How "fundamental knowledge" supports the cropping-system re-design by farmers?

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Abstract

Re-designing cropping systems to move towards agroecology leads farmers to implement practices which involve biological processes, sometimes qualified as "knowledge-intensive", as they involve the renewal of agronomic principles and numerous interactions between the systems' components and their regulations. Agronomists have developed an abundance of models, which encapsulate partial knowledge on systems' functioning, but these appear to be seldom used by farmers. By contrast, several studies recognize the value of exchanging specific and fundamental knowledge with farmers in relation to technical change processes. This paper discusses how fundamental and generic knowledge acquires an agronomic sense and is reinvested in the action of farmers through their technical changes. We performed an inductive case study of step-by-step cropping system re-design situations. We combined individual interviews with farmers re-designing their cropping-system, and facilitated farmers meeting about a shared technical problem. From full transcripts, we identified each new element of knowledge and its reformulation, its relation to action mentioned by farmers. The focus of our analysis concerns the knowledge which made possible to develop action strategies when farmers were facing hindrances in continuing their technical changes. Our findings concern the specific fundamental knowledge actually mobilized, and the processes of its linkage with action through contextualization. We conclude by suggesting that farmers alternate between systematic and systemic thinking about the biological processes at play in their own situation. This has practical implications for agronomists wishing to support such re-design processes, and provides an insight on how farmers' experiments might be combined to fundamental scientific knowledge on agroecosystems components to enhance cropping system redesign.

1. Introduction

Re-designing cropping systems to move towards agroecology leads farmers to rely increasingly on biological processes and endogenous resources, and far less on external inputs (Altieri 1999; Biggs et al. 2012; Duru et al. 2015). This has several implications for the application of agricultural practices. First, farmers might have to implement practices corresponding to new agronomic approaches (such as, for instance, maintaining a canopy for most of the year to cover the soil, trying to control weeds, limiting leaching and possibly increasing nitrogen fixation in the case of legumes). Thus, they may face situations in which they have little experience to guide their decisions about appropriate action. Second, managing such biological processes is made harder by the variability of their functioning according to environment-specific pedo-climatic conditions, and by the numerous and largely under-explored interactions (for example, maintaining a cover crop may lead to an increase in the slug population). This increases the uncertainty of the targeted effects or leads to unintended impacts. In view of these specificities, some authors have described the related practices as "knowledge-intensive practices" (Röling and Jiggins 1994; Ingram 2008). This stresses the acute need for new knowledge to apply these, particularly because they involve "*the adoption of technology that requires a high level of management skills, with an emphasis on observation, monitoring and judgement*"(Ingram 2008).

Agronomists have developed three main strategies to fulfil this need. First, some have made more intensive use of the knowledge developed by farmers, either to broaden agronomic knowledge, or to design and assess agro-ecological cropping systems (Walker et al. 1999; Altieri and Toledo 2005; e.g. Doré et al. 2011; Malézieux 2012). In particular, there is an emphasis on the tacit knowledge that farmers acquire through acting in their own situation, called "experiential knowledge" (Fazey et al. 2006; Baars 2011), largely based on know-how. Second, some agronomists have carried out experiments with innovative crop systems to quantify the effects of new combinations of practices enhancing biological processes, emphasizing the scope for learning (Deytieux et al. 2012; Coquil et al. 2014). Third, and this is probably the predominant strategy, many agronomists have developed integrated and complex models to describe the numerous interactions within a cropping system (e.g. McCown et al. 1996; Rossing et al. 1997; Constantin et al. 2015). By gathering the scientific knowledge available on soil-crop-atmosphere mechanisms the value of these models is thus argued to lie in their capacity to extensively take into account feedback loops and the unintended consequences of actions (such as the quantification of water and nitrogen needs of wheat at spring when sown densely and early, which have consequences on fertilization and potential water stress induced), and to predict long-term trends in the system, such as soil nitrogen and carbon content dynamics under various management practices (Constantin et al. 2012). The use of such quantitative and integrative models has been argued to provide helpful support to change practices (e.g. Hochman et al. 2000; Sterk et al. 2009). However, many authors have shown that models were of little help for the very design process of renewed practices by farmers (Prost et al. 2012). Moreover, the interactions between crops and practices that models simulate mostly concern the amounts of abiotic growing factors (e.g. water, nitrogen), and rarely biotic processes, while these strongly impact low-input systems (e.g. those linked to diseases, pests, soil biological activity). As a result, these integrated models may lack contextualization variables to be used successfully by farmers or advisors to design locally-adapted crop systems.

These limitations of models underline the issues about direct use of scientific knowledge in re-design situations: how can farmers mobilize general scientific knowledge in a situated action process contending with systemic interactions between biological processes? The effectiveness of knowledge-sharing between agronomists and farmers has been shown to vary, based on agronomists' behaviour and social skills (Ingram 2008; Fazey et al. 2014; Reed et al. 2014). Yet, as these studies focus on social dynamics and actors' behaviours, they provide little information on the actual content of the exchanges. Furthermore, the hybridization of scientific and local knowledge is sometimes considered difficult because of their differing aims regarding agrosystems: it has been argued elsewhere that farmers' objective is to manage ecosystems (for a crop or practice to yield satisfying results in a farmer's situation), and scientists' aim is to understand them (i.e. they need to know why and how something works) (e.g. Farrington and Martin 1988; Ingram et al. 2010). Based on these distinct aims, scientists have developed numerous decision support systems, as means to transfer their knowledge to farmers, with the aim of helping farmers make the right choices based on their constraints. In so doing, scientists consider that farmers do not need to understand the functioning of their agrosystem to manage it and they encapsulate scientific knowledge in a usable tool. However, re-designing a cropping system in the context of agroecological transition does not just mean managing it: farmers do not work with a given stable system whose management is to be learnt; they actually gradually transform an agroecosystem while acting on productive resources, removing, adding or modifying some of its components.

Consequently, when the re-design of a cropping system involves biological processes, this requires a combination of scientific general knowledge on the corresponding system, the situated knowledge farmers acquire or develop, and an integrated approach to the cropping systems. Although such a category as “scientific knowledge” is commonly used, it inherently refers to an indefinite variety of knowledge forms regarding, for instance, their relevance for farmers’ action. What was referred to as “scientific general knowledge” in this article corresponds more specifically to knowledge produced by scientists by means of experimentation, measures and analysis that may not be available to farmers, and that concerns generalizable processes or laws about the agroecosystems and natural objects. We focus on knowledge that seems *a priori* not directly operational for farmers, namely produced through fundamental research,The core focus of this article relates to this combination: how do farmers re-designing their cropping system mobilize general scientific knowledge in their particular situation? How is this knowledge contextualized? What do such processes tell agronomists seeking to provide relevant resources for re-designing cropping systems? In the next section, we briefly present the methods we used in the different cases for data collection. In the results section, we present four crosscutting findings.

2. Methods

We selected in this paper two situations (out of a larger set) of technical change in *step-by-step* re-design processes, as characterized by Meynard *et al.* (2012). These case-studies concerned the implementation of new “agroecological” practices (Wezel et al. 2014), following various goals: diversifying the cultural strategies to reduce weed pressure along the crop sequence (Case 1), and changing soil tillage to improve the soil structure and fertility (Cases 2). For each case, the timescales that the data we collected in our case studies concerned, the location, and the number and professions of actors involved are stated in Table 1. On the one hand, we observed (Case 1) a group of farmers in a one-day design workshop. On the other hand, we carried out an individual semi-structured interview with a farmer (Case 2), focusing on the implementation of one specific technical change, and asked the farmer about the information sources mobilized, the successive actions he implemented, the observations he made.

We made an instrumental use of the cases (David 2003): in each case, we particularly observed the moments when new knowledge was mobilized by focusing on the agronomic objects or processes mentioned (e.g. a new crop, a soil management tool, a specific interaction mechanism between crops and weeds). Based on the identification of this knowledge, we tracked its transformation and its use until the implementation or design of a new practice, that is, how it is rephrased and connected to previous knowledge or thoughts. In this aim, we used full transcripts of the interview or meeting which were fully recorded. We identified key elements in the chronology, and focused on some sticking points and steps or events through which these were overcome. Namely, we distinguished periods of the meeting during which either each participant’s own experience was shared or a common understanding was built and discussed. In the interview, we resituated as precisely as possible each particular knowledge mentioned along the technical change process. We then identified what was specific in this knowledge shared and used by farmers in each of these steps, with a particular focus on the knowledge that made it possible to continue with the different technical changes and therefore unlock the re-design processes, with the main questions: how specific knowledge is asserted and discussed; how generic knowledge is used in a specific context or, conversely, how localized experiences are discussed and shared in general terms; and how it allows the farmers to choose new practices or strategies they intend to implement.

3. Case studies

3.1 An organic farmers meeting for the design of perennial weed control strategies

The meeting focused on the management of perennial weeds, particularly thistle, identified as a common problematic species on the group’s farms. It started with a presentation by a facilitator on biological and physiological aspects of thistle, drawing on scientific papers, agronomic press, and expert knowledge from experimenters (Table 2, line 2). During this presentation, although the techniques were not mentioned on the slides, farmers' comments directly linked the information given with possible changes in their actions. The same facilitator then presented two curative strategies: exhaustion and extraction (Table 2, line 2). The size of root fragments to support each strategy differs (long for extraction, and short for exhaustion) based on the soil management tools

Table 1 : Presentation of the case-studies.

	Case studies	number of farmers and advisors	location	farming systems: main productions	situation	time scale of the story
1	Organic farmers meeting about perennial weed management techniques	~10 farmers 3 animators 3 advisors 2 technicians	Picardie (North of France)	arable crops and legumes	discussions in a room (project led by a R&D organization)	One-day meeting (at the start of a 3-year project)
2	A farmer's implementation of stubble plowing	1 farmer	Picardie (North of France)	arable crops	individual semi-structured interview in office	A part of a 3-hour interview

The column "situation" refers to the type of interactions which were actually applyed or observed to collect data.
The column "time scale of the story" refers to the actual temporal spreading of the data collected.

used. The results from different experiments comparing various soil tillage tools quickly prompted discussions about organizational feasibility (workload, equipment, energy use), but did not lead to the emergence of new management strategies. After this first part of the meeting, farmers discussed their own experiences, but without reaching a shared conclusion, mostly underlining the specificities of situations (e.g. the possibility of having long dry periods for an efficient extraction strategy; density and age of thistle's spots). In the afternoon, the farmers were asked to each make propositions for a specific case. They started with opposing points of view, without consensus on the results of the techniques proposed (competitive effect of alfalfa or a lentil-triticale mixture; the use of specific machines adapted from other farmers' experiences, e.g. the "Wenz method"). A real strategy began to emerge only when the discussion returned to the key aspect of the dynamics of thistle's "reserves". The effect of practices (mowing, false seed bed) on this dynamic was discussed, which involved re-specifying the key moments of the dynamics, and the detailed processes of the constitution of reserves (e.g. are they at minimum at harvest? Or rather at the end of summer? Are the reserves increasing when the plant grows ?). The participants identified a specific indicator of plant development stages which was directly linked to the reserves' dynamics: the 6-8 leaves stage. Prior to this, the plant's reserves decrease, whereas after they increase again. Only then were two different practice strategies to test proposed (Table 2, line 5).

3.2 A farmer's interview in a minimum-tillage system

This farmer participated in an eight-year project with a R&D organization to develop integrated crop management using less pesticide. At the same time, he changed his cropping system by removing all ploughing practices. At first, his knowledge about the techniques associated with no-ploughing strategies was restricted to the types of machines one can use, and the problems encountered which lead to removing ploughing (e.g. the energy cost of ploughing, hydromorphic soils). Rapidly, he had to use more pesticides. In order to continue not to plough while decreasing herbicide use, he tried to adapt the techniques used for soil preparation and covering between crops. He implemented stubble ploughing after crop harvests to bury crop residues and manage weeds. However this had varying effects and the following wheat crop showed a weaker growth dynamic. He obtained various references by comparing the number and date of applications with colleagues, but this still did not give him guidance for the specific adjustment of the practice. He began to resolve this issue when a scientist studying carabid species presented basic elements **Table 2: Case-studies specificities according to the knowledge and experiences exchanges, the agronomic problematics, the technical strategies built.**

		Case studies **Organic farmers meeting about perennial weeds control**	 **A farmer's implementation of stubble plowing, cover crops, in a minimum-tillage system**
1	The initial problem	controlling perennial weeds without herbicide	Implementing non-plowing strategies consistently with other practices on the farm: stubble plowing was introduced to prevent from deep tillage while reducing pesticides use, but not well managed
2	The knowledge claimed, discussed, proposed for debate	The redefinition of perennial weeds ("*possess specific organs that allow self-multiplication and store reserves*"); the description of vegetative propagation mechanisms ("*Thistle buds are on a root that is horizontal, and it produces shoots called suckers"*); the rooting depths and suckers' dormancy (broken down when the root is cut in pieces); the soil factors favoring thistle; the life cycle and rates of reproduction by seeds and particularly the dynamic of thistle's reserves during the year and according to plant development stages and climate. 2 curative strategies: exhaustion ("*repeated destruction of aerial parts forcing the thistle to regrow or by a fragmentation of roots that bring out dormant buds and generates new shoots*") and extraction ("*fragment the rhizomes, pull them out of the ground and then export them or let them dry*").	Carabid species and basic biological elements: depth at which they live and reproduce, populations they impact on. Cover crop species characteristics (which is still in progress): 200 species description in terms of nutrient uptake and release, growth dynamic and competitive capacities.
3	The people at the origin of knowledge	An animator presented knowledge gathered from scientific papers, agronomic press, and expert knowledge from experimenters	A carabids specialist technical institute for crop techniques confirmation
4	The personal experiences brought to discussion		The different applications of stubble plowing within the group were compared (depth, results in terms of weeds germination)

5	The action strategies finally proposed	i) with a cover crop mixture sown just after the harvest and without plowing, and a plowing destruction at dawn, when thistle would have reached the 6-8 leaves stage; ii) with alfalfa introduction, either undersown in the cereal or sown after harvest, adapting the cutting frequency to the thistle regrowth, identified according to the 6-8 leaves stage indicator.	The farmer eventually build his soil tillage strategy under the constrain of a 10cm depth limit. He adapted and reinterpreted the stubble plowing action from this basis.

on carabids' biology, and namely the depth of soil at which they reproduce. He deduced that soil tilling deeper than 10 cm prevented the development of a carabid population by disrupting its habitat, thus favouring the growth of slug populations. With the help of an expert from a technical institute, he then confirmed that 10cm was a sufficient depth to grow beetroots: he considered other possible actions in his own situation, handling interactions with other practices (i.e. the presence of beetroot crops in the succession). He analysed and reinterpreted the results concerning the false seed bed action of the machine with colleagues, comparing their respective experiences to confirm some of the technique's effects.

4. Crosscutting analysis: mobilization and contextualization of "fundamental knowledge"

4.1 The mobilized knowledge is focused, partial, , often qualitative

The comparison of our case studies shows that the knowledge which appeared useful for unlocking processes of change was very specific, rather than involving the whole system in an integrated way. In fact, whereas the problems the farmers faced were highly systemic (Table 2, line 1), the knowledge that allowed them to move forward in the technical changes was very fragmentary and selective: it concerned only some components of a system and mainly the biology and dynamics of biological objects (particular species such as thistle in Case 1; cover-crop species in Case 3, and groups of species such as carabids in Case 3). These biological objects are generally not directly and intentionally manipulated by the farmers, but they are always involved in natural processes that might interact with cash crops' growth and productivity. Also, they can be influenced by the farmers via cultural practices. Furthermore, the knowledge used was fundamental, describing a biological or physiological process (such as the dynamics of thistle reserves' accumulation and depletion throughout the year, or the cycle of development of a plant disease, Table 2, line 2). This fundamental knowledge is to be opposed to more operational knowledge, for example the effectiveness of different soil tillage tools to decrease the thistle population. It concerned neither systemic interactions nor regulation. The analytical fundamental knowledge we identified was thus mostly qualitative.

This particular knowledge was proposed by a specialist in our case studies. This was expressly mentioned in Case 3 concerning the carabid species' biology (an entomologist specialized in carabid species). These specialists belonged either to research institutes or to national technical institutes, but their legitimacy in the eyes of the farmers lays in their ability to bring together a host of bits and pieces of knowledge that may also be available from other sources (websites they visit for example) but were never organized in a synthetic form. We stress the fact that this focus on specific aspects of the knowledge mobilized, which is fragmented and concerns biological objects, highlighted differences compared to what most crop simulation models showed. The prevalence of partial knowledge on a limited part of the system components might seem contradictory with the necessity to anticipate the systemic feedback effects and unintended consequences of actions. However, in the following sections we show how such knowledge may gradually be related to a particular cropping system.

4.2 Farmers use the knowledge they can link to their own action

The knowledge mobilized was that which farmers could use to steer their own actions. In fact, among all the functional aspects of the biological objects that farmers might manipulate, they considered as useful those for which they could establish a relationship between their actions (already implemented or potential) and the response of the objects. We identified four different types of relationships or patterns as described below.

First pattern: knowledge about a biological object can relate to an action that farmers already performed and manage, the effect of which is also partly known by the farmer. To understand the effects on the new object of an action already performed, further knowledge on this object is required (Figure 1, Pattern 1). For instance, in Case 1, farmers asked for specific details about the depth at which root regrowth mechanisms occur, to be able to relate this to the depth of their soil ploughing. This gave them a better understanding of the various effects of actions on roots' biology and physiology. This pattern can be considered as a first step towards *situating* knowledge: farmers try to identify the conditions of action in which the effects targeted will be obtained or not, depending on the knowledge acquired on the biological object.

Second pattern: farmers can use fundamental knowledge on biological objects when it allows them to anticipate the effect of a new action that they have never performed (Figure 1, Pattern 2). In Case 1, they asked for knowledge on thistle roots' biology in connection with the different tools used for soil tillage. In fact, since only specific parts of the roots can regrow after being cut, they tried to select the appropriate tool for soil tillage based on the depth and width of scalping. In Case 3, the farmer built a new complete soil management strategy starting with the constraint of a 5 to 10 cm depth limit for soil tillage, so as to keep the disruption of carabids to a minimum and thus reduce the occurrence of slug attacks.

Third pattern: fundamental knowledge can be used to reinterpret previously observed effects or consequences of an action (Figure 1, Pattern 3). In Case 1, the 5% spread of thistle through seeds explained the low effectiveness of topping. Farmers also associated repeated cutting and mechanical weeding with the thistle pressure increase, based on the regrowth mechanism of suckers: these cultural practices cut roots in short pieces, stimulating re-growth..

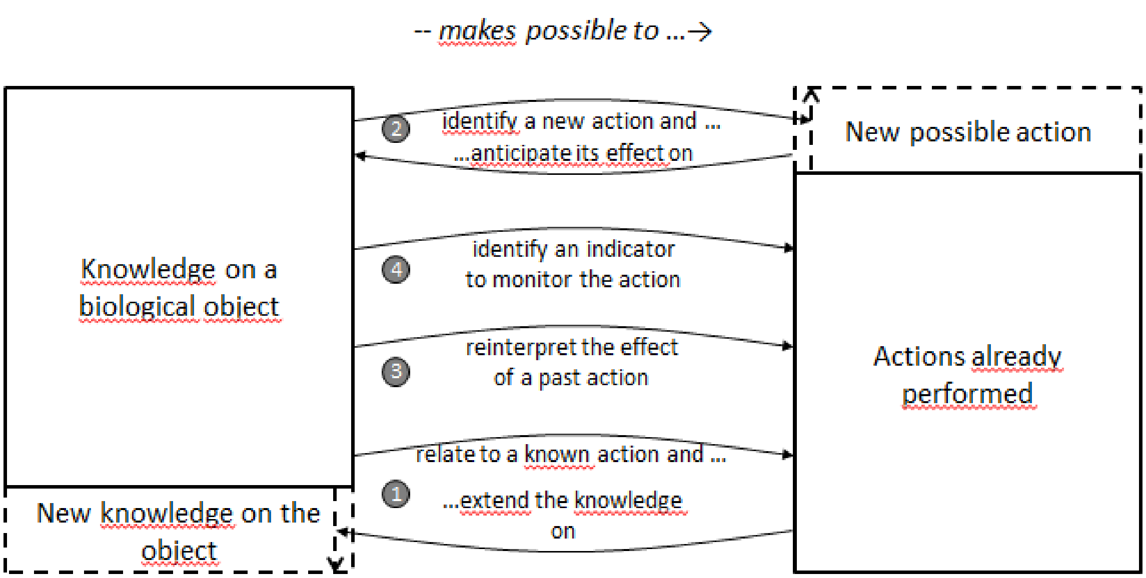

Figure 1: The different ways knowledge was linked to action. (The numbers in grey circles correspond to the four patterns described in the text).

Fourth pattern: fundamental knowledge can guide action by enabling farmers to identify an indicator to monitor their action (Figure 1, Pattern 4). In Case 1, farmers identified the thistle's development stage of 6-8 leaves as an indicator for triggering the cutting because it is the stage at which the plant's reserves are at their lowest and the cutting the most efficient..

These patterns suggest particularities in the mobilization of knowledge to design new actions in a cropping system. They highlight the fact that farmers gradually organize knowledge on the functioning of limited parts of the system, and do not embrace the whole system at once. This contrasts with the assumption that, in order to take into account all systemic interactions, one should formalize the functioning of the whole system (i.e. draw connections between numerous actions with combined but inseparable effects), which is at the core of the modelling strategy (e.g. McCown et al. 1996). Considering the functioning of a limited part of the system makes it possible to relate it to specific actions, while the assessment of a global functioning would relate to integrated actions (e.g. a complete crop management itinerary), involving a whole set of causal relations that one may not be able to grasp. In that sense, our findings converge with those of previous ergonomic studies (Amalberti 1992; Cerf 1996), which suggest that actors tackle anticipated events and plans based on a known set of actions, that is, that knowledge on the systems' processes is organized according to known action. Nevertheless, these studies considered situations where usual actions were to be applied. In our case, the design of a technical change may explain that we observed such organization of knowledge in both directions: new knowledge also led to the organization of new actions. Building an understanding of the functioning of parts of the system results from iterative loops between knowledge on the biological components and farmers' own action.

4.3 Fundamental knowledge supports the reformulation of individual experiences and makes them useful to others

Farmers readily shared their own experiences. In our case studies, we observed that simple experience sharing could rapidly lead to various explanations depending on the situation. Most of the time, local specificities were invoked as the sole cause of these differences, preventing further extrapolation, and more particularly interpretation and learning from others' experiences. Conversely, when a specific bio-physical phenomenon was used to reinterpret the various experiences, the results were not just used to deduce whether or not a technique "worked", but mostly to validate the farmer's existing knowledge specific to his situation. Personal experiences, when related to a specific bio-physical phenomenon, also provide an illustration of fundamental knowledge on this phenomenon, even if the variability of the results they show is not fully explained. In that sense, there is both a reinterpretation of these experiences taking into account the new understanding afforded by the fundamental knowledge, and a reformulation of this knowledge through existing experiences. Cross-comparing the different experiences allowed farmers to gradually confirm a particular aspect of the functioning of the system, based on fundamental knowledge. Moreover, when fundamental knowledge is confirmed, the slight differences in results or observations in various experiences may call for further specification. In Case 1, the farmers successively shared their own experiences with different thistle management strategies, discussing the results, but struggling to find a common conclusion on the effects of different techniques because of the variability in soil structure and management practices, weed pressure intensity, crop sequences, and the climate. However, when one of them related each practice and result to the dynamics of thistle's reserves, they found consistency in these results and deduced the possible management techniques to be applied to the situation discussed. They eventually reconsidered the significance of their observations (thistle regrowth becomes a positive process because it signals a decrease in its reserves), but also highlighted the need to be more accurate in the description of reserve dynamics during the discussion. Furthermore, future actions planned to compare mowing and scalping effects in an exhaustion strategy were also geared towards specifying the exact type and intensity of cutting that induces the greatest regrowth.

The reformulation of individual experiences we described in this section relates to Pattern 3 presented earlier. Also, whereas this pattern related to individual action (and was described as a process that each farmer may apply individually), this analysis of experience sharing introduces a collective dimension. The collective reformulation of individual experiences therefore corresponds to the growth of Pattern 3. Furthermore, it is worth emphasizing here the distinction we make between experience and action. Whereas action is mentally delimited in Pattern 3, experience tacitly encompasses the unintended effects and consequences of the conceptualized action. In that sense, it includes the share of unknown surrounding the implementation of action in a particular situation.

Sharing previous observations and results allows a collective to perform "narrative sensemaking" (McCown et al. 2012), which produces a combination of "if …then" rules of action, as well as an understanding of the partial system functioning underpinning these rules. This finding from our case studies is also in line with what Pålshaugen (2004) called "practical discourses" containing "public interpretations of personal experiences".

4.4 "fundamental knowledge" and farmers' own cropping-system are linked through three main processes.

We now propose an analysis of the way fundamental knowledge is mobilized in the particular situation faced by the farmer. We identified three different processes participating in the reformulation of new knowledge, which the farmers applied in order to gradually form an understanding of a part of their cropping system. These processes can be summed up as (Figure 2): 1) non-situated knowledge on generic aspects of the biological objects is tailored in order to situate a biological process/phenomenon in a given environment; 2) the situated biological phenomenon is related to the effects of actions which impact it; 3) other practices that can have the same effects on the phenomenon are considered. Although continuity between these processes may appear, they were rarely observed in the corresponding full sequence in our case studies.

First, the non-situated knowledge concerns the biological objects, and is thus independent from the environment in which such objects are or would be manipulated (Table 2, line 2). These may concern stable features of the objects, which can vary in intensity or accurate values in different environments, but of which the trend of interest for the farmer's interpretation remains (e.g. the thistle increases root reserves in summer, which is true in various environments, although the rate of accumulation and quantities may vary according to the climate and soil nutrient contents). Hence, farmers try to complement this knowledge with the influence of the environment (climatic and biotic context), so as to situate the phenomenon involving the biological objects.

Second, farmers related the situated biological process to the effects of their own actions. This allowed them to validate, confirm or specify the direct and indirect results of specific practices, and involved the various patterns presented in Section **Error! Reference source not found.**. Sensemaking in this process appeared to focus on the distinction between the description of a biological process in the environment occurring without direct human intervention and the part of the process induced by human intervention. In Case 1, a farmer asked "*you say that there is only 3 to 5% of thistle plants which come from seeds, but it is because we avoid flowering? or is this the case even in a wild system?*" This second process also materialized in Case 1 when farmers tried to re-draw the curve representing the amount of thistle root reserves throughout the year when different cuttings were performed. Interestingly, Walker and Sinclair (1998), who proposed a method to elicit and formalize local qualitative knowledge, emphasized the relevance of distinguishing the objects, processes and actions in order to establish the causal links between them.

Third, the specified influence of human action on the biological phenomenon was used as a base to broaden the range of practices that may have the same effect. This led to identifying other actions impacting the same situated phenomenon, or to specifying the quality or intensity of the relationship between an action and a situated mechanism, or to identifying other mechanisms of interest (Case 1: the cover-crops preventing soil tillage led to considering whether repeated topping would also deplete thistle reserves, and to tackling another mechanism – the effect of competition for light between thistle and cover-crop species on the accumulation of roots' reserves).

In contrast with Section **Error! Reference source not found.**, which showed how particular

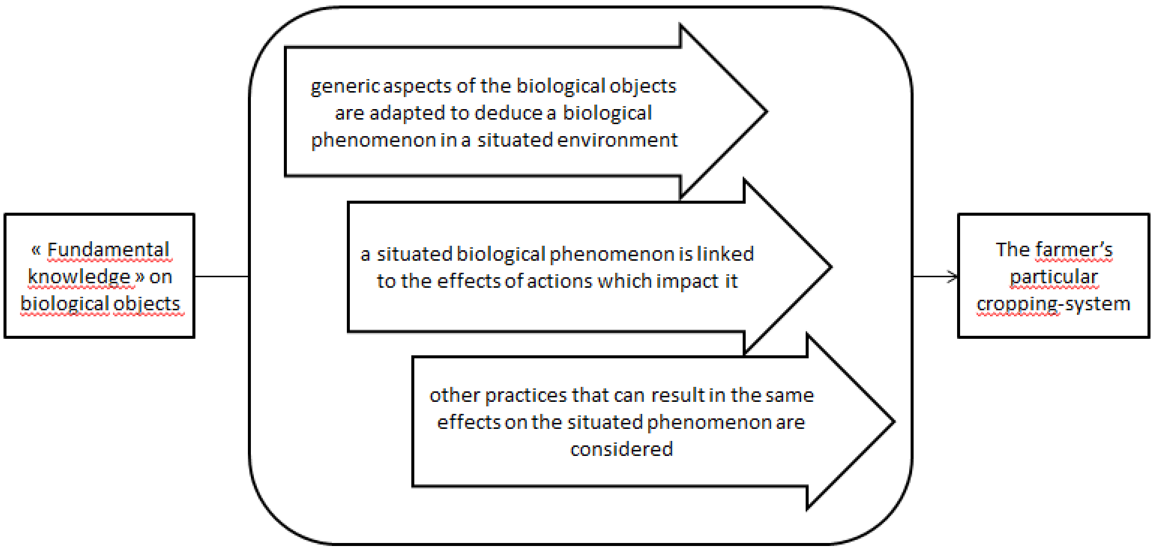

Figure 2: The three processes (large red arrows) applied by farmers in order to gradually link fundamental knowledge to their particular cropping system.

and situated experiences were used to bring out decontextualized causal relations within the cropping systems, the description of these three processes addresses the way farmers contextualize generic knowledge on non-situated biological objects. The contextualization we analysed does not amount to simply validating the knowledge discussed in a particular situation based on various contextual elements. Rather, it involves a gradual reformulation of this knowledge, in order to build situated meaning for action, that is, to construct its meaning for a particular cropping system. By distinguishing between these different elementary processes, we were able to unravel how specific fundamental knowledge may give farmers a "*hold on reality*" (Mormont 2007).

4.5 A systemic understanding built gradually

Findings from our case studies suggest that, in order to think about action within a system, farmers successively and consistently compile different aspects of the functioning of limited parts of the system. This involves decontextualization (Section **Error! Reference source not found.**) and contextualization (Section **Error! Reference source not found.**) processes, combined with gradually linking new fundamental knowledge to their particular cropping systems.

The four patterns followed to link knowledge on biological objects to farmers' action (described in Section **Error! Reference source not found.**) showed that farmers develop knowledge, in a joint and iterative way, on the biological objects involved in their cropping system, and on the actions which are part of this system (Figure 1). This leads to the situated development of an

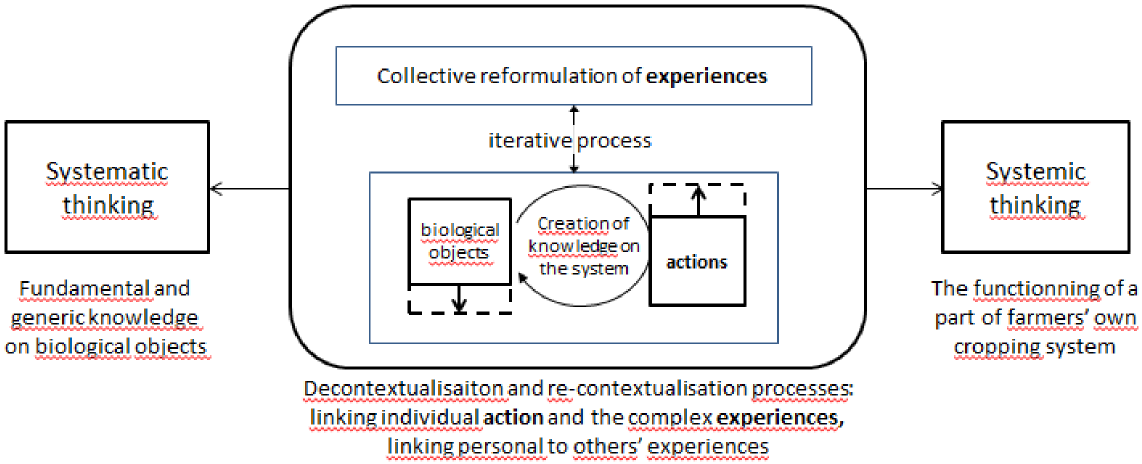

Figure 3: Farmers alternate between systematic and systemic thinking. The two elements in the central box insist on the iterations between a creation of knowledge on the system through the linking of "fundamental knowledge" to isolated actions on one hand, and the collective reformulation of personal experiences that join a complex set of actions.

understanding of the functioning of a part of the cropping system which includes action. In that sense, the contextualization of fundamental knowledge on biological objects that impact crop growth or the state of production resources corresponds to systemic thinking. Ison (2008) has defined "*systematic thinking*" as. "*thinking which is connected with parts of a whole but in a linear, step-by-step manner*", and "*systemic thinking*" as. "*the understanding of a phenomenon within the context of a larger whole; to understand things systemically literally means to put them into a context, to establish the nature of their relationships*". The findings from our case studies suggest that farmers alternate between both systematic and systemic thinking: it is systematic through the mobilization of knowledge on isolated biological objects and the natural processes they relate to, but the comparison with action and previous experiences gradually leads to addressing emerging effects and interactions between various practices which may cause unintended effects. The move from systematic to systemic thinking is operated by action (Figure 3). This is worth noting as it mitigates the claim that *"the primary prerequisites for the sound design of managed ecosystems are a profound and comprehensive understanding of their components and the relationships between them, and of the ecological processes that occur within natural and managed ecosystems."* (Hill 2014). In fact, we suggest that while such a comprehensive approach is required, design occurs throughout the process of understanding, which contrasts with the hypothesis that a preliminary understanding of the whole system's components and interactions is a prerequisite for action.

5. Conclusion

This article focused on cropping system re-design and addressed the link farmers make between generic and fundamental knowledge, their situated action on particular systems, and the systemic approach it entails. This led us to discuss how farmers take into account the immanent systemic aspects related to the re-design of cropping systems. One major finding is that farmers can choose, adapt and implement new practices based on an understanding of the functioning of a limited part of their own system, and not necessarily taking the modelling of the system, as complete and integrative as possible, as a prerequisite for choosing best practices. We propose that farmers build a situated understanding of the functioning of their cropping system in order to design new practices, but this requires continuous comparison with the results of action, known or imagined, and with past experiences reformulated in light of new fundamental knowledge. Knowledge of the system increases in a joint dynamics, along with knowledge of action that farmers implement. Our conclusion is therefore not simply that it is necessary to further extend knowledge on biological system components in any way possible, but that scientists wishing to support these re-design processes should produce knowledge which might be articulated in farmers' action. It is worth remembering that these findings relate to re-design situations geared towards a greater mobilization of biological processes. This might explain the specific focus on fundamental knowledge about biological components of the system. Furthermore, the processes we described suggest that R&D agronomists should play a particularly significant role in identifying the possible links farmers operate between generic knowledge and their situated actions for re-design (Cerf et al. 2010; Delbos et al. 2014). Rather than supplying sets of operational procedures, they should contribute to farmers' identification and observation of the situated biological phenomenon and the way they are affected by the various actions, and to the reformulation of individual experiences regarding this phenomenon. In return, agronomists' involvement in such processes might shed light on the directions which the production of scientific knowledge should follow.

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