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Securing Sustainable Livestock Production Systems in an Uncertain Economic Climate: Nurturing Flexibility and Resilience

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<http://dx.doi.org/10.5772/65087>

Abstract

Resilience is one of the three core properties of social-ecological systems, mixing adaptability and transformability. Flexibility can be defined in terms of diversity of procedures and the speed at which they can be mobilized by one organization. The analyses performed are presented in terms of levers that farmers can deploy to protect their management systems against market uncertainty. These levers differ depending on farmer standpoints, objectives, lessons learned, the collective organizations they work with, the standards and specifications they work to, etc. It is equally important to identify the interplays between overarching and underlying scale levels for the system studied and to hone in on the dynamics at work during periods of transition. Adaptive capacities of farm systems are closely linked to how the farmer perceives the situations to manage, according to his aims, to his behaviour face to risk and to his idea of what is his job. We propose to use different words to describe the properties of farming systems to cope with changes, according to the level within the system: “adaptive capacity” or “plasticity” for the animal level, “resilience” for the biotechnical level and “flexibility” for the whole system, including the manager. We think there is a real challenge working at each level on transition periods and processes, as farming systems will have more and more to adapt face to unpredictable events.

Keywords: resilience, flexibility, adaptive capacities, uncertainty, crops systems, animal system

1. Introduction

Farm businesses, just like any other business enterprise, develop response strategies in order to cope with the many demands imposed on them and the uncertainties they face. The challenge for farmers lies in securing sustainability for their business, in a context where farming is subject to wide-reaching change and where farms are increasingly exposed to agronomic trends and climatic risks that the agricultural productivity model generally seeks to overcome by controlling processes and disengaging the effects of environmental disturbance.

Incorporating the precepts of sustainable development in order to build and assess new technical agricultural systems hinges on breaking away from the rationales underpinning these systems and moving towards more holistic objectives encompassing far more than the simple production output function [1]. There are two key drivers to this breakaway: (i) reinventing how researchers interact with the other actors involved in the process of developing new systems and their multiple outcomes [2, 3], and (ii) producing tools capable of quickly rendering a priori system assessments [4, 5] as a first step towards subsequently deploying the systems in compliance with complex multicriteria specifications [6]. This means that agronomists face the challenge of translating the impacts of integrating these dimensions into terms that farmers can understand and use to reshape their farm systems, taking into account new social and environmental factors [7, 8].

This reshaping redefines the farm business as a complex system that needs to be analysed not just in terms of its type but also the rationales driving how it operates [9, 10]. A few years ago, farming system researchers started using the notion of flexibility to define the capacity of a business to weather and adapt to economic uncertainty. The concept of resilience, as pioneered by Holling [11], has also been analysed in this setting, particularly when applied in more recent social-ecological systems [12]. “Flexibility” has been researched extensively in management science and industrial economics, whereas “resilience” has mainly been used in ecology (but also in social psychology; [13]). Our study will draw on illustrative examples to highlight how the notion of flexibility can prove useful for designing and assessing innovative technical systems.

2. Flexibility in management sciences

Industrial economics and management sciences understand the concept of flexibility [14, 15] as the capacity of a business or organization to re-adapt its structure and projects in response to environmental challenges (strategic flexibility) and to re-adapt its skillsbase, reorganize its workflows (workflow flexibility) and/or adjust its production methods as a response to unforeseen variations in *inputs* from outside (operational flexibility). The concept therefore appears relevant when analysing farmers’ response strategies in the current climate governing agricultural production (characterized by regulatory developments, volatile agricultural prices, climatic variability, etc.). Tarondeau [15] (*ibid.*) stratified different sources of flexibility:

product flexibility (product range), process flexibility and inputs flexibility. The basic idea is that the capacity to cope with unknowns and carry the business forward is dependent on several factors, both material and non-material: the configurations of their technical production systems, their structures, their projects and their objectives [16]. Reix et al. [17] suggest that the drive for flexibility can be seen as the drive to maintain consistency in how the business is managed in response to a changing environment. Flexibility, as a system property, is not “given”: it is built, shaped and “nurtured,” and it has a cost [18]. Flexibility can be considered a competitive advantage insofar as it enables performance levels to be sustained in situations of uncertainty [19].

Different commentators use different terms as synonymous with or acceptances of the concept of flexibility, but there is a body of ideas that remain recurrent. Flexibility refers to organizational capacity [14, 15, 20–23, 28]. This means that the systems described are always management-led and that the organizational procedures governing their management constitute a source of flexibility for the system. In each case, flexibility is defined as an attribute that is inherent to humans, dependent on how they perceive situations to be addressed, their objectives, their level of risk aversion and the perception they hold of their business. Flexibility is a property that has to associate both change and stability, forming a paradox between permanence (continuity, mainstay) and change [16]. The authors see management flexibility as the result of constructive tension between what needs to be held onto and what needs changing. This same idea has been explored through analyses of how livestock farming systems work, with the notion of invariants [24]. The invariant acts as a backbone, a basis, a bottom line and the frame of reference for handling change (not everything has to change at the same time, otherwise the system risks getting disorganized or even collapsing into chaos). Flexibility is intrinsically dynamic. It can only be meaningfully studied in the long term, at multiperiod scale. Integrating flexibility into the analysis of a system or an organization presupposes that the decision-maker is looking to achieve short-term objectives while also securing a range of opportunities for the longer term [25]. In other words, a given decision may appear non-rational (or non-optimal) when analysed at timepoint t , but become entirely rational once events liable to arise at some point in the future are factored in (uncertainty preparedness). Indeed, the speed of response to these events is one of the key components of flexibility [15].

Furthermore, in every scenario, the concept of flexibility is also linked to the notion of interaction between the system/organization and its environment. It can therefore be measured and thus assessed, by quantifying the degree of control (according to the dual flexibility concept proposed by De Leeuw and Volberda [20]: controlled systems vs. independent systems) over environmental inputs (**Figure 1**).

The two paradigms coexist within a single system (controlling-controlled) and must therefore be analysed in tandem. However, the extent to which one paradigm dominates the other reveals specific system behaviours.

The organization as an environment-controlled system: in this configuration, the organization “copes with” environmental factors [16]. Flexibility hinges on accommodative processes [26], which hallmarks defensive behaviour in response to external perturbation [27]. The target

objective for the system will be adaptation, stability, resilience to environmental forces and robustness. Systems unable to achieve this objective would be defined as vulnerable.

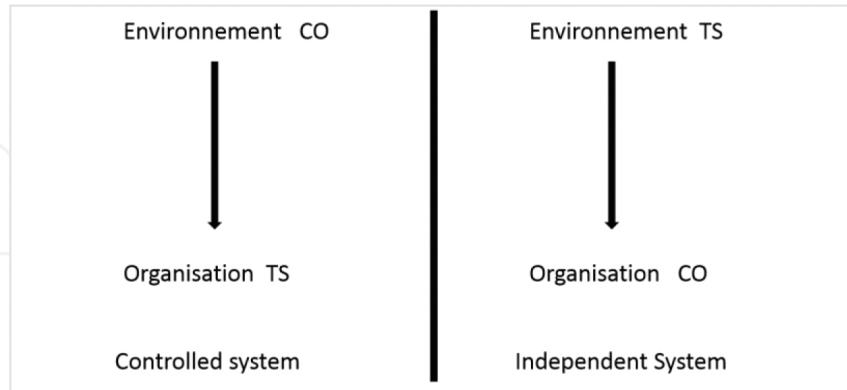


Figure 1. Organization of an environment-controlled system (left) and an environment-independent system (right) (concepts taken from Ref. [20]). TS = target system; CO = controlling organ. The arrows illustrate the direction of control exerted by the CO over the TS.

The organization as an environment-independent system: in this configuration, the organization seeks to subordinate all changes in its environment to the task of maintaining its objectives and its identity. Interactions with the environment are specified internally, and on a certain level, the environment is integrated into the organization. The processes deployed in the search for flexibility are assimilative processes, which hallmarks a pro-active pattern of behaviour that will respond to each perturbation by generating new behaviours, thereby expanding the range of adaptation options possible. These configurations define self-learning organizations with self-directed learning capacities.

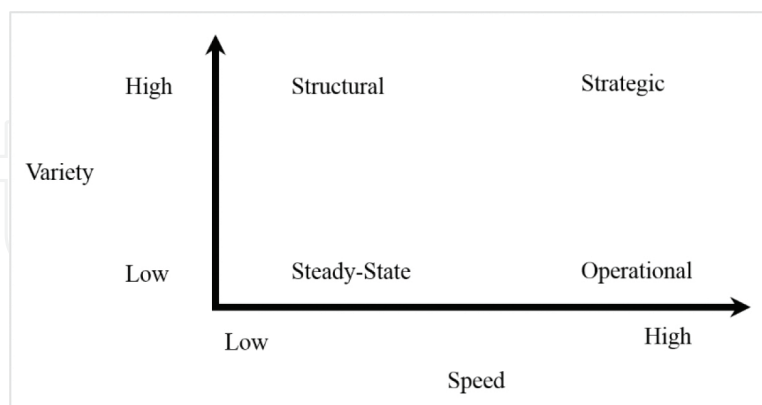


Figure 2. Different types of flexibility according to the number of planned procedures (vertical axis) and the speed at which they can be implemented (horizontal axis); adapted from Ref. [28].

De Leeuw and Volberda [20] encapsulated these two configurations by defining flexibility in terms of diversity of procedures and the speed at which they can be mobilized: (i) to increase the organization's environmental control capacities and (ii) to decrease the organization's

environmental vulnerability. The authors define different types of flexibility according to the number of planned procedures and the speed at which they can be implemented (**Figure 2**).

3. Social-ecological resilience: a kind of flexibility?

The concept of resilience is borrowed from material physics as well as ecology as a means of describing the transformation and/or adaptive capacity of a material or ecosystem in response to stressors. In ecology, Holling [11] described resilience as the capacity of an ecological system or species to absorb challenges and then recover its initial configuration. The concept was then broadened to encompass shifts, learning and human-nature interactions [29]. Resilience was then extended to describe the mechanics of “anthropized” systems [30]. More recently, the concept of resilience has been applied to social-ecological systems, where humans are a governing actor [2, 12, 31–33]. The system is thus considered as a “learner,” with a shift in the underlying idea from a return to the initial state following the perturbation towards a capacity to reconfigure itself while maintaining the core objectives and projects, where stakeholders can continue to plan for the future [2]. According to Ref. [34], there are three potential strategies capable of increasing the resilience of actively governed systems: increasing the system's buffer capacity (room for manoeuvre), scale-based governance (spatial and temporal scales) and creating opportunity for innovation (sources of change to system properties, learning capacity). These systems therefore have the ability to respond to perturbation by shifting into different stability domains rather than a single, “initial” steady state.

Walker et al. [35] outlined four main features of system resilience connected to the notions of steady state and initial state: (i) the amount of change that the system can tolerate without collapsing into an essentially different state, this idea works on the assumption that there is a threshold beyond which the system can no longer recover its initial configuration; (ii) the capacity to resist change, which is connected to properties like rigidity and robustness; (iii) vulnerability (precariousness), which is how close the system state is to the threshold cited under point 1; (iv) panarchy, which describes a system integrating a great many elements undergoing cross-scale interactions, and that the level of resilience depends on the different states and dynamics interplaying at the scales above and below.

Resilience can also be described in terms of successive system states over time. Holling [36] and Walker et al. [2] consider that ecological systems follow adaptive cycles comprising four successive phases. They posit that actively governed systems reproduce cyclic patterns of behaviour aligned to these four phases: a phase of accelerated growth (annotated r), followed by a longer phase of steady accumulation towards stability, associated with a progressive decline in resilience (K), then a sharp structural collapse (Ω) before another short phase of rebuilding and reorganization (α). Depending on the current phase of the system, a given disturbance (which can in fact be seen positively as the introduction of an accommodative stance) will not have the same effect.

4. Leverages to enhance flexibility in livestock systems

4.1. Different levers according to scale

Aaker and Mascarenhas [37] focusing on the means to enhance organizational flexibility outlined the following four levers centred on products, resources and management: (i) diversification of processes, business activities and products, running from broadening the range but also including activity in different marketplaces and extended use of different process technologies. In Ref. [38], the authors assert their notion of “relational flexibility” to account for the sources of adaptive capacity employed by livestock farmers through their marketing networks and the circuits they build or exploit to sell livestock; (ii) increasing interdependence between production units; (iii) developing a base of potentially useful resources that are deployed not continually but on a case-by-case basis “should the need arise”: functional redundancies, latent competencies, room for manoeuvre; (iv) minimizing workflow specialization, steering away from situations where tasks are accomplished by staff who have competencies deemed “necessary and sufficient” to complete the task. For example, Madelrieux et al. [39] clearly illustrate the flexibility achievable by a more collective workplace organization and workload breakdown in livestock farming systems.

Using two examples of farm systems (crop and livestock), we illustrate how these flexibility leverages can be deployed to minimize vulnerability to changes in the systems’ environments. These two examples were chosen to demonstrate how the internal organization of the system (the sequencing of the system’s structural components) and the system manager’s perception of the environment act as complementary leverage for lending flexibility to farm production systems.

4.2. Animal contribution (plasticity) to system flexibility in an organic dairy system

The Mirecourt (INRA) research team prototypes sustainable dairy systems focused on agro-environmental sustainability. One system, tested since 2004, is a low-input grass-only system, in accordance with the specifications governing organic farming and based on the hypothesis that pasture-based systems are more sustainable [40].

This system is designed to introduce rulesets and animal and farmland management modes for achieving the objectives assigned to the system at the outset. In other words, the system aims to define how to achieve a result targeted at the outset without having to run through the conventional pattern of conducting experimental trials to measure results from different management condition sets established at the outset. Systems employing this strategy are designed to be sustainable in agro-environmental terms. More operationally, we posit that in order to cope with these objectives, the systems have to be self-sufficient (no importation of fertilizers or pesticides) and able to cope with unanticipated events, especially climatic events, since self-sufficiency can render systems more sensitive to natural variations in farmland properties.

The herd breed is split equally between two breeds (Holstein and Montbeliarde) in order to test the capacities of each breed to enable the system to achieve the objectives set. Maximizing

grazed grass in the cow diet led to grouped calvings in late winter (February to April) in order to match the animals' energy requirements with grass availability. Under this management policy, cows produced 5132 kg milk/cow/year on average in 2005 and 2006: Holstein cows milked on average 400 kg milk/cow/year higher than Montbéliarde cows (respectively 5347 and 4947 kg milk/cow/year). However, at the end of the breeding period, 65% of dairy cows were pregnant in 2005 but only 27% at the corresponding timepoint in 2006. These very poor ratios affected herd sustainability, even though performance levels for replacement heifers were better (**Table 1**).

Year	2005			2006		
	<i>Herd</i>	<i>Hn</i>	<i>Mo</i>	<i>Herd</i>	<i>Hn</i>	<i>Mo</i>
Cows						
Success AI1 and AI2 (%) ¹	54	38	75	23	8	33
Fertility (%) ²	65	52	81	27	17	33
Heifers						
Success AI1 and AI2 (%)	79	80	78	71	75	67
Fertility (%)	86	80	89	88	75	100

Hn: Holstein; Mo: Montbeliarde; AI: artificial insemination.

¹Percentage of pregnant cows served once or twice.

²Percentage of animals calving after being served during the breeding period.

Table 1. Reproductive performances of dairy cows in 2005 and 2006, according to breed.

An analysis of individual animal management within the cow herd highlighted different groups. Each group corresponds to a specific calving date, which, in relation to turnout date, determines the feed diet at the beginning of lactation: a switch from winter feed to pasture grass.

The milk production of dairy cows calved after turnout increased very quickly (2–4 weeks) to maximum daily production, generating high energy requirements, which is detrimental to reproduction. The milk production of dairy cows calving at least one month before turnout showed a slower increase to maximum daily production (taking 8–12 weeks), with a smoother effect on energy balance and reproduction. Within these two configurations, Montbeliarde cows gave smoother lactation curves than Holstein cows (**Figure 3**). They were able to limit milk production, even when stimulated by turnout to grass, and thus gave better reproduction performances than Holstein cows.

In the grass-based systems, Montbeliarde cows offer more plasticity than Holstein cows. Secondly, shifting the calving period (January to March instead of February to April) should maximize the number of calvings before turnout to grass, thus lending the system more flexibility by enhancing reproductive performance.

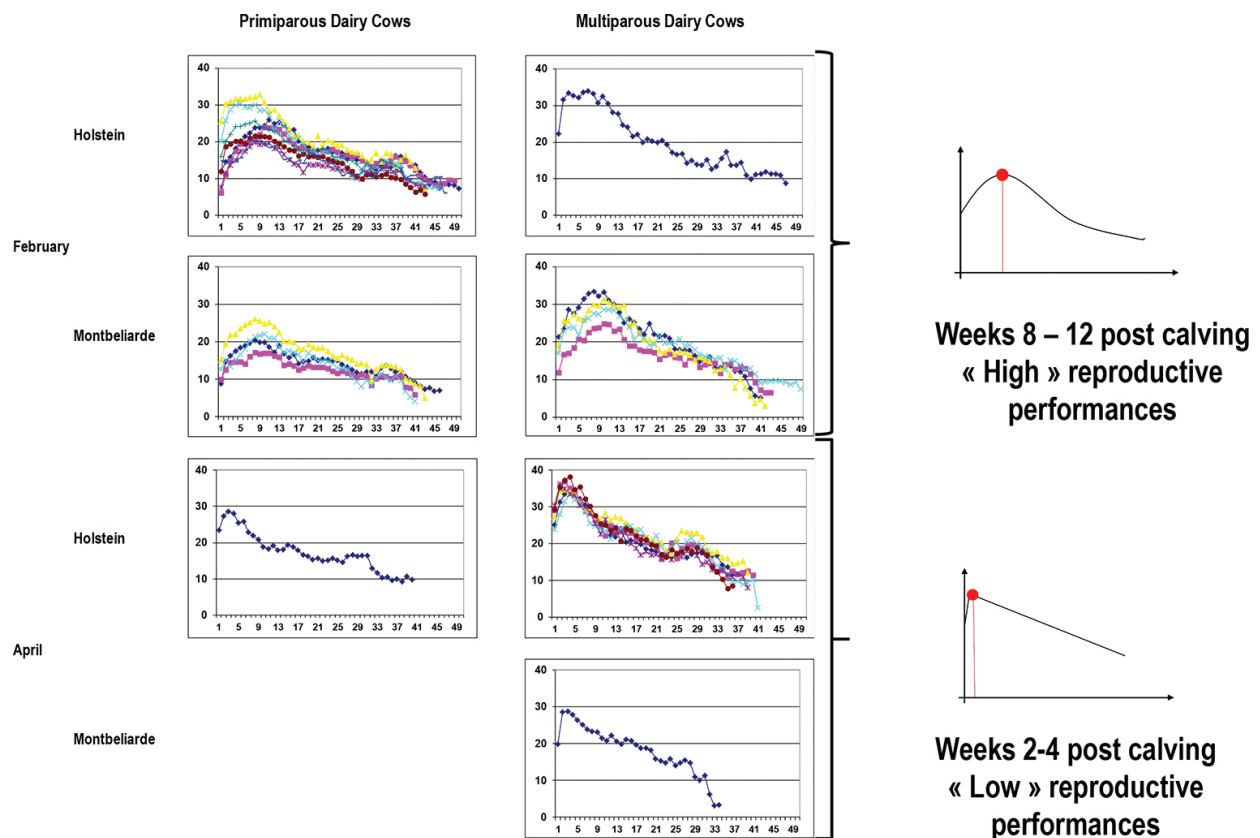


Figure 3. Individual lactation curves (milk yield in kg/cow/day throughout time after calving, in weeks) of Montbeliarde (Mo) and Holstein (Ho) dairy cows in 2005, according to the parity and to the calving period (February = at least 1 month before turnout vs. April = after turnout). On the right side, the average shape of curves for each period.

4.3. The collective workflows lever: flexibility in response to market uncertainty

The flexibility of suckler cattle farms is induced by commercial circuits: one of the features of suckler cattle farms is that they offer the possibility of selling livestock, and particularly females, at virtually any age. There are potentially over 15 different categories, with some breeders selling a minimal number of animal categories ($n=3$: male calves, female calves and cows), whereas other systems offer a broader range comprising four or more different categories. Some systems always produce the same types of animal, whereas others gear themselves with options to change in response to climate events or market openings. There is also a heavy and practically range-independent variability in the number of buyers for the animals produced (**Figure 4**): a 2005 survey sampling livestock farmers ranged from one buyer for all animals up to seven different partners. Over and above buyer numbers, buyer status is also a critical criterion for livestock breeders. We have identified two different sets of strategic choices:

- Cooperatives vs. private buyers: some livestock farmers are convinced that cooperatives rob them of their freedom to market their products and thus refuse to help finance the running costs (premiums), in contrast to other farmers who strongly believe the cooperative represents their best interests, offering them a voice and a channel through which they can

take action if problems arise. Finally, there is another category of livestock farmers who attach little importance to buyer status and who choose to sell their animals based on the prices they can get and how well they know and trust the buyer;

- Single buyer vs. several buyers: for farmers who work with a single buyer, the driving factor is the relationship of trust: the buyer understands how the farmer works and knows what animals are produced: negotiations are relatively straightforward, and sometimes a phone call is all that is needed. While the cattle farmer does need to make efforts to protect this special relationship (trust-system payments, sales spread across the year, etc.), in return they can expect the buyer to step in and make priority purchases when business is bad (security factor). In contrast, other farmers see the option of juggling between buyers as a way to take advantage of competition. If the market goes through a crisis, the farmer hopes to weather the storm by having a number of available buyers in order to sell their total livestock.

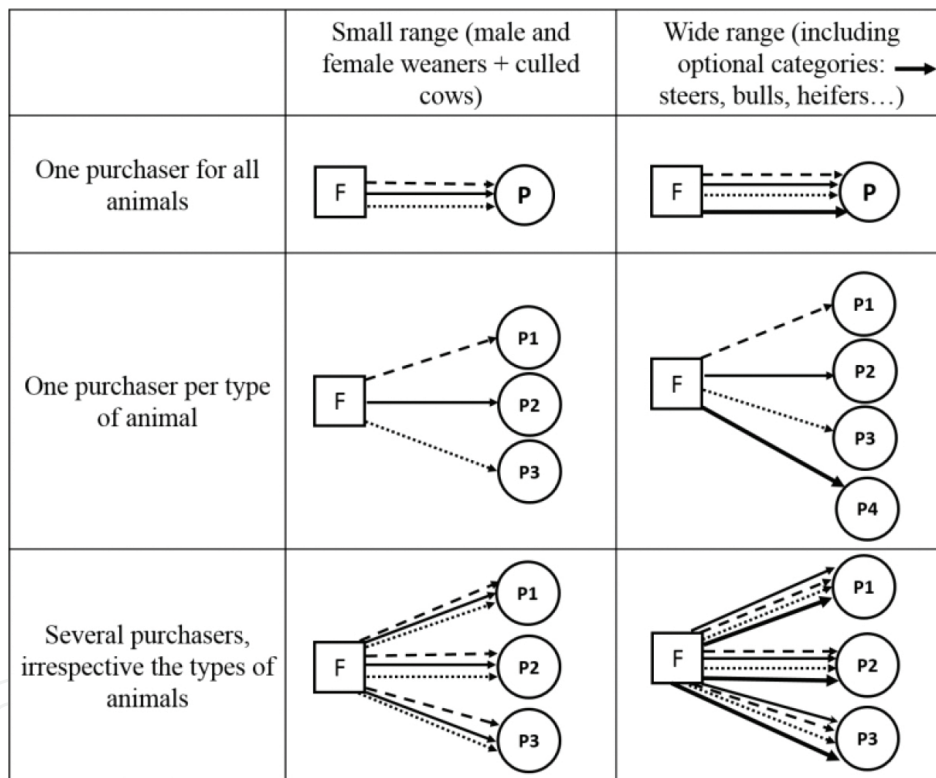


Figure 4. Different farmer (F) strategies for animal sales in livestock farming systems, combining range and number of purchasers (P); (one arrow corresponds to one specific category of animals sold, i.e. culled cows, weaned calves, heifers, bulls and steers).

The components of biophysical systems (plants, animals and soils; **Figure 5**) confer a relatively greater level of system-wide flexibility through their own, intrinsic properties: (i) delayed differentiation process: unicity, particularly for females from suckler cattle breeds, regardless of their end purpose and their age at sale [41]; (ii) plasticity, breed diversity and ability to adapt to different management strategies [42, 43]. Gaillard et al. [44] showed how Simmental breed diversity offered dairy farmers options to take up a more or less marked position on the

intensified fodder system gradient, ranging from extensive 100% grassland systems to intensive corn silage-based systems.

Depending on the flexibility leverage deployed by the farmer [7], both the system components (structural dimensions) and their interplays (functional dimensions) will take on a certain measure of specificity. Furthermore, this distinction picks up on the distinction made by Alcaras and Lacroux [16] between the stability of an organization's structure and the stability of an organization's target objectives: (i) the “size” lever: reproductive capacities, useful lifespan and carcass yield, for animals that farmers can no longer select to work with once they opt to increase the size of their holding through internal growth (zero buy-in); (ii) the “responsiveness” lever (short-range opportunity-taking): versatility, ability to handle change (feed type and volume), malleability, breed mix, capacities for out-of-season production; (iii) the “collective workflows/technicity” lever: quantitative performance, standardized high-tech information system, records; (iv) the “room for manoeuvre” lever: versatility, simplicity, hardiness.

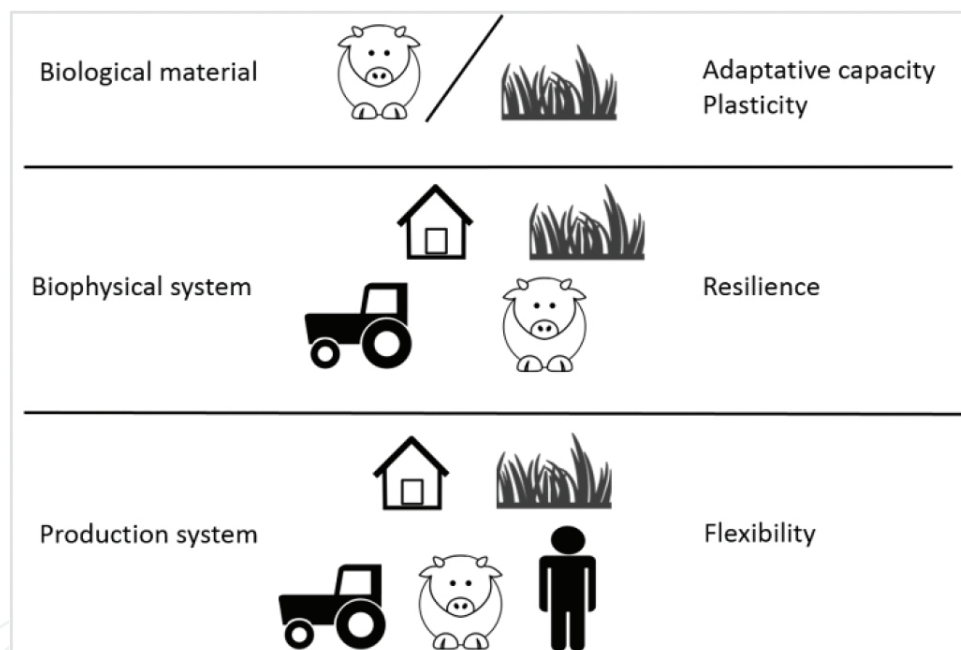


Figure 5. Descriptors assigned to adaptive capacities according to level of organization in the functional analysis of production systems.

5. Discussion and conclusion

The foundations of resilience analysis have progressively shifted towards the foundations of flexibility analysis. Our assertion is based on qualifying the set of properties that will enable a system to secure sustainability by restricting the use of the two terms to different levels of organization (Figure 5): “flexibility” to cover the level overarching the entire production

system and “resilience” to cover the underlying level of the biophysical (or operant learning) system. The terms used at the next level down, comprising the organic system entities such as plants and animals, would be “plasticity” and “adaptive capacity” as employed in Ref. [42]. The three examples of production systems highlighted earlier share a common denominator in that they are all “extensive” systems, that is, where productivity per surface unit of land is not maximized compared to intensive systems. A clear pattern emerged, wherein the adaptive capacities of these systems are perceived differently under the two scenarios. The design and development of intensive systems (high production per surface unit of land) consisted then, as now, in targeting measures capable of absorbing the negative effects of increasing performance. This means that for the animals, the primary property needed is “robustness,” that is, the ability to produce a lot and regularly, regardless of the environmental disturbances.

The levers that farmers can deploy to protect their management systems against market uncertainty will differ depending on farmer standpoints, objectives, lessons learned, the collective organizations they work with, the standards and specifications they work to, etc. Therefore, in order to properly analyse the attributes of systems that make them less vulnerable to unknowns, the focus should be directed towards the information systems employed by farm system managers [45]. It is equally important to identify the interplays between overarching and underlying scale levels for the system studied (panarchy) and to hone in on the dynamics at work during periods of transition.

Literature review combined with the examples compiled reveals that studies directed at developments and changes in farm systems harnessing ecological-biological (animals, plants, etc.) and human-social (farmers’ strategies and objectives) dimensions can use the notion of flexibility to gain a sharper and more explicit analysis of the interactions between these dimensions.

The move to revitalize the analytical framework governing livestock farming systems has to explicitly factor in dimensions stemming from interactions between animal production science and social sciences (formalization of livestock farmer strategies, workflow organization; [46]) as well as between ecology (resilience) and management science (flexibility). The target is to combine the analytical perspectives on (i) the regulatory properties of management-led biological systems (such as the herd, whose dynamics are shaped by interactions between human decisions and the biological functions of the animals; [43, 47]) and the leverages capable of parrying the effects of climatic risks and economic unknowns (types of product, relations with downstream factors, socio-technical networks).

There has been a key turning point in the way agronomics researchers have addressed the issue of performance in farm production systems. There has been a move away from focusing on ways to control or increase quantitative performance metrics (although there are shades of ecological intensification policy that still encourage this kind of outlook; [48]) and towards other rationales, such as “multicriteria” system design and assessment frameworks. Looking at the issues left unresolved and the various standpoints on offer, we have identified at least two courses of action:

- The interplay, or rather the fitting of abilities between production system components (system entities) and the type of system environment. This standpoint leads to a subsequent issue of whether there are advantages to be drawn from preserving certain specific animal or plant genotype characteristics that are underrepresented or tend to pale in comparison when balanced against the yield capacities of different breeds and the so-called improved crop varieties.
- The advantages of mixed farm systems combining different animal breeds/plant species, where the farmer is hedging on complementarity between the properties of each breed/species to cope with climatic unknowns (species offering different hardiness or which develop at different periods of the year) or variations in market prices (which have different effects on different farm outputs).

Approaches based on concepts and theories borrowed from disciplines such as ecology and management science are particularly fruitful for fuelling reflective thinking and reframing analyses in agronomics science when the aim is to investigate the dynamics of change and the adaptability of farm in response to situations of uncertainty.

For farmers, the art of farm management resides in tackling head-on how they define and readjust the production objectives set, how they lead negotiations with other farm stakeholders in order to achieve these objectives given the resources available, how they tackle uncertainty and how they tackle opportunity. These are all complex adaptation processes occurring at the interface between the farm and its environment, which emerge not only in the decisions taken but also in the short-term and long-term practices that we have termed “flexibility.” Our analysis of these processes applied to three real-world systems enabled us to highlight a handful of principles governing farm business flexibility. First, the situational contextualization: flexibility is dependent not only on the technical features of the production system components (plasticity) but also on the socio-economic environment in which the businesses evolve; second comes the collectiveness component: flexibility becomes greater as the business integrates the collective dimension of farm activity, even if the overriding aim is to maintain decision-making autonomy over the production system. Finally, from the methodology standpoint, trials led at our experimental farm station have prompted us to continue investigations into methods for qualifying and if possible even quantifying the sustainability of farm structures in interaction with their environment, factoring in the different farm-structuring organizational levels. This research will ultimately be used for inter-farm comparisons integrating on-farm production system adaptability over time.

Acknowledgements

This work was carried out with the financial support of the “ANR—Agence Nationale de la Recherche—The French National Research Agency” under the “Programme Agriculture et Développement Durable,” project “ANR-05-PADD-04-01, Discotech.”

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