Adaptive farming systems – A position paper

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Abstract: *In the last decades, there have been profound changes in the understanding of farming systems, in particular regarding their need for on-going adaptation to an ever-changing environment. Indeed, the rapid pace of change and its often unforeseeable direction requires farmers to keep their farms flexible and adaptive. We thus need to understand the attitudes, structures and activities that build and sustain the ability of farmers and of farming communities to cope with change and to use the opportunities offered by change. The approach we propose is based on an understanding of the workings of complex systems and entails another viewpoint on system properties, boundaries and dynamics. It focuses on ensuring sufficient room to manoeuvre, identifying transition capabilities and extending the degrees of freedom. It emphasises the need to ensure that farmers are prepared for turbulences by increasing their adaptive capacity. The concepts of flexibility, resilience and adaptive management may help in learning how to make constructive use of unforeseen change. Indeed, changes are the triggers for experimentation, for the reorganisation of resources, for the renewal of systems capable of learning and adapting. In particular, we will examine the factors that may support the capacity of farming systems to create, test and maintain an adaptive design.*

Keywords: *adaptive farm management, resilience, adaptive capacity, evolutionary approach, complex dynamic systems*

Introduction

The last two decades saw a cascade of regional and global transformations affecting European farms. Sources of uncertainty include the enlargement of the European Union (EU), the reform of the Common Agricultural Policy (CAP), new environmental regulations, more stringent quality and traceability requirements, the increasing frequency of extreme climatic events and of the dramatic change in prices of some agricultural products. While many of the technical innovations designed to help farmers, used to be focussed on increasing productivity or improving product quality, they now focus on ecological intensification. The goal is to cope with the increasing demand for safe food produced using environmentally friendly methods. However, given that future conditions are uncertain, innovations must take into account the need for flexibility at the farm level. Indeed, the rapid pace of change and the often unforeseeable direction of change require farmers to keep their farms adaptive to be able to respond to new challenges as they arise. A number of the transformations that can be observed at farm level (e.g. larger farms, lower share of family-labour, diversification of farm activities, pluriactivity) may indicate strategies implemented by farmers to face uncertainty on the long term (Lemery et al., 2005).

Some researchers, when trying to understand how farms can persist amidst change, focus on risk-management strategies. The term 'risk' denotes the likelihood that an undesirable event may occur and is thus linked to the assumption that the probability of an occurrence is known (when it is not known, economists usually use the term "uncertainty", see the seminal work by Knight, 1921). Given its reliance on probabilities the concept implicitly assumes that future occurrences can be predicted (often derived from historic data) and that the nature of these occurrences is known. This concept has received stringent critiques by social scientists, who have pointed out that the concept does not take into account values and preferences or organisational malfunctions (see Renn, 2008). From a system point of view, the approaches building on the concept of risk have further weaknesses, in particular because they underestimate issues such as nonlinearities, feedback loops and delays.

We would like to draw attention to a different approach, one that assumes that the future cannot always be predicted (i.e. extrapolated from past events). This approach thus centres on ensuring that institutions, people and farming systems are fundamentally able to cope with change. To pinpoint the difference this evolutionary view makes, we briefly summarise the core assumptions on which conventional farm management is based as well as the historical development of farming systems. We believe that including the dynamic dimension of evolving farming systems can make an important contribution to the renewal of the farming systems perspective. We conclude by presenting some implications for the design of adaptive farming systems.

A brief historical overview of the approaches to farm management

Farm management in the reductionist ‘command and control’ approach

Much of the work on adequate technical and economic farm management focuses on production efficiency, on creating optimum conditions so as to maximise profit. Because fluctuations are problematic when production goals are to be met, managers seek to control processes and to stabilise the output of the farm. This approach to management, guided by the desire to control variation and to make the future harvest predictable, has been referred to as “command-and-control” (Holling and Meffe, 1996). The attributes at the core of this approach are: efficiency, constancy and predictability. A problem (e.g. too low crop productivity, threat from pests) is perceived, a technological solution developed and implemented to achieve a predictable outcome. The goal is to reduce the range of natural variation of the farming system, aiming at making it more predictable, and at ensuring a stable supply of goods and services to satisfy societal needs. Thus, agricultural pests are controlled through pesticides, nutrient competition is reduced through herbicides, natural, multi-species grasslands is converted into monoculture, water supply for crops is regulated through irrigation or drainage, and field patterns are reorganised to reduce border effects and increase labour productivity. More recent developments, such as precision farming, aim at adjusting crop management steps to account for field variability by using technological means (satellite navigation, sensors, etc.). In greenhouse production, optimal control of environmental conditions is already ensured through sensors and software. In all these approaches, the purpose is to turn an unpredictable and ‘inefficient’ natural system into one that produces standardised commodities in a reliable, predictable and economically efficient way.

The normative and prescriptive solutions within this approach are usually developed in a strictly disciplinary way. Indeed, until the mid-1960s there was little collaboration between technical agricultural scientists and agricultural economists, much less with sociologists. This “reductionist, analytical worldview which divides systems into ever smaller elements, studied by ever more esoteric specialists” (Funtowicz and Ravetz, 1993:739; see also Beranger and Vissac, 1994) ensured that e.g. in animal production, feeding, breeding, health and housing each developed in separate and distinct disciplines. The assumptions underlying reductionism was that the results could be added to one another: optimal breeding + optimal feeding + optimal housing = ‘best’ animal production. Also, much of the research results were based on laboratory experience and controlled environments, i.e. the study of an isolated piece of the farming system that is kept unnaturally pure, stable and reproductible.

The same approach prevailed in agricultural economics, where the goal was to maximise income by optimising the allocation of scarce resources. Thus the various elements – e.g. various sources and types of feed, animal type, crop production, off-farm inputs, labour requirements – were combined to design the ‘optimal farm’. This ‘package’ was then recommended to farmers: they should combine the various elements in the prescribed way and ensure that all variables stayed at the optimum level (e.g. protein in feed, air temperature in the animal housing, water availability, etc.). This framework is indeed tightly linked to a top-down process of knowledge transfer: farmers were supposed to apply recommendations, they were supposed to think and act as rational decision makers and profit maximisers.

The proposed technological solutions were very efficient in the short run, as the strong increase in productivity in the 1970s and 1980s, both in crop and in animal production, has shown. The increase in productivity took place in a supportive economic and political framework (i.e. ready access to cheap fertilizer, government-guaranteed output markets, stabilised prices) and in favourable production environments (i.e. good soils, reliable water supply) which led themselves to the implementation of ‘technological package solutions’ (Norman, 2002).

As a by-product, the short-term success of increasing yield in homogenized environments contributed to creating a mental model in which farm management is largely independent of Nature’s services (cf. Daily, 1997). According to this thinking, Nature can be conquered, controlled and ruled (Folke et al., 2003). This approach is based on the implicit assumption that the world is stable and develops in a linear, predictable way. The solution to a problem is seen as being direct (i.e. there is a linear relation between cause and effect), appropriate (clearly defined), feasible (relatively simple, no complex interrelationships) and effective over the relevant spatial and temporal scales (focus on small spatial scales and on short durations, assumption that there are no side-effects at other scales). In other words, it makes the world appear more simple, tractable and manageable than it really is.

Whereas the initial phase of command-and-control is nearly always quite successful – insect pests are reduced by pesticide use and better and more efficient ways to kill insects are developed – the result is increasing dependency on continued success in controlling nature. When unexpected events or system failure happen, dependency leads economic interests to pressure for further command-and-control measures (e.g. physical protection against frost) and for measures to buffer against variation (e.g., through crop insurance schemes). However, unanticipated events are bound to happen (e.g. chemical pollution from intensive agriculture, loss of top-soil due to erosion, sudden price swings on the market for agricultural commodities). As Holling and Meffe (1996) point out, monocultural, energy-intensive farming practices are the epitome of reduction of variation and loss of resilience. Monocultures are notoriously susceptible to the effects of drought, flooding, insect or pathogen outbreaks, and market vagaries. Consequently they require large inputs of energy (fertilisers, pesticides, herbicides, irrigation) and often large societal subsidies in the form of price supports, guaranteed loans, disaster relief and surplus buyouts (see Jay, 2007). These monocultures are fundamentally unresilient to natural or social perturbations.

Holling and Meffe (1996:330) argue that crises and surprises are “the *inevitable* consequences of a command-and-control approach” (italics in original). Indeed, when the range of natural variation in a system is reduced through command-and-control, then the system becomes less resilient to external perturbations, resulting in crises and surprises. The surprise is intensified by the fact that we tend to forget that ecological change is not incremental and local, but sudden and extensive (Holling and Meffe, 1996)

Farming systems approach

The shortcomings of the reductionistic, command-and-control approach to agricultural research became increasingly evident, especially as it was understood that the farmers’ production environment were much more heterogeneous than had been thought. Indeed, farmers in less favoured areas (and also in countries of the South) resisted these innovations and did not adopt the technological packages. This raised the awareness that technological innovations needed to be assessed not only through their immediate efficiency. They also needed to be flexible (Sebillotte, 1990) and needed to take into account the farmers’ perception of uncertainty and security, their long term perspectives and their farming goals (Lev and Campbell, 1987; Dedieu et al., 2008).

Thus, it was recognized that the research approach needed to be more integrative, systemic and comprehensive (Hart and Pinchinat, 1982), and that multiple spatial and temporal scales needed to be taken into account (Lev and Campbell, 1987). Also, the limits of a science-based recommendation were acknowledged and with it the need to take an actor-oriented approach to ensure compatibility with the socioeconomic environment (Norman, 2002). This led to a new developmental paradigm, which Korten (1980, quoted in Norman, 2002) characterises as a ‘people-centred learning process’ rather than the earlier ‘technological blueprint’ approach (see also Jiggins and Röling, 1994). Thus, the farming systems approach developed in the late 1970s, which had as its key characteristics an interdisciplinary approach (i.e. collaboration between a wider range of disciplines and the inclusion of socio-economic elements) (Dent et al., 1995) and the involvement of farmers in the research process (Bellon et al., 1985; Collinson, 2000).

Initially the focus was still on how yields of particular crops could be increased. This early farming systems approach involved looking at one specific enterprise (or part of an enterprise) and identifying improvements that were compatible with the whole farming system (Norman, 2002:4). This approach allowed several developments:

- Technical scientists were increasingly sensitised to the complexity and variability of farmers’ production environment. They recognised that this environment consisted of both physical and socioeconomic components, and they also saw the need to integrate the farmer, with his/her norms and values, his/her decisions rules as a component of the systems they studied.
- The farm is understood as one system (see Osty, 1978). For example the livestock farming system approach proposed by animal scientists (e.g. Gibon et al., 1999), considers the farmer,

the herd and the resources as one socio-technical system. The (self-)regulation properties of the system, based on the interactions between its constitutive elements (information flows, adjustements of decision rules, biological homeorhetic controls (see Sauvant and Phocas, 1992, quoted by Puillez et al., 2008) at different time scales could theoretically and practically be included in a model (e.g. the flock operation model of Cournut and Dedieu., 2004).

- Economists realised that farmers' behaviour could not be understood only through maximisation of profit (Colin and Crawford, 2000). In his adaptive behaviour theory, Petit (1978, 1981) showed how farmers interactively adjust both their objectives and their situations. For farmers and farm households, choices also take into account issues such as long-term preferences, security, lifestyle and quality of life (Brossier et al., 1991; Gafsi and Brossier, 1997).

In the late 1980s and early 1990s the issue of adaptability of recommendations grew in importance, the range of social and technical disciplines associated with the farming systems approach broadened and the issue of ecological sustainability and environmental degradation came to the fore. However, the analytical focus was still on a steady-state perspective, which analyses the system at a particular point in time and space (e.g. Bourgeois and Krychowski, 1981). It provides an assessment of improvements in the 'efficiency' of the system in terms of a given set of goals, technological assets and present boundary conditions. As a result, farming system research lead to partial technological solutions (cultivars, management techniques, etc) and to the impact assessment of innovations on various farm types, instead of designing alternative farming systems (Fresco, 1990).

Norman and Malton (2000) distinguish four main phases in the development of the farming systems approach, with various, but partly overlapping, foci:

- Predetermined focus, for instance on improving cropping systems. Emphasis was on normative and prescriptive issues through application of techniques such as budgeting (soil fertility, labour, economics), optimisation with linear programming, and other tools for applied decision analysis.
- Whole farm focus, with the contribution of farm management studies involving various field survey techniques and sets of disciplines, often supported by national and international research institutions (Collinson, 1980).
- Natural resource focus, due to conflicting interests between strategies designed to improve short-run productivity and long-run ecological sustainability. This can be supported by specific methods (indicator frameworks) and approaches (eco-regions, eco-agriculture).
- Sustainable livelihood focus, which includes a wider set of issues, not just production: interactions between household, farm and non-farm activities, management of risk and uncertainty, environmental degradation, social equity, expectations on working conditions (Martel et al. 2007). The concept emerged nearly simultaneously in the farming systems literature and in a series of international conferences.

Although Chambers, as early as 1991, mentioned that technologies should increase farmers' flexibility to adapt their production to stochastic shocks and to constantly changing economic environment (Chambers, 1991, quoted in Norman, 2002; see also Lev and Campbell, 1987), the dynamic aspects were generally not at the centre of attention in the Anglophone approaches. However, in the Francophone tradition, more attention was given to systems dynamics and farmers' trajectories, a dynamic approach that often required long time periods to complete assessments (e.g. Levrouw et al., 2007; Moulin et al., 2008).

In the late 1990s, with the increasing awareness of the growing speed of change and the complex interdependences caused by globalisation, scientists realised that not only was it necessary to understand how the elements of the farming system interact, it was also necessary to understand the (co-)evolution of both the system's elements and their relationship. It thus became increasingly clear that sustainable development means a break with traditional thinking and the reductive analysis of isolated, static systems. Against the multi-dimensional background of socio-economic, political and environmental dynamics, changes and adaptations are the essential elements in any approach towards a sustainable society which underline the evolutionary characteristics of sustainability. Dedieu et al. (2008) summarized the key factors that support a change in perspective within farming systems in the European context: the questioning of the productivist model of agriculture (due to its effects on the environment and food safety concerns); the loss of guaranteed prices (which are now largely left to fluctuate following supply and demand on the world markets), the uncertainty of future policy developments (partly due to the rapid changes in the CAP, the negotiations within the World Trade Organisation (WTO), consumer demands following food scares); the territorialisation of production (e.g. through denominations of origin), the enlargement of the EU as well as a general globalisation of agricultural and food markets, and not least peak oil (see similar earlier concerns in Boiffin et al., 1978) as well as climate change.

It can thus no longer be the aim to ‘modernise’ farms, assuming a protected and certain development trajectory. The uncertainties of future developments must be taken into account. Previous concepts that guided research – such as stability, income maximisation, technical fine-tuning or biological optimisation – are increasingly replaced by such concepts as elasticity and plasticity, robustness and adaptability, resilience and flexibility.

It was also recognised, that in these approaches, the political, social and economic environment often remained a ‘black box’. The roles of public policies and institutions in shaping the changes are not addressed. Usually, the emphasis is on individual farming situations, without an analysis of their interactions with social groups (Long, 1984) or a hierarchy of driving forces contributing to adaptations.

The evolutionary, adaptive perspective in farming systems

Dynamic theories that explain the driving forces requiring the adaptations of the system over time, and the mechanisms through which they operate, have come to be labelled ‘evolutionary’. In the context of farms, these evolutionary theories try to explain how farms generate, and adapt to, change, and how these processes are intertwined with what happens both at the lower level of individual behaviour and the higher level of markets and the farm’s environment in general (see Rathe and Witt, 2001). This evolutionary perspective allows for a definition and assessment of adaptability of the system, i.e its ability to perform well according to unknown future boundary conditions and goals that might change over time.

In an evolutionary framework, continual development and innovation at the farm level is needed to maintain its ‘fitness’ relative to the systems it is co-evolving with. Subsequently, this ‘imperative to innovate’ highlights that there can neither be any best state, nor a stable equilibrium nor an optimal path of development (Rammel, 2003). This implies a trade-off between efficiency and adaptability: whereas efficiency takes advantage of existing favourable conditions, adaptability sustains the long-term survival by maintaining high compatibility in the face of a changing environment. There is thus a need to shift the weight from economic efficiency and short-term optimality to conditions fostering adaptive flexibility and long-term sustainability.

Exploring the flexibility properties and the ‘room for manoeuvre’ that a farming system offers, becomes a key issue. Understanding how farmers perceive and understand uncertainty, how they debate the need to adapt within their social networks, also appears as a major research topic. The way they construct in their long-term development path, their trajectory to last, gives information on how they act, or could act, in situations of uncertainty. Indeed, these approaches stress the role of creativity and imagination of the various members of the farm family. They point out that the farm is much more than a device to exploit economies of scale and scope as a response to technological progress. Rather, what a farm can produce with given resources thus hinges critically on the conceptions and capabilities of the farmer. To recognise the crucial role of the farmer for the development of a farm over time also implies that the farmer’s view of what business to conduct and how to conduct it need to be better understood.

As an example of a research approach assessing adaptability in livestock feeding systems, Roggero et al. (1996), identified four components of flexible strategies: (i) organisation and planning of local resources, taking into account their renewal in space and time, while giving priority to grazing, (ii) use of existing diversity and diversification of the resources, (iii) integration and multiple use of resources, having various utilisation patterns, (iv) adaptation and development of security devices, including anticipation of climatic hazards (see also Bellon et al., 2004). At a more general level, Lopez-Ridaura et al. (2005), based on a literature review, identified 30 attributes of peasant adaptive natural resource management systems. Of these, eight play a prominent role: productivity, stability, equity, adaptability, resilience, security, self-reliance and acceptability. In the evaluation framework they propose, these attributes are tightly intertwined, especially at the temporal scale.

In contrast to strategies aiming at short-term optimisation and economic efficiency, Rammel and Staudinger (2002) argue that the conditions and circumstances maintaining variability and momentary sub-optimal alternatives are highly relevant for a socio-economic system that aims at sustainable development. Instead of trying to get rid of disturbance, the existence of uncertainty and surprise as well as their unpredictable nature needs to be an accepted part of farm management (Funtowicz and Ravetz, 1993; Folke et al., 2003). Surprise and crisis create space for reorganisation, for renewal and novelty and provide opportunities for new ways of organising the farm. This approach to management emphasises the capacity to deal with surprise, to learn, and to support flexibility more than traditional farm management. It also stresses the limits of our knowledge and of our understanding of complex adaptive systems, and therefore emphasizes the importance of continuous processes of learning and adjusting.

Strengthening the adaptive capacity of farming systems

Lee (1999) argued that the key solution is to increase adaptive capacity by strengthening the ability to adequately respond to change, rather than reacting to the adverse impact of that change. This requires the ongoing development of a portfolio of alternative activities and resource use patterns that can be implemented quickly if needed. Adaptive management is thus concerned with the establishment of a continuous learning process that attunes to new information by reformulating hypotheses and models, and understanding activity implementation as experiments (see also Westley, 2002).

The basic requirement for this potential is adaptive capacity, meaning the ability to address changing conditions through a process of continuous adaptive learning and the possibility to initiate new development trajectories (Rammel, 2003). Indeed, every successful adaptation is only a temporary 'solution' to changing selective conditions which could be altered by the 'solution' itself. It is the diversity and repertoire of alternative options and innovative activities which increase the possibility to leave maladaptive developments and exhibit sustainable change.

If there are no single optimal solutions, no universal stable equilibria, the objective must include initiating and maintaining a diversity of alternative options so as to increase the chance of finding an adaptive response to unpredictable change (Rammel, 2003). There is a trade-off between short-term optimisation and long-term adaptability (Lev and Campbell, 1987) and between economic efficiency and adaptive flexibility. In order to manage a farm, both short-term optimisation and long-term goals need to be pursued. It is not a question of either or, but rather a question of finding the right mix. This trade-off between efficiency and diversity, or adaptability, was extensively described by Giampietro (1997). Walker and Salt (2006) describe management for maximum output as the opposite to management for resilience.

As an example of such an adaptive approach at the farm level, Lemery et al. (2006) have described two strategies implemented by suckler cattle farms in Burgundy, which are tightly linked to the farm trajectory:

- “To do with”: sub-optimal combinations of activities were deliberately kept, to be able to easily cope with changes in the context of production. This strategy was associated with two farm development trajectories: i) farming extensively at all times, or ii) engaging in pluriactivity (either on- or off-farm) enabling the farmer to adjust the extent and the objective of each activity depending on the context.
- “To act upon“: a long-term target was defined for the farm and short-term pressures for change were met in a non-sensitive and non-reactive approach. This strategy was associated with intensive farming systems that were committed to collective action (cooperatives) so as to protect them from hazards. Another farm trajectory was scale increase, where enlargement phases guided the rhythms of changes.

This study, which is currently reproduced in other farming contexts, identifies several implications of the evolutionary approach. This approach has an impact on farm management, e.g. securing access to resources (see also Tarondeau, 1999) either through extensive management or through collective action. But it also has impacts on understanding the values of the farmers, who integrate the need to adapt into their professional experience (Dubar, 1991) and their behaviour.

Several concepts might be particularly helpful in strengthening the adaptive capacity of farming systems: resilience, flexibility, diversity and variability. These will be discussed in more detail in the next sections.

Resilience to reduce vulnerability

Resilience is the capacity of a system, e.g. a farm, to absorb disturbance and reorganise while undergoing change so as to still retain essentially the same function, structure and feedbacks (Walker et al., 2004). The opposite of resilience is vulnerability. Vulnerability can be described as the susceptibility of harm caused by stresses associated with environmental and social change combined with the absence of the capacity to act (Adger, 2006; Fabricius et al., 2007). While the initial resilience work focused on the buffering capacity of ecosystems to absorb shocks, the current is concerned with the opportunities that disturbance opens up in terms of recombination, renewal and emergence of new trajectories (Holling, 2001; Folke, 2006).

Indeed, resilience is linked to adaptations, which aim to reduce vulnerability by responding to, and by shaping change (Smit and Wandel, 2006). Whereas resilience may be considered a precondition for adaptive capacity (Folke et al., 2003), adaptive capacity is also the ability of actors in a social-ecological system to manage resilience. Indeed, Walker et al. (2006) point out that adaptive capacity depends on the available social, human, natural, manufactured and financial capital as well as the system of institutions and governance (see also Daly, 1990; Rigby et al., 2000).

The concept of resilient farming systems implies the recognition of dynamic systems, the presence of non-linear changes and the notion that human action and social structures are integral to ecosystems (cf. Milestad and Darnhofer, 2003). Indeed, a farming system can be described as a social-ecological system, emphasising social-ecological resilience rather than social *or* ecological resilience (see Folke et al., 2003). The concern is thus for a farm management that secures the capacity of the farming system to sustain societal development and progress, while providing essential ecosystem services.

Flexibility to enhance adaptive capacity

In management sciences, the concept of flexibility is seen as a means to face uncertainty and thus also defined in relation to adaptive capacity (Reix, 1979). Tarondeau (1999) distinguished operational flexibility from strategic flexibility. Operational flexibility refers to the short-term regulation properties of a system facing hazards. Strategic flexibility refers to long-term choices and to the capacity to change the structure, the ressources, and the competences of the enterprise in anticipation of or to react to changes in the environment. Tarondeau (1999) identified three sources of flexibility in production systems: the products (diversity, exchangeability); the processes (the organisation of the technical system authorizes several processes) and the inputs specification (when differents sources of inputs can be combined or substituted instead of depending of one specific input). This concept is used to analyse the adaptive capacity of socio-technical systems (see also Astigaraga et al., 2008; Chia, 2008; Chia and Marchenay, 2008).

In a sense, in a flexible situation, the final products and services produced by a farm at any given time merely represents one of several ways in which it could be using its resources. This means that for a farm, what matters is the way in which the resources are used, not the resources themselves. The ‘productive opportunities’ of the farm, even with an unchanged set of resources, are not objectively given, but depend on the conceptions of individual actors (see Rathe and Witt, 2001:339). What a farm can produce thus hinges critically on the conceptions and capabilities of the members of the farm family. This approach stresses the role of creativity and imagination of the farmer, the farm being much more than a device to exploit economies of scale and scope as a response to technological progress. We thus need to recognise the crucial role of the farmer for the development of a farm over time. Thus, the conceptions of the farm family of what business to conduct and how to conduct it must be better understood.

Flexibility of a farming system is also enhanced if the selected technological paths enable reversibility. For instance, in fruit production, orchard planting systems based on better understanding of tree biology as well as interactions among research and extension workers provide a more regular yield, favour fruit quality and demand less pesticides (Lauri et al., 2008). They also enable transitions towards alternative orchard patterns. This means that farms are interpreted as learning systems whose survival and growth strongly depends on the successful generation and absorption of new knowledge. The impact of farms’ cumulative searching and learning, the accumulation of knowledge and capabilities on organisational transformation and systematic developmental change, needs to be considered. In other words: developmental change at the level of the individual farm deserves to be explored in its own right.

Diversity to cope with variability

Managing complex systems and building farm resilience implies spreading risks and creating buffers, i.e. not putting 'all eggs in one basket'. Here diversity – which is tightly linked to flexibility – can play a pivotal role. Indeed, as Rammel and van den Bergh (2002) argue, long-term sustainability calls for an evolutionary potential. This potential builds on a diversity of co-existing alternatives. This diversity has been shown to play an important role in the reorganisation and renewal process following disturbance (Folke et al., 2003).

As Rammel and Staudinger (2002) argue: "it is impossible to predict changes or to eliminate uncertainties, humans are only able to minimise the risk of insufficient or maladaptive responses to future challenges, which, in accordance to evolutionary theory, is best done through maintaining a high degree of variability as a diversity of alternative traits". Indeed, a selection that reduces variability decreases the number of possible future developments. In other words, it is the capacity to maintain alternative solutions, which increases the chances to address inevitable changes successfully.

Evolutionary systems do not relate to stability in a static sense as they are faced with moving equilibria and the dynamics of coevolutionary[1] interactions which cannot be foreseen ex-ante. Given this permanent process of unpredictable change, any kind of optimising must be understood as local and myopic (Rammel and van den Bergh, 2003; Walker and Salt, 2006). If optimality exists, it will be temporary, because through evolution, selection and innovation, and environmental change, it is easily transformed into a maladaptive trait. Under such conditions, diversity is a key element of long-term stability and even survival. Indeed, since every successful adaptation is only a temporary 'solution' to changing selective conditions, maintained diversity represents a repertoire of alternative options. This repertoire increases the possibility that altered conditions can be successfully met through pre-adaptations and further evolution, which Rammel and van den Bergh (2002:127) refer to as "evolutionary potential".

Despite the limitations of analogies from biological evolution (Fauvergue and Tentelier, 2008), we might argue that optimising is a short-term adaptive strategy, which is attuned to the narrow conditions of the moment. In the long run, inevitable alterations in the external and internal conditions of the farm demand new innovations and could transform former adaptive traits into maladaptive historical burdens (Walker et al., 2006). There is thus a need to monitor ecosystem conditions and dynamics embedded in social institutions. Often, farmers have a deep understanding of the dynamics through living, observing and using the systems in a variety of contexts. Monitoring change is key to increasing the ability to respond to change and shape management practices.

One way to approach diversity is at the whole-farm level. Here activities of the members of the farm household can be diversified, which includes both on- and off-farm activities. But this strategy is not yet well understood. As Penrose (1997:35) points out: "of all of the outstanding characteristics of business firms perhaps the most inadequately treated in economic analysis is the diversification of their activities, sometimes called 'spreading of production' or 'integration', which seems to accompany their growth". The role of diversification in the process of growth reinforces the view that a farm is essentially a pool of resources that can be used and combined in different ways, depending on the farmer's preferences and priorities. More research is needed to understand diversification and pluriactivity, the coordination and interaction between the activities and the involved work organisation problems (see e.g. Madelrieux and Dedieu, 2008). We also need to precise to what extent the combination of resources is possible and gives rooms for manoeuvre: the farmers may have subjective reasons to be attached to some specific activities which give to him/her more than money, such as coping well with animals (Fiorelli et al., 2007)

Another way to approach diversity is at the technical system level. Here the focus is on the role that diversified resources, production processes and type of products play to secure the system and to allow its evolution. For instance, a study has shown that creating and maintaining a diversity of land resources can play a key role in the management of a dairy farm to reduce the sensitivity of milk production to climatic variations (Andrieu et al., 2008). Similarly, a system that allows for a diversity of

[1] Coevolutionary processes refer to interdependent dynamics and to the complex interactions between economic agents, society and environmental systems (see Norgaard, 1994). These make any strict distinction between endogenous (within the farm) and exogenous (environment) changes arbitrary. Lack of sensitivity for coevolutionary processes may for example lead structural adjustment policies to have undesirable social and ecological side-effects (Tisdell, 1999). Coevolution thus plays an important role in the context of adaptive farming systems, however we do not have the space to discuss it in detail in this paper.

reproductive trajectories (e.g. accepts infertile phases for the females) are far more resistant on the long-term, at the herd level, to periodic forage shortages (Tichit et al., 2004).

In a more general way, to navigate long-term social-ecological dynamics, diversification and redundancy seem to be more appropriate than simplification and specialisation. There seems to be a dynamic interplay between diversity and disturbance that is part of resilience and key to sustainable development (Folke et al., 2003). Reducing the impacts of change while at the same time taking advantage of the opportunities created by change seem to be intricately linked. Both functional diversity and response diversity increase the variety of possible alternative reorganisation pathways following disturbance and disruption (cf. Elmqvist et al., 2003; Walker et al., 2006). Functional diversity refers to the number of different functional groups: the more types of actors there are, the more functions can be performed. Response diversity (or 'functional redundancy') refers to the types of response to disturbance within a functional group. Since efforts to increase the short-term efficiency of farm production tend to focus on removing apparent redundancies, this also reduces the options of a farm to adapt to change and thus farm resilience (Walker et al., 2006). Recognising that diversity is more than an insurance against uncertainty and surprise, it implies that diversity should be actively nurtured to allow for reorganisation and renewal.

Diversity also buffers and protects the system from management failures that are based upon incomplete understanding of the system dynamics[2]. Mistakes and feedback systems allow farmers to learn and therefore actively adapt their farm management. Indeed, learning and adaptive management are key elements of farm resilience (Milestad and Darnhofer, 2003). Learning benefits from combining different types of knowledge, e.g. experiential and experimental knowledge (see also Scoones and Thompson, 1994), from expanding from knowledge of structure to knowledge of function, from understanding about the dynamics of complex systems, from understanding the complementarities of different knowledge systems and the significance of people's knowledge. Indeed local knowledge systems not only result from long time series of observations, they can also be based on a different conceptualization of the world compared to science-based farm management knowledge (Olsson and Folke, 2001). Above all researchers need to recognise that farmers live with change and uncertainty. They need to be able to learn from crises, to expect the unexpected, to take advantage of change and crisis and to turn it into an opportunity for development (Folke et al., 2003). It is thus important not to dilute, homogenise or diminish the diversity of experiential knowledge systems, but to nurture diversity (Folke et al., 2003).

Conclusion and outlook

Modern, conventional farm management recommendations often seems to create simplified, specialised farms with an impoverished diversity and a limited capacity to adapt to environmental and societal change. By trying to remove or ignore surprises, they also remove incentives for responding to environmental feedback (Sundkvist et al., 2005). They hinder the building of a social-ecological knowledge system and thereby impede learning. However, change seems ubiquitous and its pace is accelerating. Learning to live with change and uncertainty requires a fundamental shift in thinking, from assuming that the world is in a steady state and can be preserved as is by controlling change, to recognising that change is the rule rather than the exception. Farms thus need to be managed so as to live with and shape change, need to be managed for diversity and flexibility.

Including this evolutionary, dynamic perspective within the farming systems approach seems to be a promising way forward. It fits well with farming system's notion of incremental change, rather than quantum shifts in the systems. It also underlines the importance of empowering farmers and their families, to take a participatory approach, to include a wide range of disciplines and to focus on the interactions between the components of the system.

To better understand these dynamic aspects that characterise both society and ecology, requires a shift of research interests towards identifying management strategies that allow farms to recognise change, and to identify the opportunities that are offered by changes. Researchers need to understand the required level of diversity that balances the inevitable trade-offs between short-term survival and long-term resilience, i.e. between efficiency and adaptability. Researchers need to assess the various

[2] This includes panarchy, i.e. cross-scale dynamic interactions where individual levels have non-linear multi-stable properties which can be stabilised or destabilised through critical connections between levels. Panarchy turns hierarchies into dynamic structures and can help understand the interplay between change and persistence (see Holling et al., 2002).

sources of flexibility in the various farming systems and farm types, and they need to understand the strategies farmers implement to cope with surprises and to shape transition processes.

References

Adger, N., 2006. Vulnerability. *Global Environmental Change* 16(3): 268-281.

Andrieu N., F. Coléno, M. Duru, 2008. L'organisation du système fourrager source de flexibilité face aux variations climatiques. In: B. Dedieu, E. Chia, B. Leclerc, Ch. Moulin, M. Tichit (eds) *L'élevage en mouvement. Flexibilité et adaptation des exploitations d'herbivores*. Paris, Ed Quae, 97-112.

Astigaraga L., E. Chia, S. Ingrand, 2008. Production flexibility in extensive beef farming systems in the Limousin region. In this CD

Bellon, S., J.F. Mondain-Monval, D. Pillot, 1985. Recherche-Développement et Farming System Research: à la quête de l'opérationnalité. In *Actes du Colloque Syst. de Prod. Agric. caribéens et alternatives de Dév*. 9-11/5/85, Martinique. Univ. Antilles-Guyane, DAC, pp. 467-486.

Bellon, S., G. Guérin, F. Léger, 2004. Anticiper les aléas climatiques en programmant des sécurités. In: J.P. Duboeuf (Ed). *Evolutions of sheep and goat production systems: Future of extensive systems and changes in society*. Options méditerranéennes. Série A, n°61. Ciheam/ FAO/ ICZS/ Cirval, pp. 137-146.

Béranger, C., B. Vissac, 1994. An holistic approach to livestock farming systems: theoretical and methodological aspects. In: A. Gibon, J.C. Flamant (eds) *The study of livestock farming systems in a research and development framework*. EAAP Publ., 63: 5-17.

Boiffin, J., P. Huet, M. Sebillotte (eds.), 1978. *Exigences nouvelles pour l'agriculture: les systèmes de culture pourront-ils s'adapter?* Paris: Ed. INA-PG.

Bourgeois, A., T. Krychowski, 1981. L'adaptabilité des exploitations laitières: essai d'appréciation de certaines de ses composantes, à partir de douze cas du Maine-et-Loire. *Fourrages* 88: 3-38.

Brossier, J., E. Chia, E. Marschal, M. Petit, 1991 Gestion de l'exploitation agricole familiale et pratiques des agriculteurs: vers une nouvelle théorie de la gestion. *Revue Canadienne d'Economie Rurale*, 39: 119-135.

Chambers, R. 1991. Complexity, diversity and competence. Toward sustainable livelihood from farming systems in the 21st century. *Journal of the Asian Farming Systems Association* 1(1): 79-89.

Chia, E., 2008. La flexibilité relationnelle: rôle des réseaux, groupements et associations d'éleveurs. In: B. Dedieu, E. Chia, B. Leclerc, Ch. Moulin, M. Tichit (eds) *L'élevage en mouvement. Flexibilité et adaptation des exploitations d'herbivores*. Paris: Ed Quae, pp. 137–144.

Chia, E., M. Marchenay, 2008. Un regard des sciences de gestion sur la flexibilité: enjeux et perspectives. In: B. Dedieu, E. Chia, B. Leclerc, Ch. Moulin, M. Tichit (eds) *L'élevage en mouvement. Flexibilité et adaptation des exploitations d'herbivores*. Paris: Ed Quae, pp. 25-38.

Colin, J.P., E. Crawford, 2000. Economic perspectives in agricultural systems analysis. *Review of Agricultural Economics* 22(1): 192-216.

Collinson, M., 1980. Farming system research in the context of an agricultural research organisation. In: H. Ruthenberg (ed). *Farming systems in the tropics*, 3rd Ed. Oxford University Press, pp. 381-389.

Collinson, M. (ed.), 2000. *A history of farming systems research*. Wallingford: CABI Publishing.

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

Daily, G.C. (ed), 1997. *Nature's services: societal dependence on natural ecosystems.* Washington, D.C.: Island Press.

Daly, H.E., 1990. Towards some operational principles of sustainable development. *Ecological Economics* 2: 1-6.

Dedieu, B., E. Chia, B. Leclerc, Ch. Moulin and M. Tichit, 2008. Introduction générale. In: B. Dedieu, E. Chia, B. Leclerc, Ch. Moulin, M. Tichit (eds) *L'élevage en mouvement. Flexibilité et adaptation des exploitations d'herbivores*. Paris: Ed Quae, pp. 11-24.

Dent, J.B., G. Edwards-Jones, M.J. McGregor, 1995. Simulation of ecological, social and economic factors in agricultural systems. *Agricultural Systems* 49(4): 337-351.

Dubar, C., 1991. *La socialisation. Construction des identités sociales et professionnelles*. Paris: Armand Colin.

Elmqvist, T., C. Folke, M. Nyström, G. Peterson, J. Bengtsson, B. Walker, J. Norberg, 2003. Response diversity, ecosystem change and resilience. *Frontiers in Ecology and Environment* 1(9): 488-494.

Fabricius, C., C. Folke, G. Cundill, and L. Schultz, 2007. Powerless spectators, coping actors, and adaptive co-managers: a synthesis of the role of communities in ecosystem management. *Ecology and Society* 12(1): 29. [online] URL: http://www.ecologyandsociety.org/vol12/iss1/art29/

Fauvergue X., C. Tentelier, 2008. Flexibilité adaptative: biologie évolutive, théorie des jeux et psychologie In: B. Dedieu, E. Chia, B. Leclerc, Ch. Moulin, M. Tichit (eds) *L'élevage en mouvement. Flexibilité et adaptation des exploitations d'herbivores*. Paris: Ed Quae, 39 - 58

Fiorelli C., J. Porcher. B. Dedieu, 2007. Pourquoi faire de l'élevage quand on a un autre travail? *Renc. Rech. Rum*., 14: 389–392.

Folke, C. 2006. Resilience: the emergence of a perspective for social-ecological systems analysis. *Global Environmental Change* 16(3): 253-267.

Folke, C., J. Colding and F. Berkes, 2003. Synthesis: Building resilience and adaptive capacity in social-ecological systems. In: F. Berkes, J. Colding and C. Folke (eds). *Navitaging social-ecological systems. Building resilience for complexity and change*. Cambridge: Cambridge University Press, pp. 352-387.

Fresco L.O., 1990. Problèmes dans la recherche sur les systèmes de production agricole. Séminaire international de vulgarisation rurale. Atelier II. Systèmes de connaissance dans le développement agricole, IAC, pp. 57-68.

Funtowicz, S., J. Ravetz, 1993. Science for the post-normal age. *Futures* 25(7): 739-755.

Gafsi, M., J. Brossier, 1997. Farm management and protection of natural resources: Analysis of adaptation process and the dependence relationships. *Agricultural Systems* 55(1): 71-97

Giampietro, M., 1997. Linking technology, natural resources, and the socio-economic structure of human society: A theoretical model. *Advances in Human Ecology* 6: 75-130.

Gibon A, A.R. Sibbald, J.C. Flamant, P. Lhoste, R. Revilla, R. Rubino, J.T. Sorensen, 1999. Livestock farming systems research in Europe and its potential contribution for managing towards sustainability in livestock farming. *Livestock Production Science* 61(2-3): 121-137.

Hart R.D., A.M. Pinchinat, 1982. Integrative agricultural systems research. In: J. Servant, A. Pinchinat (eds). Caribbean Seminar on Farming Systems Research Methodology. Pointe-à-Pitre, Guadeloupe, FWI, May 4-8, 1980. INRA-IICA Ed., pp. 555-565.

Holling, C.S., 2001. Understanding the Complexity of Economic, Ecological, and Social Systems. *Ecosystems* 4: 390-405.

Holling, C.S., G. Meffe, 1996. Command and control and the pathology of natural resource management. *Conservation Biology*, 10(2): 328-337.

Holling, C.S., L. H. Gunderson, D. Ludwig, 2002. In quest of a theory of adaptive change. In: L.H. Gunderson, C.S. Holling (Eds.). *Panarchy: Understanding Transformations in Human and Natural Systems*. Washington D.C, Island Press, pp-pp. 3-22.

Jay, M., 2007. The political economy of a productivist agriculture: New Zealand dairy discourses. *Food Policy* 32(2): 266-279.

Jiggins, J., N. Röling, 1994. Systems thinking and participatory research and extension skills: Can these be taught in the classroom? Occasional Papers in Rural Extension, No. 10. Dept. of Rural Extension Studies, University of Guelph.

Knight, F., 1921. Risk, uncertainty and profit. New York: Harper.

Korten, D., 1980. Community organisation and rural development: A learning process approach. *Public Administration Review*, 40(5): 480-510.

Lauri P.E., E. Costes, J.L. Regnard, L. Brun, S. Simon, P. Monney, H. Sinoquet, 2008. Does knowledge on fruit tree architecture and its implications for orchard management improve horticultural sustainability? An overview of recent advances in the apple production. In *First Symposium on Horticulture in Europe (SHE)*, 17-20th Feb. 2008, Vienna, Austria, ISHS. Book of Abstracts: 122-123.

Lee, K.N., 1999. Appraising adaptive management. *Conservation Ecology* 3(2): 3 [online] URL: http://www.ecologyandsociety.org/vol3/iss2/art3/

Lemery, B., S. Ingrand, B. Dedieu, B. Degrange, 2005. Agir en situation d'incertitude: le cas des éleveurs bovins allaitants. *Economie Rurale* 288: 57-69.

Lev, L., D. Campbell, 1987. The temporal dimension in Farming Systems Research: The importance of maintaining flexibility under conditions of uncertainty. *Journal of Rural Studies* 3(2): 123-132.

Levrouw F., H. Morales, P. Arbeletche, I. Malaquin, J.F. Tourrand, B. Dedieu, 2007. Les élevages uruguayens, le long terme et les incertitudes : une diversité de stratégies pour se maintenir dans la production. *Renc. Rech. Rum.*, 14, 413 – 416.

Long, N., 1984. Creating space for change. A perspective on the sociology of development. *Sociologia Ruralis* 24(3/4): 168-184.

Lopez-Ridaura, S., H. van Keulen, M. van Ittersum, P.A. Leffelaar, 2005. Multiscale methodological framework to derive criteria and indicators for sustainability evaluation of peasant natural resource management systems. *Environment, Development and Sustainability* 7(1): 51-69.

Madelrieux, S., B. Dedieu, 2008. Qualification and assessment of work organisation in livestock farms. *Animal* 2(3): 435-447.

Martel G., B. Dedieu, J.Y. Dourmad, 2007. Do labour productivity and preferences about work load distribution affect reproduction management and performance in pig farms? *Livestock Science*, in press.

Moulin C.H., Ingrand S., Lasseur J., Madelrieux S., Napoléone M., Pluvinage J.' Thénard V. 2008 Comprendre et analyser les changements d'organisation et de conduite de l'élevage dans un ensemble d'exploitations : propositions méthodologiques In: B. Dedieu, E. Chia, B. Leclerc, Ch. Moulin, M. Tichit (eds) *L'élevage en mouvement. Flexibilité et adaptation des exploitations d'herbivores*. Paris: Ed Quae, 183 – 198.

Milestad, R., I. Darnhofer, 2003. Building farm resilience: The prospects and challenges of organic farming. *Journal of Sustainable Agriculture* 22(3): 81-97.

Norgaard, R.B., 1994. *Development Betrayed. End of progress and a coevolutionary revisioning of the future*. London: Routledge.

Norman, D.W., 2002. *The farming systems approach: A historical perspective*. Presentation held at the 17th Symposium of the International Farming Systems Association in Lake Buena Vista, Florida, USA, 17-20 Nov. 2002.

Norman, D.W., P.J. Malton, 2000. Agricultural systems research and technical change. In: J-P. Colin, E.W. Crawford (eds) Research on Agricultural Systems. Accomplishments, Perspectives and Issues. Nova Science Publishers, Inc, pp. 17-47.

Olsson, P., C. Folke, 2001. Local ecological knowledge and institutional dynamics for ecosystem management: A study of Lake Racken Watershed, Sweden. *Ecosystems* 4(2):85-104.

Osty, P.L., 1978. L'exploitation agricole vue comme un système. Bulletin Technique d'Information. Paris: Ministère de l'Agriculture.

Penrose, E., 1997. The theory of the growth of the firm. In: N. Foss (ed.) *Resources, firms and strategies. A reader in the resource-based perspective.* Oxford: Oxford University Press, pp. 27-39.

Petit, M., 1978. The farm household complex as an adaptive system. Proceedings of the 4· Forschungscolloquium des Lehrstuhls für Wirtschaftslehre des Landbaus. Arbeitsbericht 78/1, Institut für Landwirtschaftliche Betriebs- und Arbeitslehre. University of Kiel, pp. 57-70.

Petit M., 1981. Théorie de la décision et comportement adaptatif des agriculteurs. Formation des agriculteurs et apprentissage de la décision, Dijon, ENSSAA, INPSA, INRA, INRAP.

Puilliez L., O. Martin, M. Tichit, D. Sauvant, 2008. Simple representation of physiological regulations in a model of lmactating female: Application to the dairy goat. *Animal* 2(2): 235-246.

Rammel, C., 2003 Sustainable development and innovations: Lessons from the Red Queen. *International Journal of Sustainable Development* 6(4): 395-416.

Rammel, C., M. Staudinger, 2002, Evolution, variability and sustainable development. *International Journal of Sustainable Development and World Ecology*, 9(4): 301-315.

Rammel, C., J. van den Bergh, 2003. Evolutionary policies for sustainable development: adaptive flexibility and risk minimising. *Ecological Economics*, 47(2-3): 121-133.

Rathe, K., U. Witt, 2001. The nature of the firm – Static versus developmental interpretations. *Journal of Management and Governance* 5(3-4): 331-351.

Reix, R., 1979. *La flexibilité de l'entreprise*. Paris: Editions Cujas.

Renn, O., 2008. Concepts of risk: An interdisciplinary review. *Gaia* 17(1): 50-66.

Rigby, D., D. Howlett, P. Woodhouse, 2000. Sustainability Indicators for Natural Resource Management and Policy. A review of indicators of agricultural and rural livelihood sustainability. Working Paper 1. IDPM, University of Manchester, Manchester.

Roggero P.P., S. Bellon, M. Rosales, 1996. Sustainable feeding systems based on the use of local resources. *Ann Zootech* 45, Suppl., 105-118.

Sauvant, D., F. Phocas, 1992. A mechanistic model to simulate the long term regulation of the dairy cow nutrition. *Journal of Dairy Science*, 75 (suppl 1), 168.

Scoones, I., J. Thompson (eds.), 1994. *Beyond farmer first: rural people's knowledge, agricultural research and extension practice.* London: Intermediate Technology Publications.

Sebillotte, M., 1990. Some concepts for analysing farming and cropping systems and their different effects. In: Scaife A. (ed.). Proceedings of the 1st ESA Congress, Paris 5-7 Dec. 1990. ESA. Colmar, session 5, pp. 1-16.

Smit, B., J. Wandel, 2006. Adaptation, adaptive capacity and vulnerability. *Global Environmental Change* 16(3): 282-292.

Sundkvist, Å., R. Milestad, A.M. Jansson, 2005. On the importance of tightening feedback loops for sustainable development of food systems. *Food Policy* 30(2): 224-239.

Tarondeau, J-C., 1999. Approches et formes de flexibilité, *Revue Française de Gestion*, 123: 66-71.

Tichit M., S. Ingrand, C.H. Moulin, S. Cournut, J. Lasseur, B. Dedieu, 2004. Analyser la diversité des trajectoires productives des femelles reproductrices: intérêts pour modéliser le fonctionnement du troupeau en élevage allaitant. *INRA Prod. Anim*. 17(2): 123–132.

Tisdell, C., 1999. Coevolution, agricultural practices and sustainability: Some major social and ecological issues. Economics, Ecology and the Environment Working Paper No. 34, University of Queensland.

Walker, B., D. Salt, 2006. *Resilience thinking. Sustaining ecosystems and people in a changing world*. Washington DC: Island Press.

Walker, B., L. Gunderson, A. Kinzig, C. Folke, S. Carpenter, L. Schultz, 2006. A handful of heuristics and some propositions for understanding resilience in social-ecological systems. *Ecology and Society* 11(1): 13 [online] http://www.ecologyandsociety.org/vol11/iss1/art13/

Walker, B., C.S. Holling, S. Carpenter, A. Kinzig, 2004. Resilience, adaptability and transformability in social-ecological systems. *Ecology and Society* 9(2): 5. [online] http://www.ecologyandsociety.org/vol9/iss2/art5/

Westley, F. 2002. The devil in the dynamics: Adaptive management on the front lines. In: L.H. Gunderson and C.S. Holling (eds). *Panarchy. Understanding Transformations in Human and Natural Systems*. Washington D.C.: Island Press, pp. 333-360.