Agroecology as farmers' situated ways of acting : a conceptual framework

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Abstract

The limits of numerous agricultural systems developed on principles set after the Second World War are increasingly highlighted. Meanwhile, agricultural and food systems associated with agroecological principles are progressively institutionalized in various countries. Whereas a dominant research production by agronomists consists in deduction of "agroecological practices" from fundamental agroecological principles, a gap remains between those principles and the specific management actions on farms that allow to build new agroecological framing systems. In this study, we stem from an analysis of management actions in 8 different case studies corresponding to farmers' collectives engaged in an evolution of their practices towards agroecology. We review the agroecological scientific literature in order to identify shared principles and system properties deduced from them, that we iteratively compared to the practices implemented by farmers, making the transition in our case studies. Our proposal is then to describe agroecology "in the making" as 4 interconnected *ways of acting*, each corresponding to specific relations between management actions and the systems' properties. Lastly, the analysis of agroecology from the actors' management practices allows us to support a new viewpoint about a research agenda for agronomists, giving reflexive benchmarks to relocate research activities within the institutionalization dynamics of agroecology.

Keywords: agroecology, management, transition, practices, principles, ways of acting.

1. Introduction

The dominant agricultural systems developed after the Second World War no longer allow them to fulfil the goals that were set for them at the time, in particular their environmental and social goals. In various countries across the world, one of the possible orientations for the sustainable development of agricultural and food systems is now considered to be agroecology – which implicitly challenges current agricultural paradigms and the management systems underpinned by them (Hubert, 2012). The conditions of the implementation of agroecology still remain to be defined, however, especially since the emergence, institutionalization (Lamine et al. 2012), and practices related to ecological forms of agriculture differ from country to country (Wezel *et al.*, 2009), as do the different models (e.g. ecological intensification, eco-agriculture, diversified systems, biodiversity-based agriculture, agroecology(Tittonell 2014)).

Yet consensus does seem to be emerging around the fact that sustainable agroecosystems, as opposed to conventional farming systems relying on the use of synthetic inputs, are grounded on the maintenance and strengthening of biological regulation and ecological interactions (Gliessman 2005). For example, the literature describes a number of general principles[1] on which it is claimed to be based, such as strengthening the natural control of biological pests, making use of regulation systems (nutrient cycles, water, etc.), promoting agro-biodiversity, and so on. Given their diversity, these principles result in partial consensus on the agricultural practices stemming from them (e.g. Altieri 1999; Dumont et al. 2013; Wezel et al. 2014; Duru et al. 2015; Nicholls and Altieri 2016) and the properties[2] of the systems managed. Properties such as elasticity, resilience, robustness, flexibility, and adaptability are contrasted with the efficiency, constancy, and predictability of more conventional systems (Milestad et al. 2012). Lastly, while Duru et al. (2015) argue that the implementation of agroecology "relies on agroecological principles that have to be adapted to problems and places", these specific principles and properties are rarely described in such a way that they provide concrete benchmarks for the practice. Yet, the management of agroecological farming systems[3] appears to be

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[1] Here, the term "principle" is used in the sense of a general proposition from which the reasoning for the management of the agro-ecosystem is derived.

[2] A "property of the managed system" is a distinctive attribute of the system that we can relate to the ways of acting of nature or mankind. These properties are a set of phenomena and attributes which are specific to a particular system that can determine how it reacts under specific conditions.

[3] In this article, we use the term "agroecological farming system" to refer theoretical developments that intended to integrate technical and ecological aspects with the human dimension (e.g. "livestock farming systems"; Gibon et al. 1996). In line with Darnhofer et al. (2012), what we call "agroecological farming system"

marking a significant departure from that of conventional systems. Standard descriptions of "agroecological practices" (e.g. Wezel et al. 2014) contribute nothing to establishing this link between principles and ways of constructing new agroecological farming systems.

Many studies on the implementation of agroecological farming systems show that the practices and approaches in these systems are very different from those of the farming systems developed during agricultural modernization (Boiffin et al. 2013; Girard et al. 2015; Coquil et al. 2017). The optimization extolled by this modernization, with the condition of eliminating chance and uncertainty, leads to the definition of systems management strategies that aim to control biophysical processes and to limit disturbances in order to obtain the maximum productivity permitted by the genetic potential. Farmers therefore have to apply the technical itineraries derived from these strategies, which are seen as "methods" to achieve set goals, and must apply practices pertaining to "increasing levels of top-down, command-and-control management to natural resources" (Holling and Meffe 1996).

Agroecological management of systems undermine this idea that is primarily planned and partially disconnected from local conditions and from the uncertainty that farmers face. "Strategic planning" appears to be based mainly on predicting the future states of the system and the ordering of actions in a plan (Thévenot 2006). It meets its limits in designing and managing agroecological farming systems, as it does in the corporate world where it leads to traps and mistakes, and particularly "*the illusion of control*", the formalization of general programmes, the assumption of the predetermination of context, and the detachment of thought from action (Mintzberg 2000). Agroecology, by contrast, implies recognition that agroecosystems cannot be entirely controlled, and that the results of technical actions cannot always be known (Berthet *et al.*, 2015). Some authors therefore propose to study the resources and means allowing farmers to retain a capacity for adaptation and flexibility, for instance through their learning processes (Coquil et al. 2014; Chantre and Cardona 2014; Cristofari et al. 2018).

A gap nevertheless remains to be bridged between the design of agroecological farming systems on the basis of agroecological principles, and the analysis of specific systems practices showing a low degree of artificialization (Toledo et al. 2003; Altieri 2009; Malézieux 2012; Girard et al. 2015). Setting general principles for the operation of agroecological farming systems while granting a central place to adapted and local practices within it puts agroecology at risk of a divide between aspects pertaining to generic scientific knowledge and always-specific ways of doing things from which no lessons can be learned. While agroecology calls for a process of relocalization of knowledge production (Warner

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"include material objects (e.g. soils, plants, animals, buildings) as well as subjective perceptions, values and preferences, i.e. how farmers 'make sense' of their practices", and situates the farm "in a territory, a locale, a region, with its specific agroecological setting, economic opportunities and cultural values".

2008), the question remains of how to produce generic knowledge from agroecological practices embedded in context (Lyon et al. 2011). In the lines of Bell and Bellon (2018), we assume that agroecology entails contextual thinking, encompassing "*trying to do different things in different places*" as well as "*doing different things in the same place"*. However, although these authors suggest to "*focus not on agroecological systems but agroecological principles that have general relevance but not universal outcomes"*, the literature rarely studies what is contextual farming (Lyon et al. 2011). As a result, the distance between agroecological principles that aim to support the expected properties of agroecological farming systems, and contextual agroecological management, appear to be under-investigated.

Faced with the challenges of re-conceptualizing agroecology in action, the aim of this article is to propose a conceptual framework that theorizes the links between the principles put forward by the agroecology (AE) literature, the properties of agroecosystems, and the ways of acting on agroecosystems. In particular, this framework is based on the assumption that agroecology in action should be viewed as specific ways of acting. Grounded on a large number of case studies of AE practices (N=8), our conceptual framework represents AE in action as the combination of 4 dimensions of "ways of acting" related to 10 properties of agroecological farming systems. We show how it enables identifying knowledge gaps and builds a new agenda for research, aimed at understanding and contributing to AE implementation in the field. Figure 1 summarizes our approach, which we will detail in the respective sections of this paper.

In the following section we present the theoretical foundations on the basis of which we examine both the properties of agroecological farming systems and the agroecological actions in these systems. We thus propose an organized interpretation of the properties of agroecological farming systems along with a conceptual framework that allows us to study the links between these properties and ways of acting (Figure 1, stage 1) (agroecological actions). In the third section we detail our approach as well as the different case studies used. In the fourth section we present the results of our analysis, that is, the combinations found between the properties of agroecological farming systems and what we call "ways of acting" in agroecology (Figure 1, stage 2). Finally, in the last section, we discuss how this review of agroecology in action leads us to reconsider the knowledge to be produced, as well as the tools and forms of support (Figure 1, stage 3).

2. Theoretical background: agroecology as specific combinations of system properties and ways of acting

Our conceptual proposal therefore aims to associate the expected properties of agroecosystems with the particularities of "agroecological management". We start by summarizing the former, which are barely described in the literature, and continue by arguing for the change of standpoint that the management of agroecological farming systems implies.

First we carried out a scientific literature review focused on agroecology operating principles, regardless of whether these principles were clearly stated by the authors (Dumont et al. 2013; Bonaudo et al. 2014; Girard et al. 2015) or were implicit in redefinitions of human-nature relations, in the research field of the sustainability of agricultural systems (Lemery et al. 2005; Dedieu and Ingrand 2010; Biggs et al. 2012). We then analysed eight case studies (both published and unpublished) based on interviews with farmers who claimed to act in favour of the agroecological transition or were detected by experts (local advisors, agronomists from research in agroecology related subjects) as using practices associated with agroecology in order to identify concrete management actions for agroecological farming systems (Figure 2 and Table 2). Our approach consisted in using an analysis grid to cross-reference the agroecological principles resulting from our bibliography with the design and management actions resulting from our case studies. This iterative process allowed us to illustrate, complete, and revise the properties suggested in the literature in order to identify a homogenous series of agroecological farming systems' properties in relation with agroecological management actions (Figure 2).

2.1. Agroecological principles and agroecological farming systems properties: A brief review

Autonomy is a dominant principal in the agroecological literature. It concerns both the ability to maintain one's own production resources, and to use existing resources for production processes. The principles related to it therefore concern diversity, complementarity, and exchanges between components of the agroecosystem.

Diversity is thus seen as the "ability of ecologically intensive farming to provide ecosystem services of support and regulation" (Tittonell 2014). Duru *et al*. (2015) mention three levels: planned diversity (i.e. crop sequences, intercropping, mixtures of species and varieties), associated diversity (i.e. corresponding to semi-natural elements on the farm), and diversity at the landscape scale. Diversity is the preferred way of optimizing resource use: Altieri and Toledo (2005) insist on the effects of facilitation between plants that have a different impact on the environment and the complementarity of the resources used.

This diversity approach contributes to a specific property of agroecological systems, namely the fact of being anchored within an ecosystem and a local agronomic and socio-economic landscape: the "locally-based" property (N°1 in Tab. 1). For example, Marsden (2012) speaks of an approach "which replaces, and indeed relocates, agriculture and its policies at the heart of regional and local systems of ecological, economic and community development”. This has already been stressed by Loucks (1977; cited by Gliessman 2013), who insisted on the need for an agroecosystem approach for not only improving yield performance, but also determining the long-term stability of such yield improvements and their impacts on ecosystems in the broader landscape in which the agroecosystems were located.

Recycling is also a very common principle in theoretical research on agroecological farming systems (Altieri and Toledo 2005; Wezel and Peeters 2014; Tittonell 2014). Tomich et al. (2011) directly relate this principle to that of diversity, insisting on the fact that diversifying crop sequences allows the biological activity of soil to be maintained and to thrive, and facilitates the efficient recycling of nutrients. Bonaudo et al. (2014) associate this recycling principle with the goals of “clos[ing] the energy and material cycles; i.e. minim[izing] losses and external inputs, and substitut[ing] chemical inputs with natural inputs” and “optimiz[ing] the nutrient availability for crops and animals. Nutrient availability is more often a question of temporal settlement […]”. Biggs et al. (2012) relate this to the management of “slow variables”, that is, variables which determine the structure of systems, as opposed to fast variables, the interactions and regulations of which induce systems dynamics and respond to the conditions created by slow variables. The physico-chemical composition of the soil is an example of a slow variable.

In the latter case, the properties targeted for agroecological farming systems are specifically “optimizing resource recycling and availability” (N°6, Table 1) and “maximizing ecological or production-based interactions” (N°8, Table 1).

The ability to adapt to chance and uncertainty (and the related properties of resilience, flexibility, robustness, and elasticity (Darnhofer et al. 2010; David et al. 2010; Sauvant et al. 2010) is a key principle in many texts on agroecology positioning. It comes in multiple versions, with specific levers, in contrast with the efficiency and assurance that constitute the basis of modernized systems. According to several authors (Dedieu and Ingrand 2010; Lin 2011; Milestad et al. 2012; Dedieu et al. 2013; Darnhofer 2014)), the adaptation capacity of systems is based on three principles:

a) a “buffer capacity” of the system, which could be said to be based on retaining room to manoeuvre. This idea manifests itself from the point of view of: i) the mobilization of production resources (e.g. keeping room to manoeuvre in the adjustment between animal needs and the offering of resources via a moderate animal load); and ii) the intensity of biological functions by remaining below the maximum expression of genetic potential (for example, limiting dairy production levels in order to limit sensitivity to diseases such as mastitis in dairy cattle, or accepting early nitrogen deficiencies for wheat which do not have a harmful effect on the production of seeds (Ravier et al. 2017). Therefore, the systems properties related to this first principle are to be “balanced (regarding needs-production adequacy)" (N°3, Table 1), to be under genetic potential for production (N°4, Table 1), and to be variable regarding the quality of productions (N°9, Table 1).

b) a system that stimulates the regulation between its different components in order to operate within an uncertain environment. Diversity is probably the most often-mentioned principle in the literature. It has two variants: one emphasizes the production of ecosystem services (see below), while the other stresses diversity as a means to reduce the vulnerability of agricultural systems. In particular, it specifies that it can provide *functional redundancy* (e.g. Gliessman 1998; Biggs et al. 2012; Nicholls and Altieri 2016) that is beneficial for flexibility (Chia and Marchesnay 2008). Altieri *et al.* (2015) detail the difference between functional diversity ("the variety of organisms and the ecosystem services they provide for the system to continue performing") and the diversity of responses ("the diversity of responses to environmental change among species that contribute to the same ecosystem function"). It is thus accepted that the final performance is a result of the actions and reactions of varied components, and hence that the states of the system also vary widely, although *within controllable limits*. A more direct link with agricultural practices appears in Bonaudo *et al*. (2014), who associate this diversity with the heterogeneity of forms of land occupation and biotic and abiotic components; and in Dumont et al. (2013), in the form of the inter-specific diversity of farms, and intra-population and intra-herd genetic diversity (Ratnadass et al. 2012; Ollion et al. 2016).

Another principle that is often related to the previous two is that of "regulation" and interconnection. Nicholls and Altieri (2016) highlight the maintenance of connectivity or interactions based on production factors, such as those resulting from the integration of animal and plant components at a mixed crop-livestock farming operation (Bonaudo et al. 2014), as well as on the scales of the landscape and semi-natural elements. Connectivity is defined by Biggs et al. (2012) as the "way and degree to which resources, species, or social actors disperse, migrate, or interact across ecological and social landscapes", which includes interactions between species, and corridors between different habitats. In livestock farming, the connectivity between the production cycles of paddocks enabled by the organization of multiple staggered reproduction intervals during the year, and reform rules authorizing reproduction failures and changes of paddocks for infertile animals, creates a diversity of production areas favourable to adaptation to unforeseen events (Cournut and Dedieu 2004; Tichit et al. 2004). Implementing and maintaining these regulations and interactions implies taking the properties of *integration into the non-cultivated environment* into account in the design of systems, and therefore also taking the "Integration of cultivated and non-cultivated diversity" (N°2, Table 1) into account, as well as basing production processes on elements of the local ecosystem.

c) a systems that behaves in an adaptive manner, in other words “the ability of a system to adjust in the face of changing external drivers and internal processes, thereby allowing for development while staying within the current regime”; and a transformative manner, that is, “the ability to implement radical changes” (Darnhofer, 2014). This concerns humans and the actions that they undertake within the production system. It therefore corresponds to an ability to question their practices or even their production project (what zoologists define as the type of animal product, its quality features, and expected delivery periods, for example). According to conventional reasoning, defining the production project comes first: everything else follows (practices, the crop sequences, etc.). In agroecological reasoning, it is necessary for the types of products expected and their quality to be called into question, depending on the conditions of the moment (Williams 2011; Milestad et al. 2012; Girard 2014). This implies the adequate capacity and room to manoeuvre, to react and to modify how a project is related to the stages of its implementation(Toffolini et al. 2016).

This adaptive and transformative behaviour also concerns the ability of the other components of the agroecosystem to adjust. For example, in livestock farming, the ability to maintain health and production in a fluctuating environment may be an objective of selection (Knap 2005; Phocas et al. 2014; Ollion et al. 2016).

These overarching principles originating directly in the literature lead us to consider the properties of certain agroecological farming systems mentioned by the authors. Here, we group them together in a homogenous list (Table 1), the categories of which we organize in light of the different case studies that will be presented subsequently.

The homogeneous whole thus constructed shows how general principles can be manifest through different properties of managed systems. Identifying them is not intended to establish them as prerequisites or necessary characteristics in order for a production system to be labelled as agroecological, but rather forms a basis for better understanding how, beyond general principles and those of these properties, it is a multitude of localized forms of action that make up forms of agroecology “in action”. Combining these agroecological actions with the properties of the systems managed is the main aim of this article, through the definition of “ways of acting”, specifically to move beyond the proposals of simply “farming without a recipe” (Lyon et al. 2011). For example, diversity is a principle that is directly related to multiple properties: functional redundancy, optimizing resource recycling and availability, maximizing ecological or production-based interactions, and the variable quality of production. Nonetheless, the way of managing diversity is specific to each farmer insofar as it involves locally adapted elementary actions with varying attention to different properties, depending on the farmer's context and goals. These properties therefore transform the principle of the "maximization" of diversity into forms of action that allow one to directly orient the management of the system in a way that is adapted to the context.

2.2. Actions that target the described agroecological farming systems properties

2.2.1. "Ways of acting"

Agroecological management of agroecosystems leads to a different way of seeing the interactions between a farmer and his/her context, or more precisely the "situation" in the sense of Dewey, that is all the moments during which the interaction between a human being and his environment takes place in the form of a reciprocal action. In contrast with the instrumentalization of nature and the environment to the benefit of agricultural production, in this vision nature is considered an actor, with which human action must come to terms by adapting to situations. Conceiving of an agroecological approach therefore means conceiving of the ways in which the actions or dynamics specific to nature are combined with the human management of these systems. Accordingly, we analyse how agroecological farming systems' properties and ways of acting are combined, basing our work on approaches that theorize farmers' relationships with situations, in their management actions.

To express the idea that farmers are engaged in the world, we employed the notion of "way of being in the world", from Merleau-Ponty (1945). This notion emphasises the importance of the sensory relationship to the world, and the fact of no longer exclusively considering action as the result of purely cognitive processes. Our proposal is therefore to describe different "ways of acting" in order to formalize the different concrete registers of this "situated action" (Suchman 1993). From this point of view, the success of the action depends on the actors' ability to adjust their behaviour to the parameters of the situation, in which case plans – i.e. pre-existing representations or prescriptions – would be no more than one of the resources mobilized during a situated action (Suchman 1993). Therefore, we suggest focusing our attention on the way farmers *experience* the world, which, in the sense of the pragmatist philosophy, refers on a tension between "doing" and "suffering". We believe that this experience help them to develop a form of "vigilance" (Chateauraynaud 2011) of the situation : in other words, attention to the potentialities of the environment, based on sensory experiences which enable attention to details that are overlooked by prescriptive and ready-made solutions. Beyond a strategic plan to guide actions toward a fixed goal upstream, this vigilance would be accompanied by the construction of the meaning of the action as it takes place (Journé and Raulet-Croset 2008) and by a continuum between the ends and the means (Dewey 1929). This vigilance must enable farmers to develop a sort of "familiarity" with their situation, in other words, for them to be comfortable with the adjustments to people and things required by their actions (Thévenot 2006), or more specifically, with "ecological embeddedness" (Whiteman and Cooper 2000).

2.2.2. Our conceptual framework

On this basis, our proposal consists in representing agroecology in action as the combination – which is specific for each farmer – of different "ways of acting" and the expected properties of agroecological farming systems.

Each "way of acting" is not completely dissociated from the others, and certain properties can correspond to two ways of acting (Figure 2). There is no linearity between a general principle, a system property, and a way of acting. Through this representation, we aim to show that these system properties and ways of acting are interdependent, and that each property can be associated with multiple specific ways of acting, as demonstrated below.

2.2.3. Implementing ways of acting

We analysed case studies (both published and unpublished) based on interviews with agricultural actors claiming to belong to the agroecological transition or who were detected by local intermediary actors as using practices associated with agroecology, in order to identify concrete management actions (Figure 2 and Table 2). We created a second analysis grid that allowed us to reveal 21 practices, which we were able to group together into 4 main ways of acting in agroecological farming systems.

4. Results – Agroecology in action as specific combinations of "ways of acting" and system properties

The aim of our conceptual proposal is to identify the properties of agroecological farming systems in relation to the the ways of acting they correspond to. Based on the various practices observed in our case studies (grouped into 21 elementary practices, see Table 3), we distinguish four "ways of acting" and then show how they are combined with certain properties of agroecological farming systems.

4.1. Identifying four ways of acting based on 21 agroecological actions

The data resulting from the case studies as a whole revealed four "ways of acting" as combinations of elementary techniques or agroecological actions. These four "ways of acting" cannot be precisely delimited, but rather constitute axes for the aggregation of ways of doing things and practices with possible overlap (Figures 2 and 3).

The first way of acting, namely “adapting to local agroecosystems”, consists of managing the system consistently and in continuity with the pre-existing environment, the ecological dynamics present, the history of practices, and the changes that they produce (e.g. amount of organic matter in the soil and changes in this as a condition for the implementation and success of soil fertility management practices). The goal is to manage the system while asking not only “what is going to work in this particular situation”, but also and above all “what processes are underway and how is it possible to make do with them”. It is related to indirect actions, mainly based on the recognition of the “objects of nature” (Barbier and Goulet 2013) and their autonomous dynamics. The second way of acting, “intertwining multiple time (and spatial) scales and buffers”, is tied to the constant association of different scales of time and space. This involves taking into account not only the dynamics of system states at a given moment that will determine the implementation and success of a practice, but also those that will be produced by this practice over the longer term and that will configure and construct the structure and operation of the future system. It is therefore that which directly links the management of the system to its design on the scale of the time necessary for the implementation of biological regulation and the evolution of “slow variables” (Biggs et al. 2012). This way of acting underlines specific aspects that relate to designing while doing. The third way of acting, “flexibility and adaptiveness in management”, is at the heart of adaptive management theories. It consists of *increased and diversified observations*, which are often mentioned in theories of adaptive management and by farmers who claim that they “get off their tractor”, implying that they actually observe the state of their soil, the growth of their crops (Casagrande et al. 2012), but also the pests (or beneficial insects)(Lefevre et al. 2015) and diseases, and so on, similar to the action of “walking out on the land” to “gather ecological information” as identified by Whiteman and Cooper (2000). The fourth way of acting, “critical and reflexive engagement in action towards learning”, emphasizes the dimensions of practices related to opening up the farm to emergence, “surprise” (Milestad et al. 2012; Brédart and Stassart, 2017), and experiential learning (Kolb 2014). It highlights the knowledge constructed in action, as well as more generally an attitude that considers the situation to be a “managerial classroom” by developing openness to learning how to “mak[e] mistakes” and accept fallibility, imperfections and lapses (Whiteman and Cooper, 2000).

4.2. Description of the four ways of acting

Locally-embedded: This first “way of acting” is clearly strongly influenced by the expected system property of being *locally based*. This means *using local breeds and/or breeds adapted to local conditions* in terms of local adaptability as well as diversity with respect to the species and varieties present in the surrounding agricultural landscape. It also implies *locally breeding to increase adaptive capacity*, with specific consequences in terms of selection practices, evaluation criteria, and the choice of cultivars, for example. In addition to the species introduced, this first aspect also refers to *adapting management practices to each species' biology*, for example with respect to the dominant self-propagating plant species in the local agroecosystem and understanding and using their life-cycle features in order to manage them.

With respect to the property of integration in the non-cultivated environment, this aspect also consists in *letting the field edges lie fallow*, in other words, integrating semi-natural elements of the landscape (hedges, the edges of land parcels, grassy strips, trees) into "actor" objects in regulation and production dynamics. This results in *using natural resources available on site and by-products*. The latter two dimensions of action lead to the need to be capable of identifying the resources present and the ecological dynamics that they permit: How to carry out an initial diagnosis of beneficial or harmful species that benefit the habitats provided by the semi-natural elements of the landscape? How to evaluate a biodiversity "reserve" and the functionalities or equilibrium that it provides?

Moreover, *adapting to local agroecosystems* also refers to adaptation in terms of the target productivity in relation to the system properties of being *balanced regarding needs/productions* (3) and *below potential productiveness* (4). Maintaining the structure and operation of the system consistent with the local agroecosystem specifically results in the fact that the *target is below the "potential"* and that the *target shifts from production to the state of the system supporting the production*. The goal is above all to conserve immunity and regulation functions for production (as opposed to maximizing production), and relates to the system properties of *optimizing resources recycling and availability* (6) and *maximizing ecological or production based interactions* (8). This requires identification of the limits within which the system can be managed, which are no longer reduced to a productivity ceiling but rather are states of the system that allow ecological practices to be maintained. Lastly, locally adapting to these processes means *tolerating defaults* with respect to products. Tolerating defects does not only mean accepting lower quality from time to time, but above all being capable of distinguishing between anecdotal defects and others that reflect a negative trend of change in support and production functions (e.g. significant drop in soil or animal fertility?).

Intertwining multiple time (and spatial) scales and buffers: The second major aspect of the relationship to system management actions once again consists in using local breeds/varieties and/or breeds adapted to local conditions, considering not only their suitability to local conditions but also the way in which they will act upon the situation, for instance by influencing the growth of perennial self-propagating plants based on the coverage capacity or by modifying soil structure through a specific root system. Regarding the target performance, this classically implies a shift towards performance calculated on a multi-year scale (target shifts from production to the state of the system supporting the production), with priority being given to the changes in a slow variable, even if this temporarily prevents action to maximize production (e.g. maintaining simplified soil tillage to improve soil structure). More generally, this effectively consists in managing slow variables (e.g. soil biological activity, structure, weeds, and natural enemy population) and minimizing losses/optimizing the relocation of nutrients. To do so, the indicators are also specific in this aspect of the relationship to action. They imply diversification of observations and shifting from indicators of performance to indicators of states of the system supporting production. These are indicators that allow one to acknowledge and anticipate system change dynamics in order to evaluate long-term dynamics.

Finally, *intertwining multiple time (and spatial) scales and buffers* relates to different elements of practices pertaining to biodiversity management: *using cultivar mixtures and intercropping, managing heterogeneity in land-use patterns and biotic and abiotic components, managing indirectly-related biodiversity* as a potential resource.

Flexibility and adaptiveness in management: The third aspect of the relationship to action in managing systems undergoing an agroecological transition is flexibility and adaptability, which, along with the identified properties of managed systems (*local ecosystem based, integrating the non-cultivated environment, fluctuating within manageable limits*), allow one to define the specific directions of the development indicators and types of observations to which this may correspond (Cf. Section 2). This also consists in managing *slow variables* and *complementarities in time and space* (e.g. the continuity of habitats or resources for communities of auxiliaries). An identified way of contributing to this is by *managing heterogeneity in land-use patterns and biotic and abiotic components*, which also contributes to functional redundancy and the maximization of ecological interactions. Last of all, this aspect contains the elements of practices that are related to variability in productivity, and namely a *target below the "potential"*, *tolerating defects*, and *increasing harvest frequency* (when possible, especially for vegetables). In particular, this implies flexibility on the level of market opportunities in order to sell fluctuating qualities and quantities of products.

Critical and reflexive engagement in action towards learning: This way of acting involves the ability to continuously learn and adapt practices. One lever is involvement within groups in different ways. The first one is about *drawing inspiration from/adapting to others' practices locally* (e.g. others' practices as indicators for local climate effects on productions, and possible evolutions of the system). The second one is *situating oneself in groups* to establish reference points and assess the potentiality or limits of different agroecological farming systems and to better relate practices and their feedbacks in a variety of agricultural contexts. . Another lever is experimentation[4], which permits the production of both situated knowledge and knowledge for action, an understanding of the biological processes at work in the production system, and the continuous adaptation of production practices. Experimentation once again involves *tolerating defects*, especially when the experimental practice requires latency time prior to the appearance of results in the production system structure.

These aspects as a whole allow one to inter-relate the key dimensions of agroecology as "ways of acting". Their originality is not in their novelty (as some of them correspond to aspects of research on adaptive management, for example), but rather in the way in which they allow one to associate the same practices with the properties of managed systems.

5. Research agenda and discussion

Agroecological management of agroecosystems leads to different ways of acting related to certain specific agroecological farming systems' properties. In the last section of this article, we would like to discuss the existing knowledge and tools that today contribute to developing these different ways of acting, and to propose future pathways for developing this knowledge.

In this section we have made use of the heuristic frameworks built to identify needs for knowledge, tools, and research processes. We are thus proposing a research agenda for repositioning agronomic research in line with agroecological transition dynamics.

5.1. Existing tools and knowledge

5.1.1. Diversity of tools and their functions

Numerous decision support tools have been developed by agronomists as a way to support the development of agroecological farming systems. However, the indicators used in these approaches primarily concern performance, are measured statically, and do not always correspond to observations directly related to production system management actions. As Duru et al. (2015) point out, for these indicators, such as that of the "visual soil assessment" method, "local interpretation of the result is needed to take local characteristics and key practice × soil/climate interactions into account". Other tools are based on cropping models or cropping or farming systems, but their design all too rarely takes

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[4] Defined in this case as « *a process in which farmers plan the introduction of new ways of farming on their farm, implement it, takes the necessary means to follow it up, and finally evaluate the results*" (Catalogna and Navarrete 2016).

into account usages and therefore their application, which results in low levels of use by practitioners (e.g. McCown 2002; McCown et al. 2009; Cerf et al. 2012; Rose et al. 2016). On the other hand, recent research by Prost et al. (2016) demonstrates four important aspects of decision support tools: (i) the involvement of living entities (intermediary between natural and artificial), (ii) variability and unpredictability, (iii) the collective dimension, and (iv) the use of heterogeneous forms of knowledge, which may echo the way of acting in the world that we have presented here.

Moreover, research increasingly takes into account the relationship between cultivated systems and their development contexts. To focus on the links between cultivated systems and the context of the landscape, it appears to be important to describe and characterize the diversity of flora and fauna in given situations. However, this no longer consists of inventory-type lists of species, but also of taking into account the interactions between these species and establishing and using functional categorizations with respect to the cultivated systems in question. The characterization of plant species as a function of their role as food in grazing (Agreil and Meuret 2004) or the description of land parcels as a function of their role in an annual food strategy (Bellon et al. 1999) are examples of this. However, ways of evaluating biodiversity and the ecological processes from which certain effects can be expected, including in uncultivated spaces (edges, hedges, boundaries), are yet to be developed.

5.1.2. Spatial-temporal scales and dynamics

Considering the links between cultivated systems and their development context also implies considering spatial scales that are larger than those of the land plot or group of plots. The development of agroecological farming systems research has thus led to an expansion of the spaces and time frames considered by agronomists, who have since been integrating multi-year and landscape scales, along with a diversity of factors that may be involved in the object studied. For example, this is the case of the development of experimental systems, which aim to study a question by considering a combination of agronomic factors and which may at times go so far as to analyse the impact of the business channels through which the product of the experiment will be sold (Lechenet et al. 2017). In this respect, zootechnicians, and in particular in the Livestock Farming Systems community (Gibon et al. 1996), have a viewpoint which is far more focused on the farm, their herd(s), the diversity of resources, and associated business channels. The progress made by this research specifically covers the ability to integrate multi-animal species systems approaches, with certain species having the main purpose of providing services and recycling (Dedieu et al. 1991, 1992); the integration of crops and livestock farming on the farm and territorial scales (Lemaire et al. 2014; Bonaudo et al. 2014; Moraine et al. 2016, 2017); and last of all, the consideration of the different facets of anchoring livestock farming activities within territories (Ryschawy et al. 2012).

Developing agroecological farming systems furthermore requires the production of knowledge on much more flexible management mechanisms. Because this consists in addressing the agroecological system along with its context, management rules must be able to adapt to different situations, thus leading to an increase in research on "adaptive management strategies" (Williams 2011). For example, in the case of the market gardening experiment based on the use of natural regulation discussed in this article (case study 1, Table 2), the agronomists aim is not to produce knowledge on the management and modelling of the above-mentioned crop system, but rather to provide future users with methods for assessing natural regulation at work, so that they can plan the technical interventions best suited to this regulation.

Behind this notion of flexibility and its variants of static, reactive, and proactive flexibility (Chia and Marchesnay 2008) lies the preparation for a diagnosis and an adaptation to a diversity of system states, and for an understanding of the dynamics according to which they evolve under the effect of the actions of nature, humans, or both. Understanding these dynamics implies the ability not only to monitor populations (e.g. pests, self-propagating plants, auxiliaries) or the animals in herds over several years (Ollion et al. 2016), but also to interpret changes in them in terms of trends and rates. This is counter to the still dominant definition of decision-making rules based on references in the form of thresholds (Ollion 2015). It also consists in being able to distinguish anecdotal performance defects from those that correspond to a trend in the deterioration in resources or production processes. This calls for a renewal in the use of indicators (Toffolini et al. 2016), shifting it toward the description of system states in their complexity (e.g. soil structure not reduced to compaction or porosity but rather which indicates the dynamics of root growth, the composition of agglomerates, leaching) and their potential or desired changes. Traditionally oriented towards evaluation functions, and in particular the stages of establishing productive, social, and environmental performance, indicators should have anticipation and learning functions, given that they are primarily *descriptors* of intermediate agro-ecosystem states and the pathways of change that they indicate. We currently have little indsight with respect to these indicators and the way in which they are mobilized and combined in action. Last, some recent work from Brédart and Stassart (2017) puts forward the fruitfulness of thinking about farmers' trajectories of change as "*a constant process of adjusting goals and means that is punctuated by events*" and thus to develop their attentiveness to events.

5.1.3. Sharing experiences within groups of farmers

Last of all, adapting agroecological farming systems to different situations implies the adoption of critical and reflective standpoints with respect to the techniques proposed or the practices of other farmers. Devices and tools have already been developed in view of this. The permanence of groups of farmers pertains to this prospect, because they allow farmers to talk about their difficulties, doubts, and solutions for implementing changes in practice (Lamine 2011). With regard to the recent development of tools as a part of the implementation of the Ecophyto Plan in France, aiming to accompany the reduction in pesticides, information sheets were drawn up, describing farmers' practices to enable a reduction in pesticide use. While these documents were initially rather impersonal, essentially presenting graphs and statistics as a form of proof of performance, over time they were increasingly personalized to better highlight the context of the farm and the trajectory of the farmer, using photos, testimonials, and the increased consideration of the specific history of the farm in question. This consisted in better highlighting the interaction between the farmer's experience and practices, and the situation in which he or she acts, which was also described for the conservation agriculture community (Goulet 2017). Similarly, the technical information sheets produced by the Patur'Ajuste Network[5] describe ways of considering and organizing grazing areas, and are accompanied by highly personal testimonials from farmers. The appearance of tools based on digital technologies also allows for the creation of virtual communication groups, such as the online platform "Osaé", which aims to develop agroecology by explicitly making use of the "know-how" and "testimonials" of farmers[6]; or the website for information exchange and localized training between farmers, Agrifind[7]. This requires these users to have the ability to extrapolate if they are to use the subjective dimensions presented, depending on their situation. However, our various works in the field show that farmers very often seek out this type of information on others' experience.

5.2. New orientations for knowledge production

Development of the described ways of acting represents a minority in farming practices, but it nonetheless suggests new lines of research around new objects: tools as well as new ways of valorizing what is already produced.

Support for development of agroecological farming systems can be encouraged by increasing the possibilities allowing for sharing of experiences among farmers. Such possibilities can rely on dedicated devices or collective organization for the socialization of practices, and should especially allow to

[5] http://www.paturajuste.fr/

[6] http://www.osez-agroecologie.org/temoignages-d-agriculteurssur-leurs-pratiques-agroecologiques.

[7] www.agrifind.fr

combine the technical dimensions (for example, sharing the indicators used, ways of carrying out experiments) with the subjective and human dimensions that shape the strategies and experiences shared. Access to the subjective dimensions underlying practices can be facilitated through the creation of group support processes based on shared values that allow farmers to get to know one another better and that foster trust, thus encouraging communication not only around technical practices but also around values, personal experience, and the family history underlying them. Furthermore, in conjunction with the rapid growth in the development of agroecological farming systems, we are also witnessing a revolution – and specifically a digital revolution – in the means available[8] to build communication based on unique experiences. Yet the testimonies produced by these different tools (web documentary, videos, photos, texts, etc.) have seldom been considered in the analysis of practices' socialization. The same applies to the way in which they allow or do not allow generic knowledge to be produced. Last of all, how is it possible to identify, within these recollections, the indicators in the situation that allow the farmer to share the experience in its "temporal density", in the way in which it allows action within uncertainty, or by making the sensitivity of his/her life story accessible in the management of complex and uncertain processes? Starting as early as the 1990s, authors such as Röling and Wagemakers (1998) argued for the development of social learning platforms to facilitate the transition towards sustainable agriculture, in particular through the development of Farmers Field Schools (Braun et al. 2006). A great deal of research in the humanities and social sciences has since studied the operation of collectives organized around the interchange of knowledge (Local Exchange Systems, for example) or experience (for instance the study of business incubators, the Agricool network[9], the Atelier Paysan association in France[10], or third places such as fablabs). However, as Latour (2012) put it, what are the "modes of existence" of a diversity of experiences, and how can they be made to dialogue with one another? How can a unique experience be described, analysed, and transposed to other contexts of action?

Aside from the interchange of knowledge via physical media, the interchange most important to include on the research agenda is that which takes place in practice or is based on more or less collective life experiences with varied modalities. The case study of the Vergers Durables group, which has brought together fruit growers, researchers, advisers, and experimenters over the past ten years,

[8] Facebook Lookback – reliving their favourite memories on Fb -, video applications such as Animoto, WeVideo, presentation software such as Prezi; www.coe.int/t/dg4/autobiography/AEIVM_Tool_en.asp

[9] http://www.agricool.net/forum/

[10] https://www.latelierpaysan.org/

is an example of this. The group meets once a year to discuss the year's innovations, attempts, and failures. Over time, mutual acquaintance, trust, and conviviality have been established, which in the words of the participants themselves (case study 5, Table 2) allow the experiences of some to nourish the experiments of others. The same shared elements and learning are found in a homeopathy communication group that has gathered livestock farmers and veterinarians over the past ten years, and in which communication groups around practices, collective diagnostics, and a type of farmer-to-farmer advisory system are implemented. Moreover, experimentation of whole farming systems have multiplied over the past ten years, but are still rarely analysed as spaces within which occupations are reconfigured, and in which the exchange of knowledge and learning involving the diversity of actors composing them takes place (Fiorelli et al. 2014). Initial research is working towards this (Lechenet et al. 2017), but this method is frequently criticized with regard to its relevance for the production of biotechnical knowledge, which is often perceived as being highly context-dependent and therefore invalid. Such critics are not specific enough, if we consider the extension of these characteristics (embeddedness, context-dependent) even to laboratory science as demonstrated by Science and Technology Studies (e.g. Callon 1986; Jasanoff and others 2004), and that factorial experimentation can be equally invalid (Marliac et al. 2013). As of today, in terms of the research agenda, it seems necessary to capitalize on this type of experience and to analyse the interactive processes at work in these groups, along with the interchange of experience, and to identify the most appropriate formats for sharing experience. While such sharing is at the heart of certain philosophies, such as that advocated by American pragmatism (Dewey 1929), there is little research that can serve to define the necessary conditions for a unique and individual experience to be able to constitute a resource for others' action.

Lastly, it appears that the obstacles to constructing spaces for the interchange of agronomic knowledge are also epistemological. Addressing systems based on natural regulation requires that we work towards the re-articulartion of agriculture and nature to one another. Beliefs that agriculture is based on a clear separation between the wild and the domestic, and on control of the environment as an instrumentalized resource (Larrère 2002), must be questioned. These beliefs became more deeply entrenched during the agricultural modernization of the twentieth century with the goal of developing techniques that would supposedly allow for abstraction from natural conditions or climactic hazards (Jas 2005). This explains why certain farmers or agricultural advisers have had difficulty in appropriating knowledge that aims to reconcile the management of agricultural systems with ecological dynamics. It invites us to revise our very idea of what constitutes agriculture, and with equal certainty, as advocated by some authors such as Francis et al. (2011), our way of teaching it.

Conclusions

In this analysis, we identified four different *ways of acting,* which corresponds to specific combinations of practices by which farmers target farming systems properties in line with agroecological principles. Together, these ways of acting contribute to define agroecology "in the making", integrating human dimensions related to farmers work in agroecosystems and sociotechnical embeddedness. The eight case-studies on which our study was based were diversified in terms of farming systems and sociotechnical networks, which may provide a genericity of the identified *ways of acting* across a variety of agricultural production types. Applying the proposed conceptual framework to analyse agroecology institutionalization in practices in various production sectors or innovation systems may help identifying the favoured *ways of acting* or the hindrances for development paths.

The four *ways of acting* (locally embedded, flexibility and adaptiveness in management, intertwining multiple time and spatial scales and buffers, critical and reflexive engagement in action towards learning) also reveal and take in account two different dualities of farm management in agroecological transition. First, they combine the ecological dimensions of practices with specificities of designing while managing the agroecological farming system. In contrast with propositions of practices' sets that would correspond to agroecology and offer some expected environmental performances and agroecosystems dynamic equilibriums, our description of *ways of acting* grasps the tensions in farmers work between the renewed expected properties of farming systems and the redesign of practices' combinations that progressively make possible to reach them. Intertwining multiple time and spatial scales and buffers perfectly illustrate this duality, and we underlined that it supposes particular indicators and identified new directions of research regarding how the sharing of experiences may support it. Second, the four *ways of acting* intend to address at a same level the technical or technological stakes and the social aspects of new practices development in agroecological transition. Namely, the *way of acting* called 'critical and reflexive engagement in action towards learning' tackles the collective practices (among farmers, intermediaries, agronomists) participating in socialization of practices. We do not pretend to fully explore what these dualities entail in terms of agricultural knowledge, rather we propose a basis for addressing them in future agroecological research.

References

Agreil C, Meuret M (2004) An improved method for quantifying intake rate and ingestive behaviour of ruminants in diverse and variable habitats using direct observation. Small Ruminant Research 54:99–113

Altieri MA (1999) The ecological role of biodiversity in agroecosystems. Agriculture, Ecosystems & Environment 74:19–31. doi: 10.1016/S0167-8809(99)00028-6

Altieri MA (2009) Agroecology, small farms, and food sovereignty. Monthly review 61:102

Altieri MA, Nicholls CI, Henao A, Lana MA (2015) Agroecology and the design of climate change-resilient farming systems. Agronomy for Sustainable Development 35:869–890

Altieri MA, Toledo VM (2005) Natural resource management among small-scale farmers in semi-arid lands: Building on traditional knowledge and agroecology. Annals of Arid Zone 44:365

Barbier J-M, Goulet F (2013) Moins de technique, plus de nature : pour une heuristique des pratiques d'écologisation de l'agriculture. Natures Sciences Sociétés Vol. 21:200–210. doi: 10.1051/nss/2013094

Bellon S, Girard N, Guerin G (1999) Characterization of practices-seasons for understanding the planning of a grazing year. Fourrages (France)

Berthet E, Barnaud C, Girard N, et al (2015) How to foster agroecological innovations? A comparison of participatory design methods. Journal of Environmental Planning and Management 1–22. doi: 10.1080/09640568.2015.1009627

Biggs R, Schlüter M, Biggs D, et al (2012) Toward Principles for Enhancing the Resilience of Ecosystem Services. Annual Review of Environment and Resources 37:421–448. doi: 10.1146/annurev-environ-051211-123836

Boiffin J, Dedieu B, Rolland B (2013) Quand RAD-CIVAM et chercheurs se rencontrent. Le Courrier de l'environnement de l'INRA 63:77–86

Bonaudo T, Bendahan AB, Sabatier R, et al (2014) Agroecological principles for the redesign of integrated crop–livestock systems. European Journal of Agronomy 57:43–51. doi: 10.1016/j.eja.2013.09.010

Braun A, Jiggins J, Röling N, et al (2006) A global survey and review of farmer field school experiences. Report prepared for ILRI Endelea, Wageningen, The Nethrelands

Brédart D, Stassart PM (2017) When farmers learn through dialog with their practices: a proposal for a theory of action for agricultural trajectories. Journal of Rural Studies 53:1–13

Callon M (1986) Éléments pour une sociologie de la traduction: la domestication des coquilles Saint-Jacques et des marins-pêcheurs dans la baie de Saint-Brieuc. L'Année sociologique (1940/1948-) 36:169–208

Cardona A, Lefèvre A, Simon S (2018) Les stations expérimentales comme lieux de production des savoirs agronomiques semi-confinés. Revue d'anthropologie des connaissances 12, N°2:139–170. doi: 10.3917/rac.039.0139

Casagrande M, Joly N, Jeuffroy M-H, et al (2012) Evidence for weed quantity as the major information gathered by organic farmers for weed management. Agron Sustain Dev 32:715–726. doi: 10.1007/s13593-011-0073-6

Catalogna M, Navarrete M (2016) An agronomical framework for analyzing farmers' experiments. Harper Adams University, Newport, UK., p 12

Cerf M, Jeuffroy M-H, Prost L, Meynard J-M (2012) Participatory design of agricultural decision support tools: taking account of the use situations. Agronomy for sustainable development 32:899–910

Chantre E, Cardona A (2014) Trajectories of French Field Crop Farmers Moving Toward Sustainable Farming Practices: Change, Learning, and Links with the Advisory Services. Agroecology and Sustainable Food Systems 38:573–602. doi: 10.1080/21683565.2013.876483

Chateauraynaud F (2011) Argumenter dans un champ de forces. Essai de balistique

Chia E, Marchesnay M (2008) Un regard des sciences de gestion sur la flexibilite : enjeux et perspectives. In: L'elevage en mouvement : flexibilite et adaptation des exploitations d'herbivores / Dedieu Benoit (ed.), Chia Eduardo (ed.), Leclerc Bernadette (ed.), Moulin Charles-Henri (ed.), Tichit Muriel (ed.). Ed. Quae, Versailles, pp 23–54

Coquil X, Béguin P, Dedieu B (2014) Transition to self-sufficient mixed crop–dairy farming systems. Renewable Agriculture and Food Systems 29:195–205

Coquil X, Dedieu B, Béguin P (2017) Professional transitions towards sustainable farming systems: The development of farmers' professional worlds. Work 1–13

Cournut S, Dedieu B (2004) A discrete events simulation of flock dynamics: a management application to three lambings in two years. Animal Research 53:383–403

Cristofari H, Girard N, Magda D (2017) Supporting transition toward conservation agriculture: a framework to analyze the learning processes of farmers. Hungarian Geographical Bulletin 66:

Darnhofer I (2014) Resilience and why it matters for farm management. European Review of Agricultural Economics 41:461–484

Darnhofer I, Fairweather J, Moller H (2010) Assessing a farm’s sustainability: insights from resilience thinking. International journal of agricultural sustainability 8:186–198

Darnhofer I, Gibbon D, Dedieu B (2012) Farming systems research: an approach to inquiry. In: Farming systems research into the 21st century: The new dynamic. Springer, pp 3–31

David C, Mundler P, Demarle O, Ingrand S (2010) Long-term strategies and flexibility of organic farmers in southeastern France. International journal of agricultural sustainability 8:305–318

Dedieu B, Ancey V, Avelange I (2013) Agir en situation d’incertitude en agriculture. Dynamiques de protection et d’adaptation au Nord et au Sud:[Introduction]

Dedieu B, Ingrand S (2010) Incertitude et adaptation: cadres théoriques et application à l’analyse de la dynamique des systèmes d’élevage. INRA Productions animales 23:81–90

Dedieu B, Jestin C, Servière G (1991) Exploitations associant vaches laitières et brebis en Margeride. 2. Importance respective des deux troupeaux et fonctionnement des systèmes. Fourrages 125:117–128

Dedieu B, Servière G, Jestin C (1992) L’étude du travail en exploitation d’élevage: proposition de méthode et premiers résultats sur les systèmes mixtes vaches laitières et brebis en Margeride. INRA Productions animales 5:193–204

Dewey J (2014) La quête de certitude. Une étude de la relation entre connaissance et action. Editions Gallimard

Dewey J (1929) The Quest of Cetainty: A Study of the Relation of Knowledge and Action. GP Putnam’s Sons

Dumont B, Fortun-Lamothe L, Jouven M, et al (2013) Prospects from agroecology and industrial ecology for animal production in the 21st century. animal 7:1028–1043

Duru M, Balent G, Gibon A, et al (1998) Fonctionnement et dynamique des prairies permanentes. Exemple des Pyrénées centrales. Fourrages 153:97–113

Duru M, Therond O, Martin G, et al (2015) How to implement biodiversity-based agriculture to enhance ecosystem services: a review. Agron Sustain Dev 35:1259–1281. doi: 10.1007/s13593-015-0306-1

Fiorelli C, Auricoste C, Meynard JM (2014) Concevoir des systèmes de production agroécologiques dans les stations expérimentales de l'INRA:changements de référentiel professionnel pour les agents et les collectifs de recherche. Courrier de l'Environnement de l'INRA 57–68

Francis CA, Jordan N, Porter P, et al (2011) Innovative education in agroecology: Experiential learning for a sustainable agriculture. Critical Reviews in Plant Sciences 30:226–237

Gibon A, Rubino R, Sibbald AR, et al (1996) A review of current approaches to livestock farming systems in Europe: towards a common understanding. Livestock farming systems: research, development socio-economics and the land manager Proceedings 79:7–19

Girard N (2014) Quels sont les nouveaux enjeux de gestion des connaissances ? Revue internationale de Psychosociologie Vol. XIX:51–78. doi: 10.3917/rips.049.0049

Girard N, Magda D, Noseda C, Sarandon S (2015) Practicing Agroecology: Management Principles Drawn From Small Farming in Misiones (Argentina). Agroecology and Sustainable Food Systems 39:824–840

Gliessman S (2013) Agroecology: Growing the roots of resistance. Agroecology and Sustainable Food Systems 37:19–31

Gliessman SR (2005) Agroecology and agroecosystems. The earthscan reader in sustainable agriculture London: Earthscan 104–114

Gliessman SR (1998) Agroecology: Ecological Processes in Sustainable Agriculture. CRC Press

Goulet F (2017) Explorer et partager. Les expériences de réduction des pesticides dans une revue professionnelle agricole. Économie rurale 103–120

Holling CS, Meffe GK (1996) Command and control and the pathology of natural resource management. Conservation biology 10:328–337

Hubert B (2012) L'agroécologie: une mise en tension de la pensée agronomique. L'agroécologie en Argentine et en France, Regards croisés 121–150

Jas N (2005) Déqualifier le paysan, introniser l'agronome, France 1840-1914. Ecologie & politique N°31:45–55

Jasanoff S, others (2004) States of knowledge: the co-production of science and the social order. Routledge

Journé B, Raulet-Croset N (2008) Le concept de situation: contribution à l'analyse de l'activité managériale en contextes d'ambiguïté et d'incertitude. M@ n@ gement 11:27–55

Knap PW (2005) Breeding robust pigs. Australian journal of experimental agriculture 45:763–773

Kolb DA (2014) Experiential learning: Experience as the source of learning and development. FT press

Lamine C (2011) Transition pathways towards a robust ecologization of agriculture and the need for system redesign. Cases from organic farming and IPM. Journal of Rural Studies 27:209–219. doi: 10.1016/j.jrurstud.2011.02.001

Lamine C (INRA, Abreu D, Ambiente LS (EMBRAPA M, et al (2012) The place of agroecology in the new dynamics within the agricultural world in Brazil and in France

Larrère R (2002) Agriculture: artificialisation ou manipulation de la nature. Cosmopolitiques 1:158–174

Latour B (2012) Enquête sur les modes d'existence : Une anthropologie des Modernes. La Découverte, Paris

Lechenet M, Deytieux V, Antichi D, et al (2017) Diversity of methodologies to experiment Integrated Pest Management in arable cropping systems: Analysis and reflections based on a European network. European Journal of Agronomy 83:86–99

Lefevre A, Salembier C, Perrin B, et al (2015) Design, experimentation and assessment of four protected vegetable cropping systems adapted to different food systems. In: 5. International Symposium for Farming Systems Design (AGRO2015). pp 2–p

Lemaire G, Franzluebbers A, Carvalho PC de F, Dedieu B (2014) Integrated crop–livestock systems: Strategies to achieve synergy between agricultural production and environmental quality. Agriculture, Ecosystems & Environment 190:4–8. doi: 10.1016/j.agee.2013.08.009

Lemery B, Ingrand S, Dedieu B, Dégrange B (2005) Agir en situation d'incertitude: le cas des éleveurs de bovins allaitants. Économie rurale Agricultures, alimentations, territoires 57–69

Lin BB (2011) Resilience in agriculture through crop diversification: adaptive management for environmental change. BioScience 61:183–193

Loucks OL (1977) Emergence of research on agro-ecosystems. Annual review of ecology and systematics 8:173–192

Lyon A, Bell MM, Gratton C, Jackson R (2011) Farming without a recipe: Wisconsin graziers and new directions for agricultural science. Journal of Rural Studies 27:384–393

Malézieux E (2012) Designing cropping systems from nature. Agron Sustain Dev 32:15–29. doi: 10.1007/s13593-011-0027-z

Marliac G, Simon S, Fleury A, et al (2013) Contrasting effects of codling moth exclusion netting on the natural control of the rosy apple aphid. IOBC-WPRS Bull 91:81–85

Marsden T (2012) Towards a Real Sustainable Agri-food Security and Food Policy: Beyond the Ecological Fallacies? The political quarterly 83:139–145

McCown RL (2002) Changing systems for supporting farmers' decisions: problems, paradigms, and prospects. Agricultural Systems 74:179–220. doi: 10.1016/S0308-521X(02)00026-4

McCown RL, Carberry PS, Hochman Z, et al (2009) Re-inventing model-based decision support with Australian dryland farmers. 1. Changing intervention concepts during 17 years of action research. Crop and Pasture Science 60:1017. doi: 10.1071/CP08455

Merleau-Ponty M (1945) Phénoménologie de la perception. Gallimard, Paris

Milestad R, Dedieu B, Darnhofer I, Bellon S (2012) Farms and farmers facing change: The adaptive approach. In: Darnhofer I, Gibbon D, Dedieu B (eds) Farming Systems Research into the 21st Century: The New Dynamic. Springer Netherlands, pp 365–385

Mintzberg H (2000) The rise and fall of strategic planning. Pearson Education

Moraine M, Duru M, Therond O (2017) A social-ecological framework for analyzing and designing integrated crop–livestock systems from farm to territory levels. Renewable Agriculture and Food Systems 32:43–56

Moraine M, Grimaldi J, Murgue C, et al (2016) Co-design and assessment of cropping systems for developing crop-livestock integration at the territory level. Agricultural Systems 147:87–97. doi: 10.1016/j.agsy.2016.06.002

Nicholls C, Altieri M (2016) Agroecology: Principles for the Conversion and Redesign of Farming Systems. Journal of Ecosystem & Ecography 01: doi: 10.4172/2157-7625.S5-010

Ollion E (2015) Evaluation de la robustesse des vaches laitières: entre aptitudes biologiques des animaux et stratégies de conduite des éleveurs. Université Blaise Pascal-Clermont-Ferrand II

Ollion E, Ingrand S, Delaby L, et al (2016) Assessing the diversity of trade-offs between life functions in early lactation dairy cows. Livestock Science 183:98–107

Phocas F, Bobe J, Bodin L, et al (2014) Des animaux plus robustes: un enjeu majeur pour le développement durable des productions animales nécessitant l'essor du phénotypage fin et à haut debit. Productions Animales 27:181–194

Prost L, Berthet ET, Cerf M, et al (2016) Innovative design for agriculture in the move towards sustainability: scientific challenges. Research in Engineering Design 1–11

Ratnadass A, Fernandes P, Avelino J, Habib R (2012) Plant species diversity for sustainable management of crop pests and diseases in agroecosystems: a review. Agronomy for Sustainable Development 32:273–303. doi: 10.1007/s13593-011-0022-4

Ravier C, Meynard J-M, Cohan J-P, et al (2017) Early nitrogen deficiencies favor high yield, grain protein content and N use efficiency in wheat. European Journal of Agronomy 89:16–24

Röling NG, Wagemakers MAE (1998) Facilitating sustainable agriculture: Participatory learning and adaptative management in times of environmental uncertainty. Cambridge University Press

Rose DC, Sutherland WJ, Parker C, et al (2016) Decision support tools for agriculture: Towards effective design and delivery. Agricultural Systems 149:165–174. doi: 10.1016/j.agsy.2016.09.009

Ryschawy J, Choisis N, Choisis JP, et al (2012) Mixed crop-livestock systems: an economic and environmental-friendly way of farming? animal 6:1722–1730

Sauvant D, Perez JM, others (2010) Special Issue: Robustness, ruggedness, flexibility, plasticity, resilience... new quality criteria of systems of animal and livestock farming. INRA Productions Animales 23:3–101

Suchman L (1993) Response to Vera and Simon's situated action: A symbolic interpretation. Cognitive Science 17:71–75

Thévenot L (2006) L'action au pluriel: sociologie des régimes d'engagement. Éd. La Découverte, Paris

Tichit M, Ingrand S, Moulin C-H, et al (2004) Analyser la diversité des trajectoires productives des femelles reproductrices: intérêts pour modéliser le fonctionnement du troupeau en élevage allaitant. Productions animales 17:123–132

Tittonell P (2014) Ecological intensification of agriculture—sustainable by nature. Current Opinion in Environmental Sustainability 8:53–61. doi: 10.1016/j.cosust.2014.08.006

Toffolini Q, Jeuffroy M-H, Prost L (2016) Indicators used by farmers to design agricultural systems: a survey. Agronomy for sustainable development 36:5

Toledo VM, Ortiz-Espejel B, Cortés L, et al (2003) The multiple use of tropical forests by indigenous peoples in Mexico: a case of adaptive management. Conservation Ecology 7:

Tomich TP, Brodt S, Ferris H, et al (2011) Agroecology: a review from a global-change perspective

Warner KD (2008) Agroecology as Participatory Science Emerging Alternatives to Technology Transfer Extension Practice. Science Technology Human Values 33:754–777. doi: 10.1177/0162243907309851

Wezel A, Casagrande M, Celette F, et al (2014) Agroecological practices for sustainable agriculture. A review. Agron Sustain Dev 34:1–20. doi: 10.1007/s13593-013-0180-7

Wezel A, Peeters A (2014) Agroecology and herbivore farming systems-principles and practices. Options Méditerranéennes 109:753–768

Whiteman G, Cooper WH (2000) Ecological embeddedness. Academy of Management Journal 43:1265–1282

Williams BK (2011) Adaptive management of natural resources—framework and issues. Journal of Environmental Management 92:1346–1353. doi: 10.1016/j.jenvman.2010.10.041

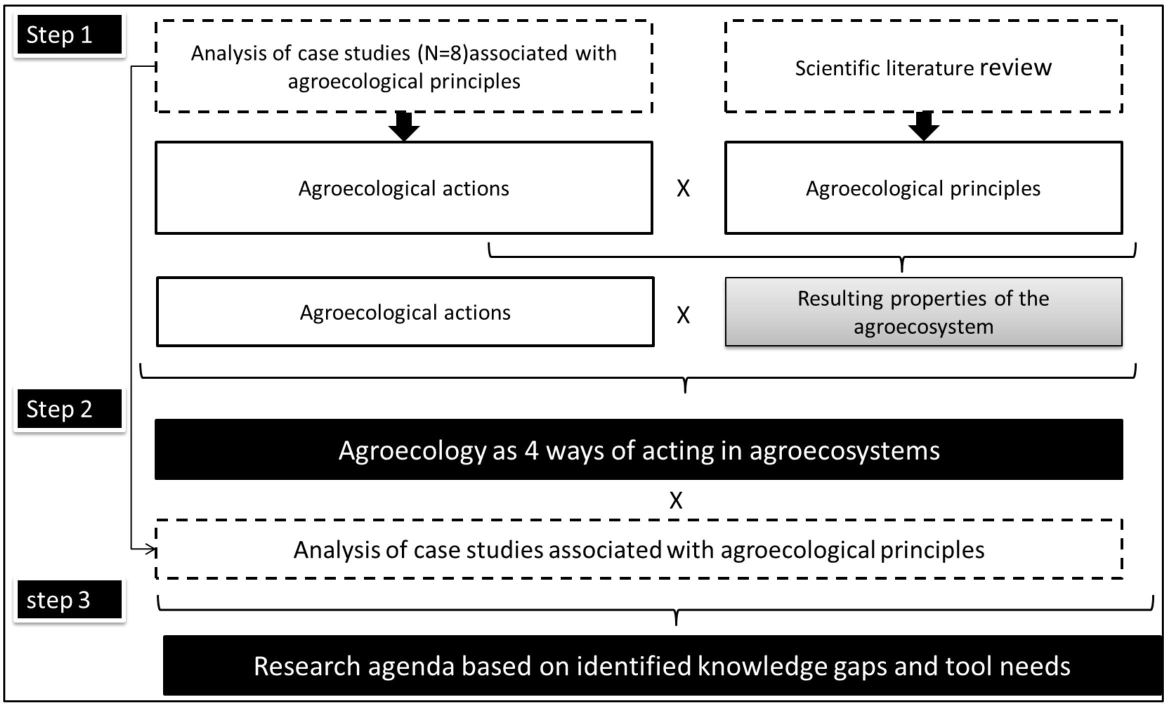

Figure 1: General approach

	Properties of agroecological farming systems	Description	References
1	Locally based	The choice of productions, the resources mobilized to produce, and production factors mainly originate from the environment of the farm and draw support from the previous states of the agro-ecosystem.	Duru et al. 2015, Gliessman 2007, Caporali 2011
2	Integration of cultivated and non-cultivated diversity	The authors insist on maintaining connectivity or interactions based on production factors and on the scales of the landscape and of semi-natural elements. Beyond the scale of land plots, this adaptation to existing conditions also results in the consistency between the spaces directly impacted by actions, and spaces that are not	Médiène et al. 2011 (Nicholls and Altieri 2016) (Biggs et al. 2012; Bonaudo et al. 2014) (Altieri et al. 2015)

		cultivated or directly managed, such as the edge of a forest. Functional diversity ("the variety of organisms and the ecosystem services they provide for the system to continue performing") or the diversity of responses ("the diversity of responses to environmental change among species that contribute to the same ecosystem function")	
3	Balanced (regarding needs in relation to production)	Dimensioning (e.g. size of livestock) is consistent with the resources available and existing flows within the ecosystem, or flows that can be maintained.	(Duru et al. 1998)
4	Below genetic potential for production	Not managed with the goal of maximizing productivity to prevent the exhaustion of resources; retain room to manoeuvre to react in the event of hazards (e.g. a drought that limits water or fodder resources for livestock farmers). Performance does not attempt to attain maximum production potential but rather to maintain the productive states of the system.	(Dedieu and Ingrand 2010) (Boiffin et al. 2013) (Milestad et al. 2012)
5	Fluctuating within manageable limits	The management of "**slow variables**" is related to this property: modulations in productivity, in system states (e.g. the chemical fertility of the soil), and in the availability of resources within the system are not controlled through fine-tuning but rather are maintained within limits beyond which the (effects of) possible management actions are no longer known.	(Biggs et al. 2012)

6	Optimizing resource recycling and availability	The recycling principle is associated with the goals of "clos[ing] the energy and material cycles; i.e. minim[izing] losses and external inputs, and substitut[ing] chemical inputs with natural inputs" and "optimiz[ing] the nutrient availability for crops and animals. Nutrient availability is more often a question of temporal settlement […]". Recycling and diversity are directly linked to one another by insisting on the fact that diversified crop sequences allow the biological activity of soils to be maintained and to thrive, as well as permitting the efficient recycling of nutrients. Re-mobilizing a maximum amount of resources endogenous to the farm (whether these are resources related to soil fertility and in particular organic materials, water resources, radiation). Autonomy	(Altieri and Toledo 2005; Wezel and Peeters 2014; Tittonell 2014) Bonaudo et al. (2014) Tomich et al. (2011)
7	Functional redundancy	Multiplying means (within space and time) that make it possible to obtain or maintain functions deemed to be essential in the system. This functional redundancy is related to the availability of resources as well as to the numerous interactions and regulations that support production. Reducing the vulnerability of agricultural systems by combining functional diversity with the diversity of responses.	(e.g. Gliessman 1998; Biggs et al. 2012; Nicholls and Altieri 2016) (Altieri et al. 2015)
8	Maximizing ecological or production-based interactions	The authors insist on maintaining connectivity or interactions based on production factors and on the scales of the landscape and semi-natural elements.	Titttonell (2014) (Nicholls and Altieri 2016) (Biggs et al. 2012; Bonaudo et al. 2014) Duru et al. (2015),

		Planned diversity, associated diversity, and diversity on the landscape scale to grant an “ability to provide ecosystem services of support and regulation”.	
9	Variable quality of productions	Variability in the quality of production is accepted as a consequence of management that gives priority to maintenance of production states over the long-term.	Boiffin et al. 2013, Dedieu et Ingrand 2010
10	Polycentric governance	Acknowledging the fact that on the landscape scale, a production system is never ecologically isolated (e.g. epidemics, transfers of pests or auxiliaries, the transversality of water resources), nor is it economically or socially isolated.	Duru, Fares and Therond (2015)

Table 1: Ten properties of agroecological farming systems

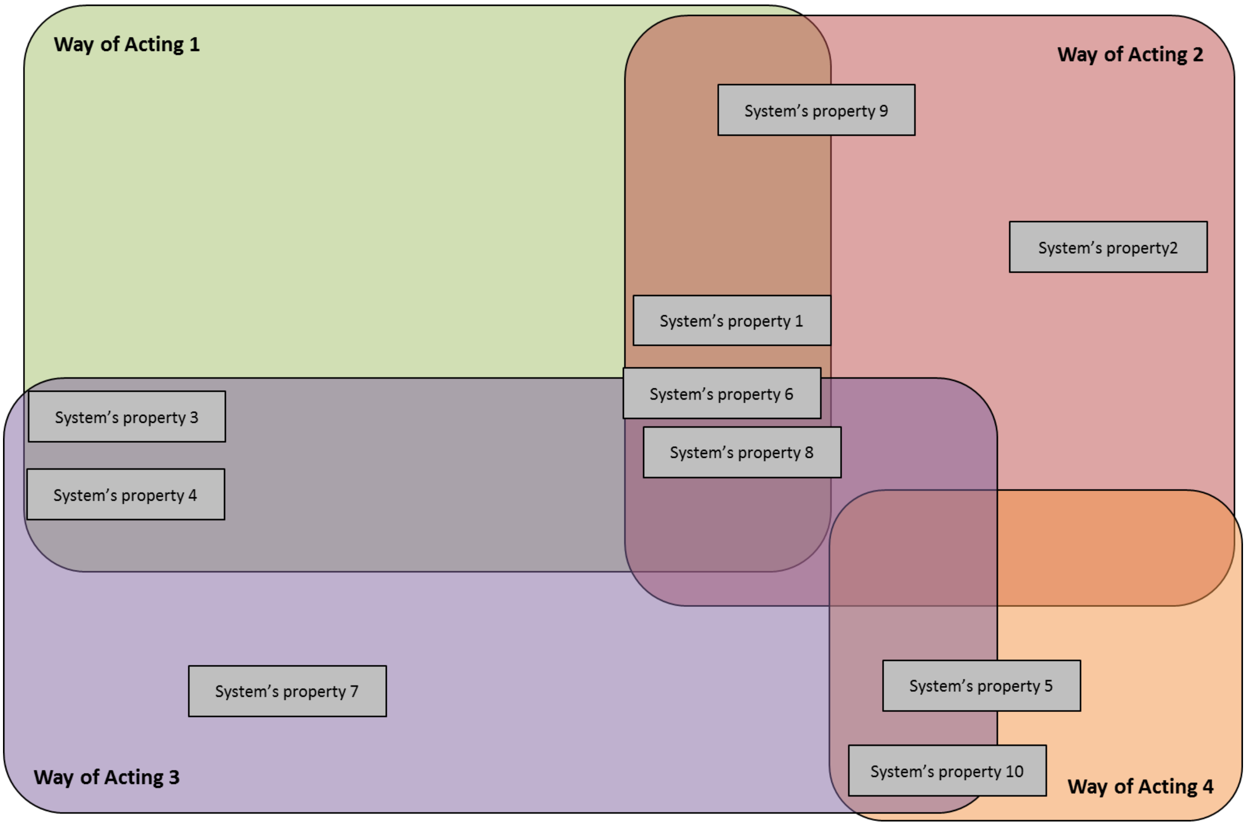

Figure 2: Agroecology as specific combinations of ways of acting and system properties

Name	Zone	Time	Production	Actors Involved	Description (description of the situation)	Bibliographic Reference
CS-1	Alénya experimental station, Occitanie (France)	Since 2013	Market gardening	Researchers Experimenters Farmers Advisers	Design and experimentation workshops for a system based on a maximum reduction in pesticide use (replaced by natural regulation) with the goal of a short sale supply chain.	(Cardona et al. 2018)
CS-2	Brittany / Normandy (France)	2014	Dairy cow farming	Farmers	Collective reflection around the suitability of local fodder resources and the genetic selection of dairy cattle in order to move towards autonomous (maximum grass usage) and economical systems.	Ollion (2015)
CS-3	Picardy (France)	Project: 2002-2012 Study: 2013-2014	Large-scale farming	Farmers Organizers Advisers	8 farmers, integrated and organic cropping systems, numerous experiments (strips and complete land plots) over an eight-year period.	Toffolini (2016)
CS-4	Ile de France Burgundy Pays de la Loire Poitou-Charentes Picardy	2013-2014	Large-scale farming	Farmers	Large-scale farmers committed to a reduction in pesticide use.	Toffolini et al. 2016 Toffolini et al. 2017 NJAS Comm. IFSA, Toffolini et al. 2016 (How “fundamental knowledge” supports the cropping-system re-design by farmers?)

	(France)					
CS-5	“Vergers Durables” Group (French-speaking fruit growers (France, Switzerland, Belgium, and Spain)	Since 2013	Pome fruits	Farmers, Researchers, Advisers, Experimenters	Collective and individual reflection around the development and design of apple orchards using organic agriculture aimed at a maximum reduction in inputs.	Personal source
CS-6	Paturajuste Network (France)	Since 2013	Livestock farming (cattle, sheep, goats)	Farmers Advisers,	Collective and individual reflection around practices for valorizing semi-natural vegetation	Girard, N., Magda, D. (2017). Les jeux entre singularité et généricité des savoirs dans un réseau d’éleveurs agroécologiques. Presented at the 10th International Symposium of the AGeCSO, Montréal (Canada)
CS-7	Practices of small-scale producers in the province of Misiones (Argentina)	2013	Various types of production, essentially market gardening	Farmers	Individual studies regarding their practices, in particular combinations of crops and varieties.	Girard N., Magda D., Noseda C., Sarandon S., 2015. Practising agroecology: management principles drawn from small farming in Misiones (Argentina). *Agroecology and Sustainable Food Systems*, 39(7), 824-840.
CS-8	Farmers involved in conservation	2015	Large-scale farming, cash crops	Farmers	Individual studies on their practices and learning.	Cristofari, H., Girard, N., Magda, D. (2018). Supporting transition toward conservation

	agriculture (southwest, northwest and Brittany)					agriculture: a framework to analyze the learning processes of farmers. Hungarian Geographical Bulletin, 66(1), 65-76.

Table 2: Description of case studies

	Ways of acting	Types of actions and objectives
1	Locally-embedded	a - Adapting management practices to each species' biology c - breeding to increase adaptive capacity b - using local breeds and/or breeds adapted to local conditions
		e - leaving be the field edges
		f - target is below the "potential" g - target shifts from production to the state of the system supporting the production
		m - Using natural resources available on site and by-products
		n - using cultivar mixtures and intercropping o - managing heterogeneity in land-use patterns and biotic and abiotic components p - managing biodiversity (which, how, which scales?)
		q - tolerating defects
2	Intertwining multiple spatial and time scales and buffers	b - using local breeds / varieties and/or breeds adapted to local conditions
		e - leaving be the field edges o - managing heterogeneity in land-use patterns and biotic and abiotic components
		f - targeting shifts from production to the state of the system supporting the production
		d - diversifying observations h - indicators shift from performance to states of the system supporting production i - Managing slow variables
		l - minimizing losses/ optimizing relocation of nutrients
		n- using cultivar mixtures and intercropping o - managing heterogeneity in land-use patterns and biotic and abiotic components p - managing biodiversity (which, how, which scales?)

3	Flexibility and adaptiveness in management	c - breeding to increase adaptive capacity / robustness d - diversifying observations
		e - leaving be the field edges
		f - target shifts from production to the state of the system supporting the production
		i - Managing slow variables (soil biological activity, structure, weeds and natural enemy pop.) j - managing complementarities in time and space
		k - maximizing soil coverage over time l - minimizing losses/ optimizing relocation of nutrients
		o - managing heterogeneity in land-use patterns and biotic and abiotic components
		q - tolerating defects r - increasing harvest frequency
4	Critical and reflexive engagement in action towards learning	u - taking inspiration from / adapting to others' practices locally
		t - increased communication between managers and practitioners
		d - diversifying observations
		s - Situate in groups
		q - tolerating defects

Table 3: Four ways of acting and the elementary practices of the systems tied to them. The letters "a" to "u" indicate the 21 agroecological actions identified based on case studies. Therefore, the same letter can correspond to multiple "ways of acting".

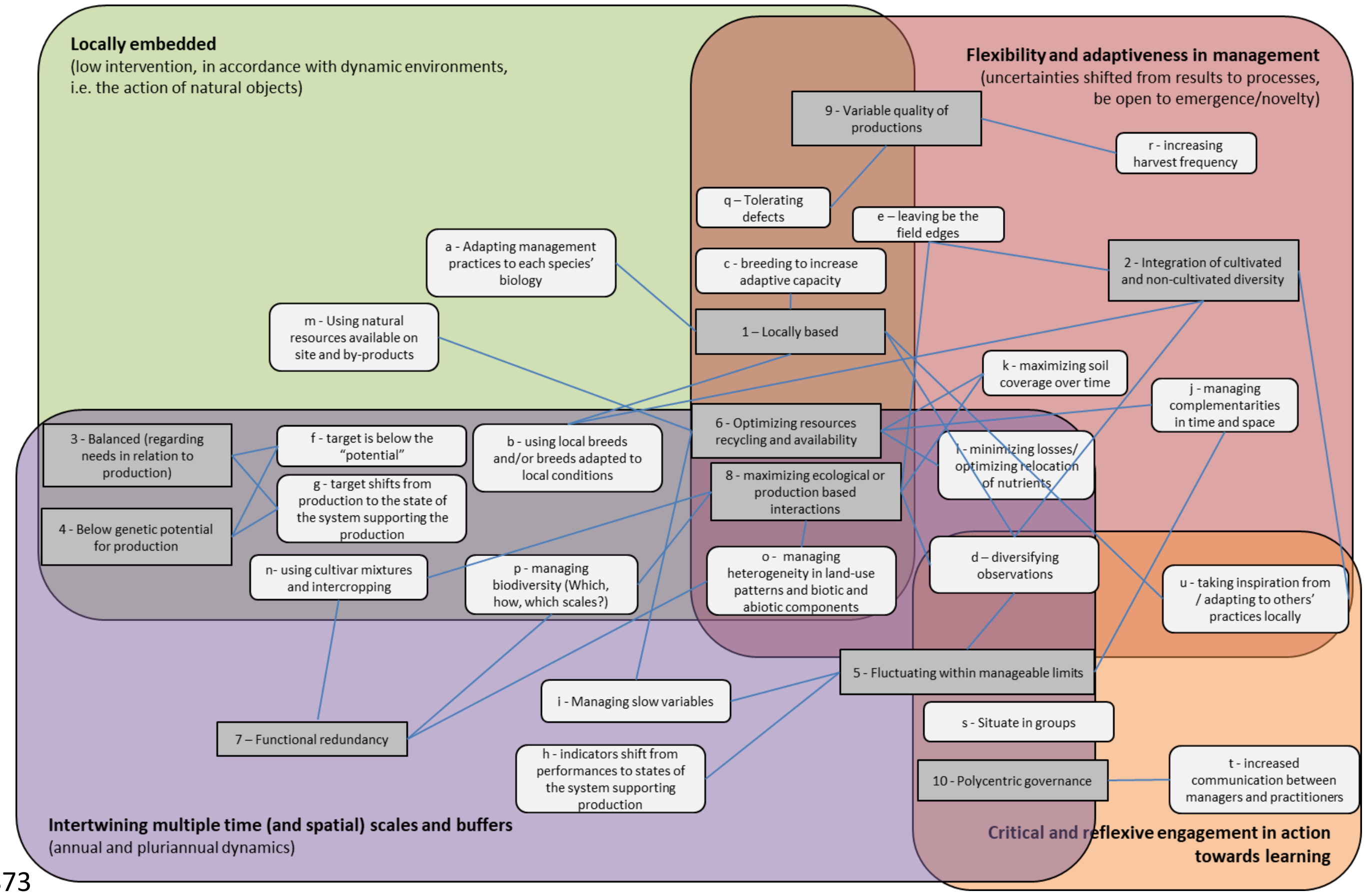

Figure 3: Relationships between ways of acting and agroecological farming system properties. The gray rectangles represent the 10 different systems properties; the white boxes present the 21 agroecological actions, identified by letters "a" to "u". The blue lines show the multiple relations between systems properties and agroecological actions that constitute each way of acting.