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A Sequential Participatory Approach to Adapt Livestock Systems to Climate Change

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Abstract: Livestock systems are and will increasingly be impacted by climate change primarily because the feed supply produced on the farm (pastures, forage crops) depends greatly on the climatic conditions experienced. To adapt grassland-based livestock systems to climate change, some transformational redesign of the farming system may be required. Redesign is basically a matter of reconfiguring land-use for feed production and management practices set up to cope with weather variability. We present a participatory method to design systems adapted to new conditions. It is based on a pre-existing game-like platform (Forage Rummy) in which various year-round forage production and animal feeding requirements have to be assembled by participants with the support of a computerised support system. The weather scenario considered is conveyed by dedicated intermediary objects (e.g. herbage growth chart, rainfall chart) for a climatic year that is fully revealed before the design process starts. The solutions developed are then evaluated according to criteria of biophysical performance, organisational feasibility, and feeding shortage risks. The method consists of a sequence of three workshops (W) for which Forage Rummy was adapted. It keeps the complexity of the design problem manageable by progressively introducing the difficulties faced. W1 aims to produce a configuration that satisfies an average weather scenario of the future. W2 refines or possibly revises the previous configuration by considering between-year variability. W3 explicitly takes uncertainty about the weather into account. Unlike W1-2, in which entire weather scenarios are shown at the beginning, weather is only revealed month by month in W3. Experimental results of the use of the method with farmers are analysed, and further enhancements of the method are outlined.

Keywords: grassland; intermediary object; livestock; strategy; tactic; variability

1 INTRODUCTION

Agricultural sustainability is facing substantial challenges from climate change. The variability of weather conditions and the frequency of extreme events are forecasted to increase. Such changes can have dramatic consequences for many types of agricultural production systems. The current challenge for research is to produce knowledge, methods and tools to help farmers anticipate and cope with the effects of climate change on their systems. Climate change influences the seasonality and productivity of fodder production and thus grassland-based livestock systems. Designing systems adapted to specific weather conditions resulting from climate change is a highly complex decision-making problem in which biophysical impacts of climate drivers interact with human management behaviour (Duru and Martin-Clouaire, 2011; Wise *et al.* 2014). Formal modelling techniques often fail to address this problem because of the complexity of the relations between climatic, biophysical and management variables. In addition, developing realistic models for a particular situation requires a deep understanding of these relations (Jakku and Thorburn, 2010). Participatory processes involving farmers and scientists (Voinov and Bousquet, 2010) have been proposed as a framework for knowledge sharing, learning and virtual experimentation of system adaptation to climate change. It is commonly agreed that cross-links between disciplines and participatory approaches are needed to develop sound solutions (Zierhofer and Burger, 2007). Participatory design sometimes uses formal modelling to enhance farmers' cognitive capacities and understanding of temporally risky production environments (Marshall *et al*., 2013).

The design scope must cover the entire farming system (Rodriguez *et al.*, 2014). The design process has to combine knowledge and skills of both scientists and farmers (Raymond *et al*., 2010) to generate salient, legitimate and credible responses. Basically, farmers have experiential knowledge, which is more focused and pragmatic than scientific knowledge and often supports a better understanding of system functioning and management risks. This knowledge also better reflects concrete aspirations and preferences of farmers. Participatory design workshops may harness a type of knowledge that is not possible to collect with surveys. The interaction between farmers and scientists should produce hybrid knowledge drawing on well-studied general principles with local perspectives. This approach aims to examine how farmers secure their livelihoods in order to reveal sustainable pathways for farming systems.

Considering this framework, we present a three-stage participatory method that supports the design of grassland-based systems adapted to new climatic conditions. It consists of a sequence of three workshops for which a pre-existing game-like platform (Forage Rummy, Martin *et al.* 2011) was adapted. Playing consists of assembling various year-round forage production and animal feeding requirements with the support of a computerised support system. We divided the process into three stages to control complexity of the design process by progressively introducing constraints to be faced.

2 REQUIREMENTS AND BACKGROUND

2.1 Requirements

Adaptation to climate change must include adaptation to climate variability (Smit *et al.*, 2000). As such, the design of systems adapted to climate change has to be based on a method in which system performances are evaluated according to a range of weather scenarios representing the variability of the future climate. Three main features are required to increase the effectiveness of the scientific information used by the method and the ability to support participatory learning and change in practices: credibility, salience and legitimacy (Cash *et al*., 2003). Focusing on livestock-system adaptations, we identify key criteria that the method should satisfy to be endowed with these features.

For saliency (relevance to livestock farmers), oversimplification should be avoided (Pannell *et al*., 2006), and the method must consider particularities of the context in which design is made (Bergen *et al., 2001)*. Therefore, the resolution of the system under consideration should be carefully considered in space (plot, set of plots) and time (day, week, month). In addition, the method must keep the climatic conditions for which the design is made changeable, as well as other characteristics such as soil properties. Finally, the method must support the design of systems that are robust to a range of climatic scenarios (i.e. that can function properly under a variety of conditions). Robustness can be achieved, for instance, by over-dimensioning the forage-production area with respect to animal requirements (configuration for resistance) or through dynamic interventions that ensure that performance is maintained (adaptability via flexibility) (ten Napel *et al.* 2011).

For legitimacy, which we define as the need to respect farmers' values and management principles, two criteria are pertinent: the transparency of design tools and the ability for participants to include their own knowledge. Transparency requires using tools that are relatively simple and with which farmers can immediately see the effects of changes to the system (Eikelboom and Janssen, 2013). It also implies that the support tool can represent the system and its environment with the types of information familiar to farmers (e.g. temperature, rainfall, soil available water, herbage availability). Many authors emphasise the need to incorporate empirical knowledge along with scientific knowledge, especially when the design objective is to increase the robustness of farms through crop diversity and appropriate management (D'Aquino and Bah, 2013). For tools applied to livestock systems, incorporating empirical knowledge is mainly a matter of calibrating plant models with management-dependent data and local forage-production expectations. Another important criterion that increases the legitimacy of participatory design is the ability to explore large variety of possible choices.

Credibility concerns the scientific trustworthiness of the technical evidence and argumentation. This feature is provided by the use of up-to-date scientific knowledge and well-founded design and evaluation methods. Scientific knowledge is particularly needed for the modelling of biophysical processes (e.g. impacts of climate change on forage production).

2.2 Background: Forage Rummy

The participatory design approach presented in this paper draws on the use of a game-based design approach called “Forage Rummy” (Martin *et al.*, 2011). It has been used in collective workshops to design and evaluate grassland-based livestock systems adapted to changes in farmers’ objectives (e.g. forage self-sufficiency) or in the production context (e.g. frequency and magnitude of extreme events). The game relies on a number of “intermediary objects” that put relevant pieces of scientific knowledge in a tractable form for the design task. These include material objects such as a temporally-structured game board, forage sticks representing year-round forage production and usage, and cards of animal feeding requirements. Playing the game consists of combining these objects to represent various components of the farming system: land use (types of forage crops and grasslands with associated area and management practices), herd subgroups (size, production target), and subgroup diets throughout the year in a given economic and climatic scenario. The consistency (e.g. the ratio of forage supply to consumption) and economic performance of each farming system designed is then assessed by participants’ opinions and a forage supply-consumption balance model embedded in a spreadsheet.

This kind of tool gives salience, legitimacy and credibility to the design process. Credibility is conferred by the use of well-grounded biophysical models of plant growth (Duru *et al.*, 2009) and animal feeding (INRA, 2007). Salience is provided by 1) the explicit representation of the major components of the farming system, the environment and their relations and 2) the ability to consider any production context (climate and soil properties) by using a plant-growth model suitable for a large range of grassland types. Legitimacy comes from 1) using simple models and pertinent intermediary objects that keep the process transparent and intelligible (e.g. forage balance model to assess animal feeding) and 2) the participatory side of the method, which integrates participant knowledge such as management rules and local production expectations into the design process. In workshops, Forage Rummy is usually focused on a single average or particular year of the current or future climate. However, to take climate variability into account, participants should consider several climatic years. Furthermore, Forage Rummy has limited ability to represent farm management constraints, due mainly to the monthly time-scale at which it runs, which is too coarse, especially in spring. It prevents properly considering changes in grazing management that could be made to cope with climate variability. Therefore, a more accurate representation of herbage availability as a function of herd location on plot types is needed to deal with climate variability. Another limitation of Forage Rummy concerns its inability to deal with the limited predictability of weather, since weather for the entire climatic year is revealed at the beginning of the workshop. Progressively revealing the weather scenario (e.g. month by month) forces participants to deal with risk and uncertainty when designing the farming system. These weaknesses have motivated an extension and reframing of the game to create design contexts that are more similar to those in which the farmers' decision-making takes place.

3 A THREE-STAGE PARTICIPATORY DESIGN METHOD

Our design method is based on the assumption that a farming system must be designed gradually, from long-term strategic choices (i.e. system dimension and main objectives) to short-term tactical choices (i.e. how to manage the system to reach these objectives). According to Sebillotte and Soler (1990), farmers’ strategic choices rely on their perceptions of the average contexts in which their systems lie, whereas tactical choices deal with the variability inherent in these contexts. In addition, farmers’ risk-aversion shapes both strategic and tactical decisions because they are made in the face of uncertainty, especially that in the weather. In this perspective, our method divides the design effort into sequential stages. First, the strategic dimension is set up according to the average climatic situation. These strategic choices are then confirmed or revised by considering a range of climatic situations and progressive uncovering of weather to build tactical choices.

The design approach (Figure 1) is structured around three consecutive workshops (W), each requiring about two hours. W1 deals with average climate change, W2 with climate variability and W3 with progressive uncovering of weather. In the course of these workshops, the realism of the decision-making environment increases. In W2 and W3, the unit of time in intermediary objects (week) is smaller than that in W1 (month). In W3, the climatic year is revealed progressively to force participants to formulate management decisions without knowing future weather. Each workshop is structured around two steps: 1) describing the climatic situation and formulating adaptations to it and 2) designing the system (i.e. making strategic or tactical choices, evaluating them, and then modifying them if necessary). During each workshop, participants evaluate the system they design with a spreadsheet that provides the forage supply-consumption balance each month in W1 or each week in W2 and W3. Participants may consider factors besides forage balance (e.g. management-related aspects) and reject what appears to be an unacceptable system. Participants can debate the advantages and disadvantages of a system during workshops and, if they find it incompatible with the weather scenario, eliminate it. At the end of the three workshops, participants will have designed a farming system adapted to the three climatic situations considered. The features of the climatic situations considered in W2 and W3 (e.g. above- or below-average herbage production, distribution of herbage production during the year) depend on the aim of the project.

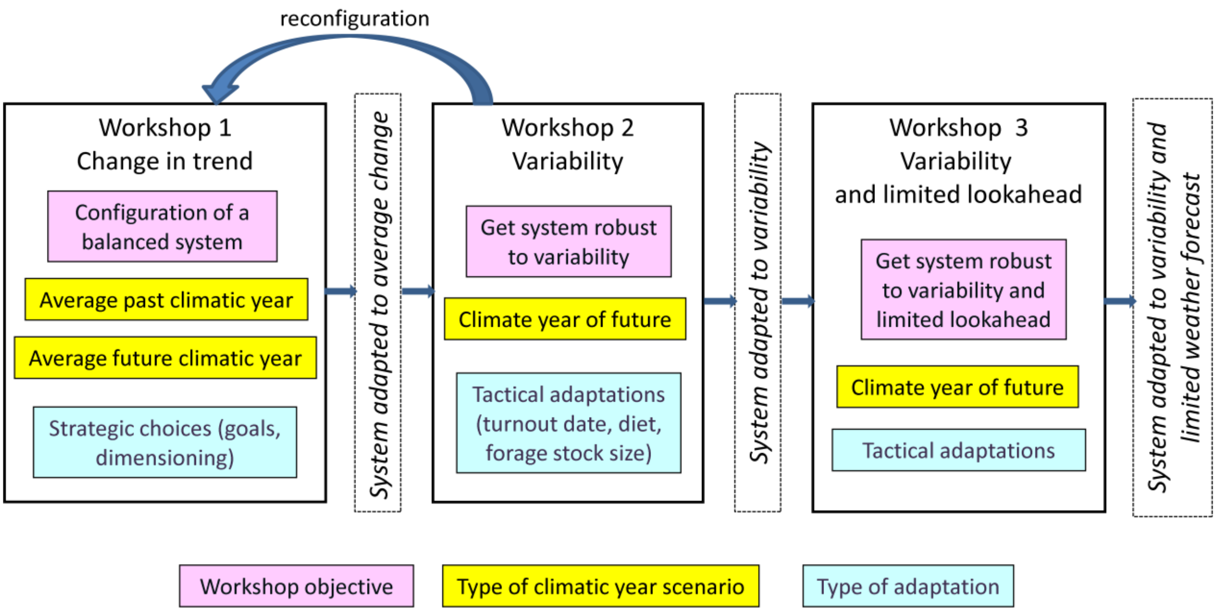

Figure 1. The three-stage design process

In W1, participants start by using the game for a well-known scenario to become familiar with the principles of the method. They have to design a farming system adapted to the current average climatic year. At this stage, they do not think about what they should change in the system to cope with climate change. Then, participants have to design a system suitable for an average climatic year of the future (e.g. by 2100). To do so they may change any component of the original livestock system to cope with the new climatic context better. As in a classic Forage Rummy workshop, the entire climatic year is revealed at the beginning of the workshop, the temporal resolution is one month, and the on-farm location of animals is ignored.

W2 aims to test and, if necessary, increase the robustness of the system designed in W1. Strategic choices made in the system might be reconsidered. The purpose is to achieve a farming system adapted to a type of year considered frequent in a future climate. The main changes expected in the system concern tactical choices (e.g. turnout to grazing, area harvested). For this, system representation is more fine-grained than in W1: the temporal resolution is one week during key grazing periods, and herd movement between grassland types (defined by type of cover and its intended use) is explicitly considered to calculate more precisely the forage available to feed animals.

W3 aims to refine the system designed in the previous workshops and, if necessary, make it more adaptive to weather conditions as they occur. The purpose is to create a management context that reproduces the difficulties encountered in real situations, in which future weather beyond few weeks is uncertain. The system is no longer designed but is tested in a realistic management context with weather forecast given over a bounded temporal horizon. For this, the climatic year is revealed progressively in four-week periods. In this way, participants react to the weather and the related forage production they have to manage during each four-week period. They also have to think about what they can do to make the system viable regardless of the weather in the next period. Here, only tactical adaptations may be performed. On the one hand, considering a frequent climatic year enables participants to evaluate if the system is adapted to future climate under realistic management (incomplete information, irreversible decisions). On the other hand, considering an exceptional year enables participants to evaluate the adaptive capacity of the system to cope with extreme climatic hazards, under the same realistic management constraints. Either way, participants only know if they are facing an extreme climatic year or not at the end of the workshop.

Each stage of the approach is essential and cannot be skipped. Indeed, participants first have to understand how to play (current average climate in W1) and then pre-design the system for adapting it to major change (future average climate in W1). This pattern is necessary to frame design of the system to adapt it to climate variability (W2). Finally, the choices made are relevant only if they are expressed in a realistic management situation in which weather is assumed to be known over a limited temporal horizon (W3).

4 THE ROLE OF INTERMEDIARY OBJECTS

Our sequential participatory design approach was applied to grassland-based dairy systems in the mountainous Aubrac region of the Massif Central (France). Grasslands cover more than the 90% of farmland area in the region, and most farmers are not allowed to feed animals with silage (hay or maize) due to their contracts with a quality label. Full grazing is performed from May to November. The farmers adapted this livestock system to average climate change with strategic and tactical adaptations during the W1. By 2085, climate change is expected to impact forage resources by i) increasing annual herbage production, ii) changing seasonal boundaries (earlier and more productive spring, earlier summer, later winter), iii) increasing year-to-year variability in seasonal herbage production and iv) increasing differences between spring and summer-fall production. Farmers managed the system considering a favourable climatic year in W2 (more forage resources availability in the year than the mean-year) and an unfavourable climatic year in W3. Intermediary objects were used during the workshops, helping the three farmers who participated to design and evaluate the system.

4.1 Describing the climatic situation and formulating adaptation to it

Intermediary objects described the climatic situation to participants by showing the weather and its consequences on herbage production over a year (i.e. daily mean temperature, monthly rainfall, daily soil moisture and daily herbage growth). Participants used these intermediary objects in all workshops, along with forage sticks in W2 and W3, to formulate adaptation ideas in brainstorming sessions.

The adaptations formulated concerned both strategic (in W1 and W2: calving dates, hay distribution in summer, proportion of farm area in hayfield) and tactical choices (in W2 and W3: date of turnout to grazing). Participants compared the climatic year under study with the current average year in W1 and the future average year in W2 and W3. Participants identified if the climatic year under study was more or less favourable than the average year at the seasonal scale by looking at herbage growth charts. However, they were not able to assess with those charts if annual herbage availability was higher or lower than in the average year. Specific intra-annual characteristics of climate year under study prompted additional adaptation ideas. For example, in W1, looking at the temperature and the herbage growth charts led to the decision not to harvest fall herbage regrowth because the temperature was too low to dry hay. Similarly, in W2 and W3, looking at the temperature, the rainfall and the herbage growth charts led participants to determine the grazing period according to snow and frost risks. The forage sticks were used in W2 and W3 to decide which plots should be harvested and which should be grazed.

4.2 Designing the system

After brainstorming about adaptation ideas, participants decided which adaptations to set up on the game board in the design step. The intermediary objects used in the design were those used during the brainstorming, plus the evaluation spreadsheet. The participants designed the system by looking at the charts of daily herbage growth, daily mean temperature, monthly rainfall and daily soil moisture; forage sticks and the evaluation spreadsheet. They roughly scheduled turnout to grazing according to the herbage growth chart and determined it precisely by incorporating specific information from the forage sticks. They decided the end date of grazing by looking at the temperature, rainfall and soil moisture charts to consider accessibility constraints (snow, frost and bearing capacity). They roughly scheduled start and end dates of summer hay distribution with the herbage growth chart. They precisely determined them by a trial-and-error approach using the forage sticks and the evaluation spreadsheet, which showed the amount of unconsumed standing herbage each week at both the batch and herd levels (the trial-and-error stopped when all standing herbage was consumed during a hay-supply period).

The participants made strategic choices in W1 such as decreasing farmland area or increasing the number of animals by looking at two values in the spreadsheet: the amount of surplus hay at the end of the year and the amount of unconsumed herbage during grazing. In W2 and W3, they decided to change the stocking rate of the grazed area according to the criterion “amount of herbage unconsumed during grazing”. They decided to increase the grazed or harvested area of a forage crop according to its productivity and precocity and the timing of standing herbage surplus or shortage. In short, each intermediary object was used to design the livestock system during the three workshops. At the end of each workshop, participants made a final evaluation of the system designed and its management. Participants checked the same evaluation spreadsheet that they looked at when designing the system.

5 DISCUSSION AND CONCLUSION

The participatory method we developed enables participants to design and evaluate grassland-based livestock systems in a short time (3*2 hours) while considering realistic management constraints in the face of climate change, variability and limited predictability of weather. Therefore, unlike previous participatory design methods which usually focus on the design effort for a single average or extreme climatic year (e.g. Faysse *et al.*, 2012), our method allows robust systems to be designed for several climatic years using a trial-and-error loop within and between workshops. Unlike simulation-centred design methods (e.g. Graux, *et al.* 2013), participants can bring practical aspects to the front in the design process. Adaptation options are generated on the basis of intermediary objects about the climate and the response of crop production to it. These options are evaluated with a forage balance model.

The success of the method in fostering learning about climate change, its consequences on livestock systems and possible adaptation options depends on participants’ motivation to engage in this process. Skilled facilitation is needed to maintain the motivation essential to design livestock systems adapted to climatic years (Dionnet *et al.*, 2013). Facilitators are in charge of managing group dynamics, ensuring that every participant gets an equal opportunity to contribute and discuss design choices, reformulating the main points that have been made, pointing out remaining issues to be addressed and keeping the workshops on time. Over the three workshops, participants’ motivation is also stimulated as participants face new design challenges related to an increase in the realism of the decision-making environment. According to participants (12 farmers participated in similar workshops), W3 was the favourite workshop because it closely resembled farmers’ day-to-day activities. As such, increasing the realism of the design process by explicitly representing the spatial organisation of plots or considering several successive years might increase the attractiveness of the approach. However, there is a trade-off between the sophistication of the design process and the acceptable duration of workshops. Moreover, participatory design approaches seem to motivate more the farmers who are already used to exchange viewpoints and knowledge with other farmers or scientists.

Nonetheless, our method has limits. Using three climatic years may be insufficient for designing a system truly adapted to climate variability, since the range of frequent climatic years is highly diverse

(Sautier *et al*., 2013). Climatic years could be chosen collectively by participants before the workshops to keep the process transparent and reduce the drawback of this simplification. Collective selection would also increase motivation, since it considers participants' needs and interests. In addition, it would be interesting to design and evaluate a system over several years, since a climatic event (e.g. summer drought) might impact system performance more than a year. Finally, the design process depends on the ability of the intermediary objects to represent the consequences of participants' management choices on system dynamics at different management scales (plot, set of plots). Currently, models are used before the workshops to construct the forage sticks, and the evaluation is based on static balance calculations. This prevents adequate representation of consequences of the strategic and tactical choices made (e.g. grazing livestock capacity influences grassland dynamics) and might overestimate forage availability, thus underestimating the magnitude of adaptation needed. The saliency and legitimacy of using simulation models during workshops (Rodriguez et al., 2014) needs further investigation. These models might increase saliency of the design and evaluation process, but they would simultaneously decrease its legitimacy, since they are complex and difficult to understand.

Climate change will lead to unprecedented climatic situations that call for anticipating adaptation options of farming systems. In this paper we presented a participatory design method, based on an existing method that we adapted to explicitly consider three features of climate (change, variability and limited weather predictability) in design and evaluation processes. The method is sequential, as it follows three stages in which complexity of the decision-making environment increases. Application of the method showed that this sequential process can test whether strategic adaptations are sufficiently robust and flexible to tactically cope with climate variability and limited predictability of weather.

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