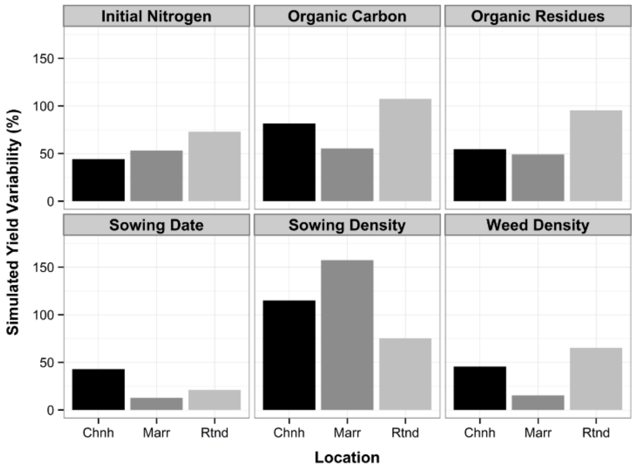

Fig. 1. CV of mean maize yield simulated by adjusting six model input parameters; values from fields with no N input use; Chnh = Chinhamdombwe, Marr = Marera, Rtnd = Rotanda.

The second modelling exercise found that by optimising agronomy, the bottom 25% of surveyed farms (all from Marera) could increase productivity by 120% and profit by US$49.66 (Table 2) – a 28% increase in mean annual income. These results suggest that such farms stand to gain from efforts to address simple knowledge gaps (Schreinemachers 2006) in agronomy. These farms require extension efforts to improve their management prior to investing in costly and risky fertilisers or other inputs advocated by some as the pathway to development of African farming systems (Bationo and Waswa 2011; Jeng 2011).

Table 2. Simulated production and profit benefits from simple agronomic changes to the bottom quantile of maize fields not using N inputs (Marera only); simulations used meteorological data from 1951-2013 with median value provided; values shown ± standard error.

Mean reported maize production *(kg/ha)*	**Optimal agronomic management**	**Improved Maize production** *(kg/ha)*	**Percentage increase** *(%)*	**Increased profit** *(USD)*
309.72 ± 39.15	Sowing: 1 December Row Spacing: 0.5 m Sowing rate: 2.5 pl./m^2	682.15 ± 19.23	120	49.66

4 Conclusions

Through studying farm-to-farm differences in maize systems of Mozambique, we were able to identify a feasible pathway to intensifying the lowest performers. Our study shows that understanding local productivity and profit levels can help to develop practicable interventions to improve farm performance. Improving basic agronomic management remains a valuable tool to improving maize production systems in Mozambique and should be pursued prior to more costly interventions.

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Possible *ex-ante* assessment of rice-vegetable systems performances when facing data scarcity: use of the PERSYST model in West Africa

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1 Introduction

Inland valleys (also called *bas-fonds*) are considered to be promising ecosystems for increasing food security in West Africa due to their relatively high and secure water availability and soil fertility compared to the surrounding uplands (Andriesse *et al.*, 1994). These areas amount to more than 22 million ha in West Africa and are of particular interest for the intensification of agricultural production, in order to feed the constantly increasing population (Rodenburg *et al.*, 2014). To achieve well-adapted inland valleys development, public and private decision-makers need accurate and reliable data on system productivity. In West Africa, agricultural yields are difficult to estimate on a large scale due to a lack of agricultural production records and crop management variability. Under such conditions, agricultural models could be a relevant option for viable yield estimation. In this study, we set out to adapt the PERSYST model (Guichard *et al.* 2013), developed by INRA in France for *ex-ante* assessment of cropping systems based on annual crops, for crop yield estimations in inland valley rice-vegetable systems under West African conditions.

2 Materials and Methods

The study was carried out in 5 *bas-fonds* in the departments of Mono and Couffo in southwestern Benin, and 2 *bas-fonds* in the Circle of Sikasso in southern Mali. In 2013 and 2014, we interviewed 49 farmers in Benin and 45 farmers in Mali, covering 160 and 94 fields, respectively, ranging from several acres to 1 ha. Data on household structure and functioning, as well as land use, crop rotation and cropping practices were recorded by technicians from extension services (public and NGO) and from research centers (Institute of Rural Economy in Mali). The field sizes were calculated by GPS tracking in both countries. In Mali, crop damage, weed pressure and harvested production were recorded on two or three observation plots per field to calculate yield. In Benin, harvesting was finished when the interviews began. Harvested yields were therefore estimated with farmers in local units. As these units varied in terms of weights, volumes and containers, we all measured them on the local markets to increase dataset reliability. Soil samples were taken at plot level (in Mali) or *bas-fonds* level (in Benin) for chemical and texture analysis, while taking into account farmers' knowledge about soil fertility. Focus groups were organized at village level to estimate inter-annual yield variability and identify the main factors affecting yields according to local farmers' knowledge. A literature review and interviews of scientific experts completed the datasets. Data collection, data checking, and analysis were performed by the scientific team using descriptive statistics and the PERSYST and DEXI models.
PERSYST is based on a participatory parameterization approach, integrating local expert knowledge. Crop yield calculations take into account crop rotation and crop management effects, allowing simulations at cropping system level. Crop management effects on yields were estimated by DEXi (Bohanec, 2008), a qualitative multi-criteria assessment tool integrated into the model.

3 Results – Discussions

The identified cropping systems mainly consisted of lowland rice during the rainy season followed by one or two vegetable crops during the dry season. In Benin, the main vegetable crops were two leafy vegetables 'crincrin' (*Corchorus olitorius*) and 'gboma' (*Solanum macrocarpon*), hot pepper (*Capsicum annuum*), and okra (*Abelmoschus esculentus*), while in Mali, potato (*Solanum tuberosum*) and sweet potato (*Ipomoea batatas*) remained the most cultivated crops.
We observed a great range between maximum and minimum yields within a cropping season (Table 1). Inter-annual yield variability was also high, with sometimes a ten-fold increase between bad and good years. According to the farmers, rainfall variability explained most of these differences. The availability of water was recorded as a main constraint. Farmers' knowledge about soil fertility matched the results of the laboratory analysis fairly well.
The GPS tool appeared to be very useful for accurate field size estimation. The field size sometimes changed between two rainy seasons. Indeed, after a rice crop, the field was split into several smaller plots for vegetable growing (Fig 1.)

and not in the same manner, thus making it difficult to clearly discern the effect of the previous crops on the following crops. Moreover, the person cultivating a field could also change from one year to the next. This practice casts doubt on the method of assessing the cropping system effect when the boundaries of the field change considerably from one cropping season to another. We also observed complex crop associations, mixing maize, cowpea and cassava, for example, and sowed on different dates.

Table 1. Estimated crop yields in Benin and Mali in 2013/2014

Country	Crop	Mean *($t.ha^{-1}$)*	Minimum *($t.ha^{-1}$)*	Maximum *($t.ha^{-1}$)*	Nb answers
Benin	Rice	2.6	1.1	4.6	21
	Crincrin	12.0	2.9	24.9	13
	Gboma	1.1	0.4	2.0	10
	Maize	2.3	0.5	6.4	14
	Cassava	4.7	3.8	5.5	2
	Hot pepper	1.6	0.4	3.3	14
Mali	Rice	1.3	0.2	4.5	Focus group
	Potato	19.5	5.3	29.9	71
	Sweet potato	12.5	10	15	Focus group
	Egg plant	2	0.7	4.0	Focus group
	Maize	0.9	0.5	1.5	Focus group

Fig. 1. Changes in land use at field level from one rainy season to the next. On the left: rice in the rainy season (year 1); in the middle: field divided for 5 vegetable crops; on the right: rice in the rainy season (year 2)

Use of the PERSYST model on African family farming systems was limited due to a lack of references and data, and a lack of knowledge and local expertise among farmers as well as among research and extension service technicians. To improve co-operation with farmers and the data collection process in terms of time saving and data accuracy and profitability, there is a need to effectively teach technicians and researchers about farming system complexity, the different reference frameworks used by farmers and scientists, and about erroneous results due to a choice of poor methods (Van Asten *et al.*, 2009). Poor quantitative information was found in the scientific literature concerning the effects of the nitrogen cycle, and of cropping systems and crop management operations on yields under local or similar soil and climate conditions. However, the credibility of the simulation model can be improved if the relevant agronomic improvements that can be promoted for smallholder farmers in West Africa can be precisely addressed (Whitbread *et al.*, 2010). By combining the research and farmer knowledge provided by the literature review and the different interviews (individual and collective), respectively, we were able to successfully parameterize the DEXi model for assessing the effect of different crop management scenarios on yield.

4 Conclusions

Although we could not fully use the PERSYST model due to a lack of scientific knowledge in the African environment, DEXi was used to estimate crop yields at field level. This study highlights key knowledge that remains to be acquired to capture the effect of cropping systems on the observed yield gaps in the context of African farming systems and land use management. Moreover, substantial investment in the training of observers and technicians from research centers, as well as extension agencies, is needed to really benefit more from smallholder farmers' knowledge as a way of increasing the use and relevance of model simulation.

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Participatory Management of Farming Systems in the Western Highlands of Cameroon for Poverty alleviation

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1 Introduction

Small farmers produce much of the developing world's food (Dixon *et al.*, 2001). Cameroon is an agricultural economy country whose rural sector provides 30% of gross domestic product (ECAM3, 2008). The western highlands agro-ecological zone, gathering the Western and Northwest regions is the main center of production of vegetable crops in the country, as well as the Central Africa sub-region. This production is completely ensured by small family units (Tankou, 2013). As an area of high human density, the steepest sloping hills (> 25%) are colonized and farmers face the soil erosion by runoff that significantly reduces their income (Djoukeng *et al.*, 2015). The smooth operation of any farming system is based on several factors including farmers, land, rural environment, production techniques, policies, institutions, market and communication. The results of the field investigations have allowed us to identify the threat on soil and rural environment factors; this threat is a harmful consequence of production techniques factor. In order to increase and maintain sustainable farmer's incomes, we participatory introduced the tied ridging seedbed preparation method in mountain's agriculture for the production of vegetable crops. The overall objective of this study is to evolve technically feasible and economically viable farming system models by integrating cropping with new technics in hilly areas with a view to generate income and employment from the farm. The Specific Objectives are:

1. To identify existing farming systems in hilly areas and access their relative viability;
2. To ensure optional utilization and conservation of available resources and effective recycling of farm residues within system, and to maintain sustainable production systems without damaging natural resources/environment.

2 Materials and Methods

The experiment was set up in 2013 with the participation of farmers with potatoes (*Solanumtuberosum L.*) at Méloh village, Fongo-Tongo subdivision. The variety "Spunta" that farmers consider as the most resistant to various attacks was used in the experiment.The depth of plowing was 0.30m in all treatments; the soil was tilled with the hoe. Demarcation was done with cut twines and branches of *Eucalyptus saligna*. The ridges had a trapezoidal shaped of 0.80m large base and 0.70m small base and were separated by a groove of 0.20m. Inter knolls were placed at intervals of 1m with a width of 0.30m that formed micro-dams between the ridges. A thermometer and a rain gauge were installed at the experimental site to collect climatic data (temperature and precipitation). These data were recorded every day during the period from January 1st to December 31st.During the crop year 2013, we tested the effectiveness of this technique compared to local techniques (flatbed cultivation and ridging along the steepest slope) on 8 blocks of Wischmeier plots in two slopes named 11% and 29%. Each slope has received 4 blocks of 3 plots with a total area of 480 m^2. Harvesting of all 8 blocks was done with the hoe on the same day. Data analysis was done using MINITAB 16. With this statistical software, we calculated the probabilities by analysis of variance (ANOVA) of several factors in the generalized linear model (GLM) at the probability level of 5%.

3 Results - Discussion

Ridging along the steepest slope caused more soil loss than the other two methods of land preparation. Cumulated soil losses in 11% slope were lower than in 29% slope (Fig.1). Considering any slope equal, cultivation on flatbed and ridging along the steepest slope caused the highest soil loss, while tied ridging caused the lowest soil loss; it retained five times more sediment than the other two soil preparation practices.

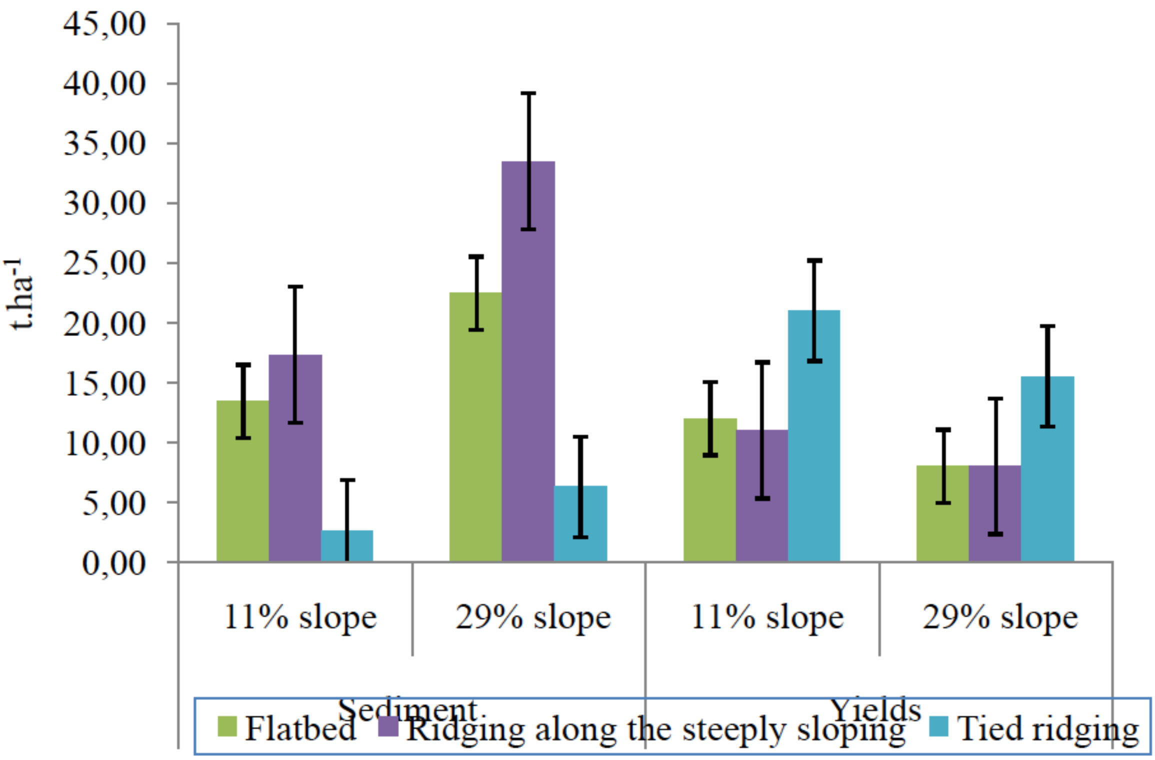

Fig. 1. Chart of average sediment and yields per hectare, per cultivation method and per slope

Analysis of variance at the threshold $\alpha = 0.05$ shows that there was a significant difference in performance between the three modes of tillage in the same slope ($p = 0.000$) and between the two slopes ($p = 0.000$); on the interaction slope and modes of land preparation and no significant difference ($p = 0.130$), amongst the land preparation in different slopes. All things otherwise being equal, yields were lower in the slope of 29% than in 11%; flatbed cultivation method and ridging along the steepest slope had lower yields, while tied ridging had higher yields (Fig. 1). In addition to the fact that tied ridging land preparation keeps the plot fertilizer for plants, this increase in performance (30% gain) is also a result of the high planting density (3% gain).

4 Conclusions

For the cultivation of potato in the Bamiléké's mountains, three modes of soil preparation were tested on two different slopes. Regardless of the value of the slope, it could be concluded that despite overall soil losses in ridging along the steepest slope the yield was almost identical to that of the flatbed; only tied ridging presented a largely positive effects on plants density (3% gain), runoff (lowers by a factor six the runoff), soil loss (lowers by a factor five the soil loss) and yield (increase by 30%). Furthermore soil losses which result in loss of soil organic matter, low yields in the flatbed and ridging along the steepest slope could be a result of leaching of fertilizers. In addition to its benefits in soil and water conservation, tied ridging leads to 10% extra work; creating employment on the one hand and increases the income of farmers on the other hand, demonstration a great socioeconomic interest. Tied ridging technique proved to be the best in terms of creation of employment opportunities, increase yields, soil and water conservation. This study is a first track to fight against rural poverty in the Western Highlands of Cameroon; the study of other production factors (human behavior, institutions, policies, market and communication) will enable us to reduce it considerably.

Acknowledgements. We would like to thank MrsValdea Mansutti (Codroipo, Italy) for his moral and financial support, and also all interested farmers who helped in data collection and popularization of tied ridging method of land cultivation.

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FIGHTING FOOD INSECURITY AND ALLEVIATING POVERTY IN THE FACE OF CLIMATE CHANGE THROUGH RICE-GROWING IN TONGA (WEST-CAMEROON)

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1 Introduction

The uncontrolled and rapid urbanization and population growth have impacted on food resources and creates negative effects on the environment. One of the main risks related to population growth that threatens the world today is food insecurity which is closely linked to poverty.

The "disengagement of the state" in the agricultural sector has already been studied by several authors who have identified the causes of this disengagement resulting to the fall of coffee and cocoa prices, and finally the economic crisis and structural adjustment policies that followed.

This context has led us to focus on "rice growing in Tonga, an activity to fight against food insecurity and poverty alleviation". This study aimed at assessing rice cultivation potential in Tonga, as the locality manages to have a food self-sufficiency while making efforts to preserve the environment. Tonga is a rural locality situated in the western region of Cameroon, with a small population size of 10.000 inhabitants, of which 78% are mainly active in the agricultural sector (Moupou *et al.*, 2008).

2 Materials and Methods

This study was investigated through sampling techniques and survey methods, data collection and processing (Thiétart, 1999 and Quivy Campenhoudt and Van, 2006); the analysis of secondary data derived from literature, field investigation (enquiries to relevant stakeholders, on-the-spot assessment). Questionnaires survey was also conducted in order to determine the benefit and problem of rice growing. Around 200 people were questioned during our investigation.

3 Results – Discussion

In this study, we checked whether rice growing in Tonga really helps to fight food insecurity and poverty alleviation. We also considered the gender and youth issue regarding land access. Both men (60%) and women (40%), mostly less than 59 years old are implicated at all level of the production. Therefore, our investigation have allowed us to demonstrate that through the implementation of the Special Food Security Program (FSP) and the Agricultural Sector Development Program (PADFA), rice growing production in Tonga has increased to 85% instead of 50%, the total cultivated area for rice is approximately 780 ha over 354 km2 of the surface area of the locality. The average land area per family or group of individual according to their workforce and financial constraints is 1.5 ha, which equates approximately to 500kg of rice yielded in good conditions of cultivation per growing season. These programs are strategies developed throughout the country and specifically in the locality. Rice production rose up to 70 000 tons these couple years because almost 40 000 hectares of lowland were serviced, which shifted the yield from 0.5 t/ha to 1.5t/ha.

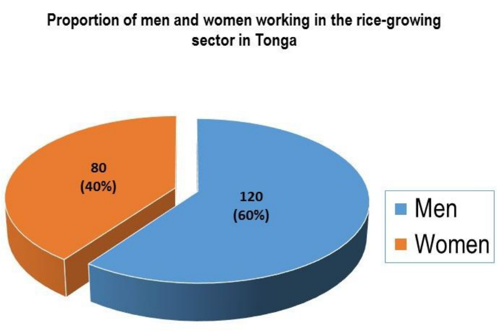

Fig. 1. Proportion of men and women working in the rice-growing sector in Tonga.

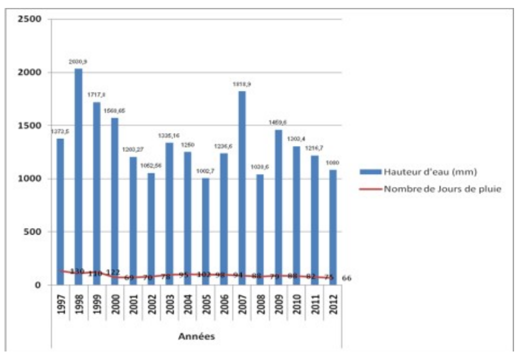

Fig. 2. Precipitations and number of rainy days in Tonga

Table 1. The composition of the population according to the annual report N° 83/42/RA/DAA/TGA.

Total area	Total Population	Density	Urban Population	Rural Population	Labour force		
					Men	Women	Total
354 km^2	10 000	28	8 420	1 580	2 100	5 677	7 777

Because of its natural environmental conditions, Tonga is suitable for rice growing. This has led to the introduction of the New Rice of Africa, type 3 (NERICA 3) that fit well with climate. The scent and special taste of its cultivated rice have contributed to the fame of the locality in terms of rice production in Cameroon. Tonga farmers are well organised into cooperatives, and farmer's organisations share their knowledge in order to make this agriculture a real profession, even if this is still a family agriculture facing many structural and organisational difficulties.

Photo 1:
Reproductive phase (heading tage)

Photo 2:
Maturation phase

Photo 3:
Harvesting of «NERICA 3» type

4 Conclusions

Food security has become a major priority of humanity, especially in the fight against poverty alleviation and hunger concerns, which is one of the Millennium Development Goals. Rice has become a strategic food in Cameroon; it is therefore important for the government to go further in establishing policies and strategies. The rehabilitation and reopening of Tonga rice industry, could make that that ambition became a reality. More supports to farmers to eradicate hunger and poverty, and finally ensure a brighter future for rice growing, new challenges and technological opportunities for rice-based production systems for food security and poverty alleviation are then needed in Tonga.

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W7. Aquaculture systems

Chair: Patrick Dugan, WorldFish Center
Co-chair: Lionel Dabbadie, CIRAD

Effectiveness of a participatory approach for collection of economic data in aquaculture systems at farm level in Brazil

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1 Introduction

The lack of economic information at farm level is one the most important bottlenecks in aquaculture sector, especially in developing and emerging countries (Flores & Pedroza Filho, 2014). This kind of information is crucial for decision making process at producer level and also concerning public institutions related to issues like insurance, credit, support policies, research, technology transfer and extension actions. However, gathering economic data in agricultural systems at farm level requires a substantial methodology in order to ensure reliability of results. This paper aims to evaluate the effectiveness of a participatory approach which is currently being applied by the Brazilian Agricultural Research Corporation (Embrapa) and Brazilian Confederation of Agriculture and Livestock (CNA) in aquaculture sector in Brazil.

2 Materials and Methods

Methodology consists in the collection and analysis of technical parameters, production costs and other economic data by applying panel method with producers of one specific region. Variables are obtained through consensus among participants of the panel (generally between 10 and 20) by using the criteria of the most frequent features of the fish farms ("modal or typical producer"). At the end of the panel, all collected data are analyzed and presented to producers in order to correct errors and to improve participants' comprehension about their economic performance in aquaculture business. One panel is promoted in each production zone selected and later data is updated in a regular basis by calling input suppliers, fish farmers and wholesalers in order to monitor prices and inputs costs variation. The information is disseminated via newsletters on website periodically. Besides, participants receive the spreadsheet filled in panel for their own use in the farm as feedback. Data released consist of: costs of production, analysis of economic viability (e.g. net margins, net present value, effective operative cost), inputs and fish price index (Matsunaga *et al*, 1976).

Fig. 1. Panels with fish farmers in Brazil

This methodology is being used by several institutions in Brazil for collecting economic data at farm level in many different sectors as poultry, pork, cattle, soybean, cotton, sugar cane.

3 Discussion

The collection of economic data at farm level is critical because it is very dependent of producer's capacity in providing reliable information. This capacity in offering reliable information is directly related to producers' knowledge about all costs concerned to fish farming production. Often, producers have difficulty to describe all items because some costs are indirect (e.g. energy) or it depends on the assessment of other technical parameters (e.g. feed conversion ratio-FCR). Furthermore, sometimes these information are related to data which is strategic and, consequently, confidential. Therefore, producers may provide this sensible information in biased way.

Table 1. Zootechnical information and indicators used in the panels – Modal fish farmer of Tilápia in cage culture / São Francisco Valley, Bahia state.

Indicators	Unit	Quantity
Size of land for support area	hectares	3
Number of cage culture ($6m^3$)	Unit	250
Duration of cultivation cycle of fish	days	180
Final feed conversion ratio	Kg of feed/kg of fish	1,61
Final density	Kg of fish/m^3	144
Initial weight of fingerlings	g	25
Final weight of fish (harvest)	g	1.100

Thus, one of the challenges is to find a methodology able to overcome these barriers and assure reliable data. The panel methodology was chosen because it offers the possibility of solving this problem by using a participatory approach. In this methodology, the consistency of collected data is assured by a triangulation process in which each information must be confirmed by the majority of participants in a consensus process. Furthermore, the presence of agents from different segments of the productive chain (i.e. feed and fingerlings suppliers, fish farmers, processors, wholesalers, policy makers) reinforces the validation of the information.

Table 2. Economic indicators used in the panels – Modal fish farmer of Tilápia in São Francisco Valley/Bahia state.

Indicators	Unit	Quantity
Price of tilapia (gross profit)	R$/kg	R$ 5,50
Efective Operational Cost	R$/kg	R$ 3,50
Total Operational Cost	R$/kg	R$ 3,77
Gross profit margin	R$/kg	R$ 1,95
Net profit margin	R$/kg	R$ 1,73

Additionally, since the methodology is applied in several production regions, it is possible to compare the economic viability of diferent species in several geographical zones.

Table 3. Comparison between economic indicators of three production zones in Brazil

Production zone	Specie	Net profit margin (R$/kilo)
São Francisco Valley/Bahia State	Tilapia	1,73
Northern region of Mato Grosso State	Amazonian catfish	1,13
Central region of Tocantins State	Tambaqui (Colossoma macropomum)	0,18

4 Conclusions

As positive aspects, the methodology shows a strong reliability of data because information is directly provided by a representative sample of producers. Moreover, data collection presents a low cost compared to individual visits to producers or to surveys method. Continuous updating of database and the high level of participation of producers are other assets of this methodology. Despite its effectiveness, the method also presents some challenges as: (a) Heterogeneity of producers' profile and consequent difficulty in standardizing data; (b) Logistic requirements related to team travel and organization of panels; (c) Producers' mobilization in order to assure their presence in panels.
One important advantage is the possibility to cover a large number of production zones, which is crucial in a large country like Brazil. For example, in large states like Mato Grosso (903.366,192 km²) it is possible to collect data in 3 fish farming regions in one week. Other advantage of this methodology refers to its low cost compared to other methods as census research, for example. Basically, the main cost for data collection consists in one travel into the production zone for a team of 3 people. This travel includes one panel with duration of about 4 to 5 hours and field visits in 1 to 2 fish farmers. In order to ensure the updating of the economic data, a trainee is in charge of monitoring inputs costs and fish prices by calling suppliers and producers by phone.

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The role of fish farming in the farming system in the Betafo areas of Madagascar : approach by agronomic analysis and socio-economic inquiries.

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1 Introduction

The reasons for the diversification of a smallholder's farming system are intricate, in particular when the diversification concerns fish farming: it can be justified by economic, environmental (water management) or agronomic reasons.
Various sources indicate that rice-fish farming has maintained itself in the Betafo areas of the Vakinakarach (Madagascar) and even more so, it may have considerably expanded. If economic reasons seem obvious, the role of fish farming among the soil fertility of rice plots is to investigate, especially in a context where soils have a low (poor) organic matter level and where it is crucial to maintain the rice plot fertility, an essential element of these smallholders farming system (Rabeharisoa, 2004). This issue arises as cattle manure resources are decreasing, linked to the increase of demographic pressure (Blanc-Pamard, 2000). To face this main fertility constraint, diversification with vegetable during the off-rice season, especially tomato cropping, is often presented as a good lever to answer it; it is also supposed to finance the supply of organic and mineral fertilisation. On an other hand, to be more profitable, rice fish farming needs ponds to stock fish during the off-rice season which is also the colder season.

2 Materials and Methods

In order to answer this questioning, a pilot study was conducted in 2007 in this area during the off-rice season (June to September) where rice plots are used for vegetable cropping (tomato) or fish farming. This exploratory study induces the sampling of plots in order to identify basic hypothesis about fertility management in order to enable further analysis. Inside plots, a balance of organic matter, of nitrogen, of phosphorus (Olsen) and other soil major indicators (pH, CEC) was conducted as the same time as an inquiry on the economic results of these crops among smallholders. 11 plots were studied (5 with tomatoes and 6 with fish farming cycle). Each amount of organic and mineral fertilisers was collected as well as crop exports during the off-rice season. Soil was sampled down to 20 cm inside the hard stratum under the mud which was also collected. Differences in C and N contents between the two sampling dates were tested (Student T-test) to assess the effect of each farming system on soil fertility.

3 Results and discussion

Although vegetable plots received higher quantities of organic matter, the results (cf. figure 1) show a significant increase ($p<0.05$) of N content during fish farming cycle and a stagnation during tomato cycle. Similar evolutions are noticed on Carbon content ($p<0.1$, figure 2).
On the economic aspect, tomato cropping systems bring a positive gross margin profit and fish farming a negative one, especially because all the fish are kept for stocking the following cycle (average was respectively 11 191 Ariari/are and -1 012 Ariari/are),. Tomatoes require a higher cash-flow (6 286 Ariari/are and 1 012 Ariari/are respectively). Fish farming during this season provides a tool to restore the fertility with limited financial means.

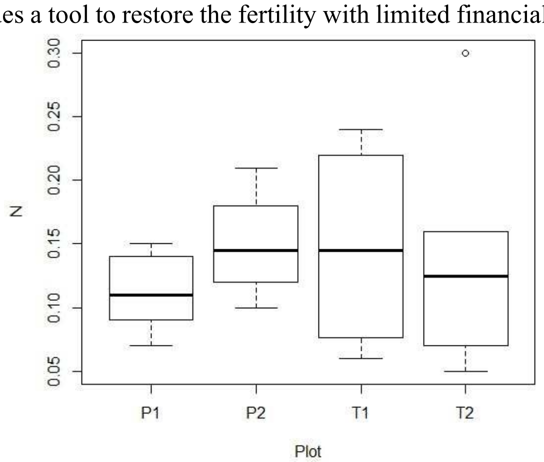

Fig. 1. Soil nitrogen in % in the collected soil samples. 1 and 2 refer to the soil samples before and after the off-rice cycle respectively. P and T refer to fish and tomato farming systems respectively. Error bars represent standard deviation.

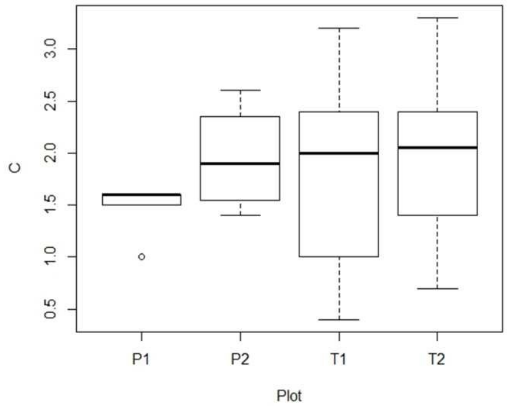

Fig. 2. Soil carbon in % in the collected soil samples. 1 and 2 refer to the soil samples before and after the off-rice cycle respectively. P and T refer to fish and tomato farming systems respectively. Error bars represent standard deviation.

These results confirm that under water, a soil stocks higher organic matter than in a dry environment (Shibu *et al.*, 2006) especially in low trophic environment. Compared to N supply, the balance shows a strong decrease for tomato cycles. (Rochette, 2008)

During the off-rice season, this study shows that, for a smallholder facing cash-flow constrains, fish farming can offer an efficient alternative known as "Masaka" in the traditional knowledge (Bouayad-Agha, 1995). From an economic point of view, it enables him to get positive environmental impacts for the next rice cycle and to improve is further gross margin on the following rice cycle by combining fish-farming and rice. At farm level, plots which are not valorised by vegetables due to lack of financial means and organic fertilisation supply, can still be valorised by fish-farming.

4 Conclusions

Despite classical restrictions of this methodology, results show that the strategy to maintain soil fertility has to be taken into account to explain how fish farming is integrated, in particular by the observed nitrogen and carbon increases it provides. This kind of analysis should be extended to the whole cropping and breeding systems to correctly analyse the rationality of the integration of fish farming inside irrigated rice systems in the area studied.

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Aquaculture systems & farming systems: inside, outside or side-by-side?

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1 Introduction

Two main approaches have been used as regard to aquaculture systems design. The first one considers aquaculture as an integral part of the farming system, as it is the case for most traditional aquaculture systems that have been designed over the centuries in a deep integration with the surrounding crop and animal production (Edwards, Little, & Demaine, 2002). However, not all aquaculture systems fit within this category. Over the centuries, aquaculture ponds have also sometimes been perceived in isolation, or even as a competitor to agriculture development, occasionally leading to their draining and destruction (Billard, 2010). Many modern technologies have also been promoted in a relative isolation from their agricultural surroundings, either because they were soilless or implemented in natural environments (lakes or marine areas, mangroves etc.). For this kind of technology, the system design has been more towards understanding the interactions with their socio-ecological system. This presentation and paper will review several case studies in order to contribute to its formulation.

2 Aquaculture, a component of the farming systems or a component of the socio-ecological systems?

Aquaculture is a millenary activity and over the centuries, highly efficient and integrated aquaculture systems emerged globally (Edwards *et al.*, 2002; FAO, 2003; D. Nhan *et al.*, 2007). They have been advocated to increase land & water use efficiency as well as nutrient recycling (D. K. Nhan, Milstein, Verdegem, & Verreth, 2006). One of the most famous is probably the Vietnamese VAC (*Vuon, Ao & Chuong* meaning garden/pond/livestock pen in Vietnamese) that combines a multi-fish-species pond with a garden producing vegetables or fruits, and livestock supplying organic fertilizers (Luu, 2003). Its widespread promotion started in the 1980s and two models developed: the upland VAC system, which is generally larger (garden: 1000-15000 m^2) and more extensive than the lowland model (garden: 200-300 m^2). Edwards (1998) developed a FSD framework comprising three interrelated aspects: production technology, social and economic aspects, and environmental aspects to describe such integrated aquaculture-agriculture systems. Studies have however pointed out their complexity of management, as the pond sub-system not only requires good management practices to maximize benefits to farmers while minimizing environmental impacts, but also implies to be integrated as much as possible with existing farming activities to maximize production while minimizing nutrient discharges (D. K. Nhan *et al.*, 2006).
The need for a system approach describing and understanding this kind of aquaculture also emerged among development practitioners, as a result of the necessity to better understand and propose technologies to fit to farmer's needs. In Africa, FSD approach including an aquaculture component was proposed in Ivory Coast, within the framework of a development project conducted in the Midwestern region (Dabbadie *et al.*, 1994). In such cases, the aquaculture system is just a sub-component of the farming system, similar to the livestock or crop systems but with its own technical and economical specificities. Considering the socio-economical conditions prevailing in the country at the end of the 1990s (Léonard & Oswald, 1995), aquaculture was a good candidate for agriculture diversification and two models emerged, based on FS diagnostics: one semi-intensive close to urban centers based on fish polyculture combining species with supplementary feeding habits (tilapia, catfish, *Heterotis niloticus*, *Hemichromis fasciatus*) and rice bran feeding + fertilization, and another one located in rural area where access to inputs was almost impossible (Dabbadie, 1996). The production was extensive but quantitatively important, by making use of very large ponds obtained by building drainable dams across valleys and stocking them at a very low fish density (Dabbadie, 1996).
But aquaculture has not always emerged as a component of farming systems, particularly in recent decades. It has also colonized new ecosystems, such as mangroves (Primavera, 2005), lakes (De Silva & Davy, 2010), coastal areas (GESAMP, 2001) and even, the open-sea (Troell *et al.*, 2009). In such areas, the systemic studies have rather considered the ecological (habitat destruction, eutrophication etc.) and social system (conflicts for resources among users, collective action and decision making) but not the farming system.

3 Conclusion

In reality, modern globalized aquaculture can never be considered in complete isolation. Even the fish produced offshore are for example largely fed with agricultural products, originating from existing farming systems sometimes on a global scale. Feed used in Vietnamese pangasius aquaculture often contains American soybeans, for example. On the other side, society demands for a better consideration of the social and environmental impacts of aquaculture. A new

FSD for aquaculture, capable of dealing with all dimensions of modern aquaculture on both the local and global scale, is thus required and the framework proposed by Ostrom (2009) could serve as a basis for this purpose. In the aquaculture-dominated Pampanga delta (Philippines), a territorial approach has been developed in a systemic manner by combining remote sensing, GIS and field analysis (Mialhe, Gunnell, Mering, & Dabbadie, 2011). By showing the spatial organization of subsystems, it has evidenced the main drivers of changes. It could serve as a basis for further FSD research and development on aquaculture systems.

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Market Access and fish farms' density in a sub-Saharan rural country side: a case study of the village of Gbotoÿe in the forested areas of Guinea.

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1 Introduction

The agro-environmental benefits of a fish-farm integrated into a farming system, mostly self-sufficient for supply of stocking fish and fish-food, are broadly admitted. But its contribution to rural household economy is sometimes qualified as insignificant, even non-profitable or even contemplative, sometimes it is only a self-sufficiency crop. In their review of African aquaculture, Brummett *et al.* (2007) identify the « local and regional marketing infrastructure for the sale of food fish produced » and the « lack of access to wealthier markets » as key constraints that are a main explanation of the failure of the promotion of a sustainable aquaculture integrated into farming systems across Africa. As a conclusion, they recommend promotion of small and medium-scale enterprises. More recently, Cai *et al.* (2012) point out that « However, the profitability of farming low-value species is usually low because of limited market potential ». So, the narrowness of the effective demand accessible to the rural fish producers would build up an impassable obstacle for the integrated fish farming development of the integrated fish farming. In these conditions, the economic benefits of this fish farming type at the level of the farming system would decrease as the number of rural fish farmers competing on the same fish market increases. Does the saturating of the so narrow local market doom the ability to densify the networking of the rural producers? This is an essential question in order to appreciate the potential contribution of this type of fish production to face the food security of the rural population in Sub-Saharan Africa. Although in Guinea, rural fish farming development schemes including the purpose of producing fish for the rural consumers have induced strong dynamics for about 15 years. Other choices targeted the quality of the integration of the fish production into the agricultural smallholding and the self-sufficiency for the supply of the fingerlings and for the fish-food. The strong development of this kind of fish farming in the region of N'Zérékoré for a decade justifies the support that the Government is providing to its promotion today. The village of Gbotoÿe is an interesting case study to answer this question. In May 2015, in this village of about 2000 inhabitants, 41 fish farming farms have been estimated to produce 11 t of fish, that means approximately 5,5 kg/inhabitant/y if all the fish is locally consumed. At the beginning of the years 2000, official estimations evaluate to 1kg the yearly fish consumption of a person living in forested Guinea. Although deepened studies show this figure was under-evaluated, the today global production seems significant before the local demand and shows a probably saturated market or becoming saturated.

2 Materials and Methods

Allthough economy and agricultural policies have focused on export crops, the rise of the food-producing sector for commercial purposes has supported strong dynamics of agricultural development (Chaléard and al. 2002 for Guinea and Chaléard 1994 for the Côte d'Ivoire). By mobilizing a geographic approach, this study seeks to explain how the fish farming sector slots into the village area and how this village area is itself connected to greater networks, particularly commercial ones. At this stage the connection of the village with N'zérékoré, a secondary town of 300 000 inhabitants (RGPH of 2014) is essential. This approach is completed by a description and an analysis of the fishfarming practices and of their evolution in order to point out how Gbotoÿe fish farmers adapt themselves to the market's opportunities and constraints. The systemic approach proposed by Cochet (2012), enables us to go over the fish-farm level in order to fit in those evolutions inside the global agricultural transformations all over the N'Zérékoré Region marked by a strong politicies instability (Marchal and al 2002, Bangoura et al 2006). This study relies on a deep understanding of those farmers and of their agriculture smallholdings. Data are issued from field surveys dated ten years between them, at the beginng of 2000 up to 2013 – 2015. Three types of inquiries have been conducted : individual inquiries to understand the course of the individual development, inquiries on the fish-farming practices and their evolution, to analyse the integration of the fish farming unit inside the familial farming system and last, historical and group inquiries to record the evolutions of the village, global evolution of the fish farming sector and processors' perceptions.

3 Results - Discussion

Initially, the start in Gbotoÿe of the fish farming activities is boosted in 2002 by a scheme implemented by APDRA (Oswald, 2013). The evolution at the begining is slow : in 2006, only 13 fish farmers have built up at least one pond. But Gbotoÿe's fish producers were able to quickly appropriate and adapt to the technical referencial frame promoted. Even il no more schemes have directly operated inside the village since 2009, the number of fish producers is still increassing. In 2015, 10 new producers are building their ponds and soon should join the 41 that already produce, that means about one farming system among five has integrated a fish-farming system depending on our estimation. Most of the low-lands suitable for setting up a fish farm that is those in the uptsream areas, are already converted (cf. Map). Up to 2009, fish production was orientated to the village fish market and self comsuption. But since 2009, a growing share has been orientated towards the fish market of N'Zerekore. In this town, like elsewhere in this country, frozen or smoked fish is distributed and contributes to the main protein intake of the population. Frozen Fish is supplied from Conakry, and the capacity of the cold-storage warehouse has doubled from 153 tons in 2001 (Keita, 2001) to 298 tons in 2015 (acording to the Direction préfectorale de la pêche et de l'aquaculture). A supply network for farmed fish has been set up, professionnal sale-women have gathered inside the Association des Vendeuses de Poissons de Pisciculture (AVPP). This evolution is not specific to Gbotoÿe, the network drains all the area and the sales-women go up to 50 km far to buy fish near ponds taking track-roads of poor quality. The complexity and adaptability of those fish selling chains give them their efficiency, similar to those described by Chaléard (1996) that enable the rise of the food-production for commercial purpose in West Africa.
Fish breeding cycles present a great heterogeneity. Fish stocking density and the duration of the fish cycle vary respectively from 0,1 to 2 fish/m² and from 3 to 12 month. That enables producers to produce the targeted size for fish dependind on their purpose, the market and their cash-flow availibility. Rather than increasing the size of the growth pond, farmers tend to multiply the number of serviceponds for reproduction, fingerling production or stocking in order to increase the number of harvests per year. Floating-rice cultivation inside ponds, planting when ponds are drained, fixes major dates of the agricultural calendar. The succes of the integration of fishfarming explains for Simon *et al.* (2009), the contribution of the fish farming to the forested Guinea. Fish producers have also taken advantage of the evolution inside the palm oil processing chain. Relative price increase leads to the use of the light= mecanization, palm kernel crushers have spread off. Palm kernel cake, a by-product of this process, has been use to feed pigs. Pig farming quickly develops all other the area. In their great majority, fish producers have combined pig farming to their pond. In a second stage the way of planning ponds was revisited in order to better the valorisation of pig manure.

4 Conclusions

In this case, the local fish market was not a constraint for the development of fish farming in Gbotoÿe, and more broadly among the Region of N'Zérékoré. In the first stage the local market of the village has allowed the setting up of an incressing efficiency by enforcingd fishfarmers to cooperate with proximity services (like the supply of fish for stocking or the monitoring of pond building). Thanks to the technical referential frame which targets to give all the lever of the management to the producers, combined witho the pragmatic and flexibility management of familial farming systems, the local fish market accompanied a true dynamic of intensification of the fish farming. In fact those fish producers consider fish as a commercial crop In this Region which quickly changes and endures major stresses, the fish farming evolution attests of a remarkable sustainability. In this agrarian system where perennial crops dominate, fish farming introduces an interesting diversification based on producing food for commercial puposes. Contributing to enabling those numerous producers in their family farming system to produce large amounts of fish is a realistic challenge, attested by the present study.

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Ré-SyPiEx
Research and development network on Extensive Fish farming in Western and Central Africa

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1 Introduction

Extensive fish farming has proven to be an advantage for small-scale farms. Requiring little cash, this activity better valorizes the existing production factors and agricultural byproducts. It also reduces the food expenses, increases the farm income and improves the diet of rural households. In Africa, the economic impact of this fish farming system in rural area tends to be under-estimated and insufficiently taken into account by the national development plans where financial and human resources are predominantly targeted at the medium or large-scale commercial aquaculture. Without questioning these choices, a more balanced perspective is needed.
The main objective of the RéSyPiex project is to make policy-makers aware that the "traditional" or extensive systems can be also driven by the market. Supported by PARRAF (Programme Supporting Research Networks in Africa), this network of various West and Central African research institutions involved in aquaculture has been initiated in 2011 by the research project "Ecological intensification of extensive family fish farming systems in West and Central Africa by the analysis of the innovation processes - extensive fish farming systems" (SyPiEx) - funded by the CORAF / WECARD. The research studies have been anchored in the development through NGO partnerships, including the APDRA – Pisciculture paysanne NGO. This presentation outlines the activities conducted by the research network and the stakes for the development of rural fish farming

2 Activities

The network teams involved in the network have strengthened their AIR4D capacity. They conducted a first literature review of previous and ongoing work to analyze the social, environmental and economic impacts of family fish farming systems in Western and Central Africa. The network also promoted the implementation of regional research and education collaborative programmes, leading to students, researchers and teachers exchanges.

Better describe to better promote the SyPiEx
The classic fish culture introduced in sub-Saharan Africa for decades has difficulty develop despite the efforts of the technical and financial partners on the continent. However, systems worn by family farms adopted by most local producers play an important role in the diversification of production and provide additional income to farmers. However, this form of farming in rural areas and in particular, the extensive aquaculture systems are poorly described. The regional literature reviews on SyPiEx in each country (Table 1), will help to publish policy notes in order to facilitate decision making in the fields of SyPiEx in West Africa and Central.

Table 1. Literature review on pisciculture and training in aquaculture in different countries of the network in West and Central Africa

Literature Review		Description
1	National syntheses of extensive fish farming systems	National Study Report (Benin, Cameroon and Ivory Coast)
2	National syntheses of aquaculture training in different network countries	Database countries (Benin, Cameroon and Ivory Coast)
3	Regional synthesis on extensive fish farming systems	Regional Study Report on extensive fish farming systems in West and Central Africa

Research and development in extensive fish farming systems: AIR4D approach

Diversity of choices and practices both in terms of the organization, breeding systems and their integration modalities have enabled the development of spontaneous innovation by fish farmers. Technical choices are made by producers from innovations that have demonstrated their efficiency in the local context. On this basis, the actual constraints to overcome to successfully lead intensification are identified and assumptions are developed with producers and all stakeholders in the innovation platform. The prioritization of constraints led to the identification three major researches related to (1): Access to property in the context of SyPiEx; (2): Farm and economic optimization of SyPiEx (3): Optimized fingerlings production in SyPiEx.

Promote the training of students through south-south mobility

Students involved in the different motilities are supervised by supervisors from different teams (for sending and receiving) thus improving the level of training of students and facilitates research partnerships between different laboratories. During 2014, 10 students involved in the network teams have benefited from mobility grants for realization of courses related to one of three cross-cutting themes identified in West Africa and Central Regions (Table 2).

Table 2. Mobility of students in different network laboratories

Countries	Numbers of students	Study level	Coming Laboratory	Country home for mobility	Home Laboratories
Benin	5	Master	URAEAq/FA (03) and FSA-UAC (02)	Cameroun (03)- Ivory Coast (02)	C.R.O (02) and UR SPGA/UPGC (01)
Cameroun	2	Master	ISH-UD (01) and FASA-UDs (01)	Benin	URAEAq/FA
Ivory Coast	3	Master	C.R.O (02) and UPGC (01)	Benin	URAEAq/FA

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Lessons learnt from a review of extensive fish farming inside family plantations economie through West Africa and of their contribution to the local value chain.

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1 Introduction

For more than a decade, integration of extensive fish farming inside smallholder's farming has been noticed as an alternative way to promote aquaculture development. Inside the plantation economies area of Western Africa, various developments have occurred. The present study analyses and compares situations from Côte d'Ivoire, Cameroon and Benin, thanks to a regional project (SYPIEX) through field data collected in those countries during 2013.

2 Materials and Methods

132 inquiries of fish farming producers were conducted in Central-West and South-West of Côte d'Ivoire and 125 in Central Region and Eastern Region of Cameroon in order to get an up to date description of rough technical and socio-economic characteristics. Inquiries and Value Chain Analyze were carried out in the three countries.

3 Results

The collected data show an interesting convergence between the two fish farming developments. The declared average ponds area is 0,67 ha for one fish farmer in Cameroon and 1,12 ha in Côte d'Ivoire, that illustrate the central function of the dam-pond which make the management of large areas easy, often associated with little derivating ponds. The pond average area is 0,30 ha in Cameroon and 0,28 ha in Côte d'Ivoire (RCI). Fish farmers combine production of various ponds: 3,65 ponds in RCI and 2,35 ponds in Cameroon. Polyculture based on *Oreochromis niloticus* is the most common practice and for the second species used, *Heterotis,* is the most favourite one. This fish farming has first a commercial function and a significant part of the producers reports fish farming as their main activity: in Côte d'Ivoire 23%., in Cameroon 24% (and in this country for Eastern and Central Region, respectively 32%. and 0%). Fish farmers are mostly farmers (92% in RCI, 61% in Cameroon). Logically the production requires mostly family workforce and the ponds have been essentially built with the household's resources. Those two characters indicate the reality of the integration of this type of fish farming that has most often an important place in the farming system. Education level fluctuates, it can be noticed that in RCI, most of the fish farmers who manage the fish farms are illiterate (63%), in Cameroon, 75% stopped their education training before the A levels. Inquiries point out a high percentage of fish farmers belonging to local professional organizations. The rate of women as fish farm managers is low, but they are involved in the fish management and often in charge of the sales. This type of fish farming concerns most of the ethnic or religious components of the local population. The average number of years of fish farming experience shows its dynamic: it is 10,17 in RCI, 10,8 in Cameroon; however this figure hides a significant difference ($p < 0,05$) inside this country, 11,4 and 6,5 for respectively the Eastern and the Central Regions ; this indicates different maturity and also a dynamism with new settings. Compilation of technical criteria (yearly production, yield) is always risky with inquiries. The quoted « yearly production » has respectively an average of 552 kg and of 353 kg in RCI and Cameroon. However, strong contradictions subsist. The declared fish breeding practices were collected and are summarized in table 1, below. The value chain analysis indicates that a large share of the added value is created in the fish production step, even if data vary and a described tendency is to supply stocking fingerlings inside local networks which is the best economic answer facing the potential high cost of the fish seeds. The fish produced is first sold on local markets, prices fluctuate around 1000 F CFA/kg in Ivory Coast to 1500 F CFA in Cameroon. When urban markets are accessible, farmed fish is preferred to other fish substitutes because of its quality. In Côte d'Ivoire and Cameroon, the added value generated by fish processor nearly doubles the one realized by the producers.

4 Discussion

Firstly, this fish farming type has become strongly settled for more than a decade and shows a dynamic. Surprisingly, this type cuts loose some clichés broadly admitted in Africa: small ponds (most often < 400 m²), fish density above 2, small fish produced, the key need of the catfish etc. It is not confronted with a question of bad fish growth, table 1 indicates from the fish farmers' declarations that the *Oreochromis* daily growth exceeds 1g/j thanks to the use of a police fish or their natural profusion (for example, *Parachanna obscura* in the Eastern Region). Fish polyculture presents a sturdy model although it is not always understood like in the Eastern Region and with a size of the ponds similar to that of the traditional Chinese one. That underlines the need to consider that this type of fish farming generates a specific alternative path with its own research-development questioning depending of its development. Secondly, this kind of fish farming is oriented by commercial purposes. Spontaneously, products integrate the surrounding urban markets, farmed fish are easily integrated in the fish consumption supply network.

Table 1. Declared fish breeding practices of *Oreochromis niloticus.*
(stocking density, duration, and initial and final average weight).

O. n. means Orechromis niloticus. In each case, the average and the standard deviation is on the first row and the median and the number of answer on the second

Country or Region	RCI	Cameroon	Eastern Region - Cameroon	Central Region - Cameroon
Density O. n (fish/m²)	1,45 (1,75) 1,00 (37)	0,75 (0,65) 0,60 (119)	0,88 (0,67) 0,75 (90)	0,32 (0,66) 0,15 (29)
Initial weight O.n (g/fish)	17,8 (9,2) 15 (93)	20,9 (18,9) 15 (118)	14,2 (6,9) 12,3 (88)	40,7 (19,3) 30 (30)
Duration. (month/cycle)	7,9 (2,7) 7 (116)	15,3 (6,4) 12 (105)	17,2 (6,1) 16 (77)	9,9 (6,5) 12 (28)
Final weight O.n (g/fish)	283,0 (81,7) 285,7 (107)	505,4 (263,1) 450 (102)	564,5 (272,5) 500 (76)	333,3 (259,5) 333,3 (26)

The results show also contrasted situations between the Eastern and the Central Region of Cameroon. In the Central Region, the activity is new and it has developed smaller pond areas, fish cycles are shorter. A significant difference ($p<0,05$) appears in the size of the fingerlings stocked (Table 1). In the Eastern Region, increasing the production of fish in the pond dams depends on the integration of nursering production inside the fish farm or improving supply through collaborative contracts with neighbours. Analysis elements and comparison with other descriptions (PDCE, 2015), tend to indicate that even if production is smaller than in the Eastern Region, yield is higher depending on the use of bigger fingerlings and lower stocking densities. It must be underlined that intensive models in Benin, that have often benefited from subsidies, generate less added value than the traditional systems and do not resist to the suspension of subsidies' (Odjoumani, 2014). At a larger scale, kinetics of adoption are varied and depend on the local conditions (endogenous evolution in Eastern Region) but also on the technical reference and the local political frame promoted. The various field reports attest of a willingness to intensify in Côte d'Ivoire; this ongoing process is linked to local socio-economic contexts. Lessons from China are interesting with fish in ponds yield improving from 724 to 5 217 kg/ha between 1979 and 2003 (FAO, 2005).

5 Conclusions

We want to insist on two difficulties met trough this study. Only an understanding of the fish breeding system including all the fish and the ponds managed, and seeking how each fish cycle fits in the global management of the producer is in capacity to provide reliable fish production data which are also needed to provide relevant economic data. This point difficult to investigate through that kind of appraoch and needs to be deepened. In spite of the little interest given by the governments, (Nguivoum 2014, Odjoumani, 2013), governments appeal for intensive technologies, the described extensive fish farming discreetly evolves with interesting contributions to sustainable development and poverty alleviation, especially in post-forested areas. This review confirms the resiliency of these models, their ability to supply farmed fish, at an affordable price for vulnerable populations and preferred to other fish supplied. With the reinforcement of their production, fish farming products integrate longer value chains generating higher added value and lots of multiplicative positive effects.

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A food systems approach to aquaculture: re-orienting farming systems for improving nutritional outcomes

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1 Introduction

The global nutrition community has shown increasing interest in harnessing agriculture to maximize benefits for the nutritional status of populations, particularly the poor and vulnerable. Often termed "nutrition-sensitive agriculture", the momentum for this movement comes largely from the recognition that: (1) rising incomes alone do not necessarily translate into improvement in dietary quality or reduction in the prevalence of under nutrition; (2) health systems alone are poorly equipped to address a multi-causal problem with deep and wide roots that include social and gender inequality, lack of ability to afford the foods that are richest in essential nutrients; and (3) large numbers of poor, smallholder farmers in countries in which under nutrition is most prevalent represent an under-utilized opportunity for sustainable improvements in under nutrition. In order to reduce under nutrition while at the same time avoiding rapid rises in over nutrition and non-communicable diseases observed in many parts of the world, greater multi-sectoral coordination that bridges the agriculture, health, and nutrition sectors is needed.

To date, however, little of the momentum of "nutrition-sensitive agriculture" has carried over into the aquaculture and fisheries sector, despite the promising nutritional content and known health benefits of fish. We argue that conventional approaches to agriculture and aquaculture in aquatic agricultural systems limit the scope for improving round the year availability of nutrient-rich foods for poor populations and that changes to existing approaches could improve the benefits. This paper explores the use of a food systems framework to identify opportunities to modify conventional approaches to aquaculture in order to lead to beneficial outcomes for human nutrition.

2. The need to revise agricultural policies to better address modern nutritional problems

Historically, agricultural policies focusing on increasing the productivity of staple foods have been highly successful in increasing the availability of energy. But as noted by Pingali (2015), a revision of those policies is needed to better address the nutritional problems of today. Dietary risk factors are the top contributor to the global burden of disease, and include (among others) low intake of fruit, vegetables, nuts and omega-3 fatty acids (IHME, 2014). While the Green Revolution led to a marked decrease in the price of staple grains over time, the real price of foods rich in micronutrients increased during that same period, and it is plausible that these increased prices have led to reduced dietary quality (Herforth and Ahmed, 2015). Recent reviews of own-price elasticity versus cross-price elasticity suggest that the most effective way of increasing access to foods of high nutritional quality by poor populations is to increase production of those specific foods, rather than making staple foods cheaper (Herforth and Ahmed, 2015).

Aquatic agricultural systems are diverse fishing and farming systems in which the annual production dynamics of fresh water and/or coastal ecosystems provide unique possibilities for crop diversity, fish diversity, and ultimately, dietary diversity of humans. Particularly in Asia, fish produced in such settings is an important contributor of animal-source foods and micronutrients in the diet: from 1950 to 2012, the annual supply of fish for food per capita more than tripled from 6 kg/capita/year to 19.2 kg/capita/year (HLPE, 2014). Since 1990, most of this growth came from aquaculture. While greater fish supply can be seen as a step in a positive direction, the shift from wild fish to farmed fish may have adverse implications for nutrition, given differences in nutrient composition and lower duration of availability of farmed fish, under conventional approaches to aquaculture (Thilsted, 2012). New innovations are needed to optimize the potential for aquaculture and agriculture to lead to nutritional benefits.

3. Expanding 'classical' views on the role of food production: the food systems approach

Taking a food systems approach to aquaculture helps to expand the classical view of production systems as isolated entities encompassing inputs, processes and outputs. It embeds production systems into a wider context of mutually, influencing interrelations with the environment, food utilization and consumption (Herforth *et al.*, 2015). Given that nutrition is the result of multiple interlinked factors spanning across sectors, systems frameworks can be particularly useful in helping to understand how different dimensions of food systems interact and influence outcomes. For example, great attention has been placed on the role of women in food systems, and how their participation in agriculture can have positive benefits on control of income and assets derived from agriculture. At the same time, engagement in agricultural activities can influence women's health or that of their infants, by virtue of increased energy expenditure or increased labor burden and reduced capacity to feed and care for their infants. Understanding these types of implications is important for harnessing the potential of agriculture and aquaculture to have nutritional benefits.

4. Opportunities in aquaculture farming design for improved nutrition: examples from Bangladesh

Having outlined the key characteristics of a food system approach, some examples of ways to redesign farming systems in aquatic systems are given below:

Opportunity 1: Pond polyculture with micronutrient-rich, small fish to increase fish availability and access for nutrition

The inclusion of micronutrient-rich, small fish ('mola', *Amblypharyngodon mola*) in homestead pond polyculture systems in Bangladesh provides more fish for consumption and sale. Usually, in polyculture systems, a number of different species of similar large size and with a long rearing time are cultivated. In Bangladesh, research has shown that the simultaneous cultivation of micronutrient-rich, small and large fish, mainly native carp species leads to an overall increase in total production of a higher nutritional quality, without use of additional inputs. This results in a sustainable intensification and as small fish breed in ponds and their harvest period is shorter than for large fish; multiple, frequent harvests are possible, thereby increasing access to critical nutrients, as well as providing regular additional income (Thilsted and Wahab, 2014).

Opportunity 2: Pond dyke farming as integrated aquaculture-agriculture systems

For diversifying production and thus diets of rural households in Bangladesh, the cultivation of vegetables (e.g. orange sweet potato) and fruit on pond dykes is being promoted by WorldFish as an integrated, multifunctional farming system. This results in increased availability of non-staple foods that provide complementary nutrients to those from fish and greater dietary diversity, year-round (Islam *et al.* 2011).

Opportunity 3: 'Gender-sensitive' gill net for empowering women in aquaculture and improving their access to fish

A gender transformative approach aims to empower women through participation in aquaculture production. Considering cultural norms, a gill net, designed in the World Fish USAID-funded project: Aquaculture for Income and Nutrition (AIN) enables women to catch fish from the pond dyke, without having to enter the pond. This has eliminated the constraint which women faced in harvesting fish and thereby empowered them to take an active role in aquaculture and increase their control over access to fish, on a regular basis (Islam *et al.*, 2015).

5. Conclusion

Food systems approaches can help to unlock the potential of agriculture and aquaculture for nutrition. As indicated by the above examples, small modifications in farming design can have large impacts on the performance of production systems and enhance their potential to benefit nutritional outcomes.

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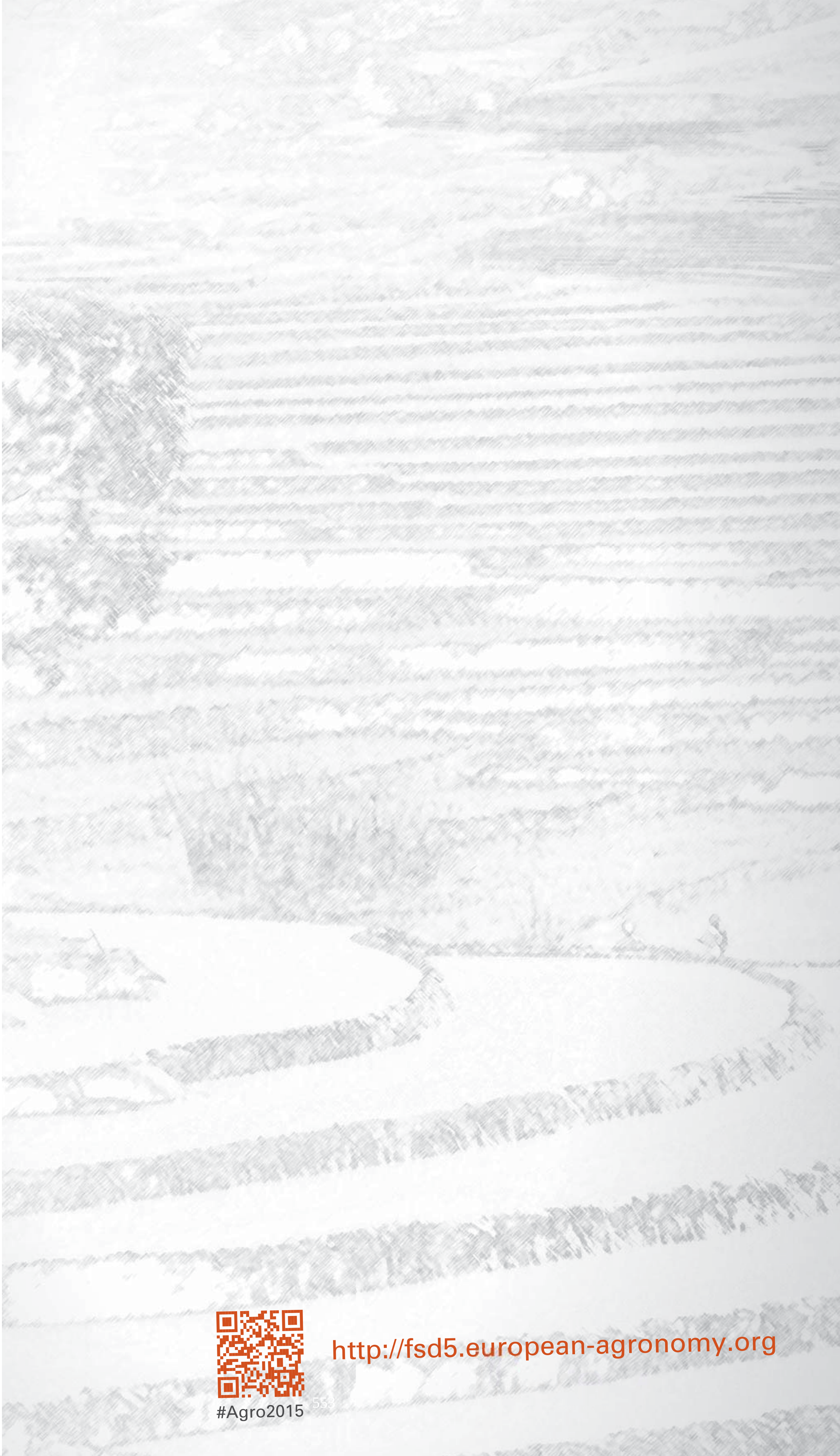

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