An agronomical framework for analyzing farmers' experiments

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Abstract

Transition towards sustainable agro-food systems questions how farmers use and build new agroecological knowledge. First, as the efficiency of biological regulation processes highly depends on each specific farming situation, farmers cannot only apply technical packages built elsewhere. They have to adapt or even to create agroecological knowledge to fit their own situation. Second, farmers engaged in agroecology have to act with uncertainty, for example on dynamics of the systems or on long-term effects of a practice. Hence, the issue of farmers' experiments returns to the forefront, although its contribution to the farmers' learning process was observed long ago. We built an analytical framework derived from the agronomic experimental process to describe farmers' experiments and discuss the learning processes. The framework is used in a heuristic way to re-read the literature on farmers' experiments. Experiments are described with 3 phases: (1) design (objectives, experimental design planned, modalities compared, location), (2) management (indicators to monitor the systems, way to collect them, reaction to unexpected events), and (3) conclusion (interpretation of data to assess the systems tested and build new knowledge). Results are two-fold. First, the framework enables to describe the diversity in farmers' experiments as described in the literature even if few articles are precise enough to fully complete the framework. Second, the framework is used to describe three experimenting situations coming from a case-study of producers located in the South of France. This communication should be regarded as a contribution to the debate on the relationships between learning and innovation processes, and on the possible synergies between scientific and empirical knowledge.

Keywords: farmers' experiments, farmers' learning, agronomic experiments, on-farm experiment factorial experiment, system experiment, agroecology

1 Introduction

Transition towards sustainable agro-food systems questions how farmers use and build new agroecological knowledge, for two main reasons. First, as the efficiency of biological regulation processes highly depends on each specific farming situation, farmers cannot only apply technical packages built elsewhere. They have to adapt or even to create agroecological knowledge to fit their own situation. Second, because of the gap in scientific knowledge and of the agroecological systems intrinsic characteristics, farmers have to act with uncertainty, for example on the dynamics of the systems (*e.g.* biological regulations) or on the long-term effects of a practice (*e.g.* weeds population with no-tillage practices). Hence, the issue of farmers' experiment returns to the forefront with the recent developments in agroecology (Darnhofer *et al.*, 2011; De Tourdonnet *et al.*, 2013; Kummer, 2011) although this learning process was observed long ago (Johnson, 1972; Richards, 1989).

Based on previous definitions of farmers' experiments (Quiroz, 1999; Rajasekran, 1999; Saad, 2002; Sumberg & Okali, 1997), we define it as a process in which farmers plan the introduction of new ways of farming on their farm, implement it, takes the necessary means to follow it up, and finally evaluate the results. We limit our definition to cropping activities such as new crop species, varieties, cropping practices, farming material, technologies. The term "new" refers either to a completely new way of farming coming out of their mind, or simply to something already implemented elsewhere but new for them, and that must be adapted on their farm. Nevertheless it must be noted that despite the definition attempts, the boundaries of farmers' experiments remain fuzzy. Can we say that farmers planting trees on the whole farm area in an agroforestry perspective are experimenting (or are they only redesigning deeply their farm strategies)? Can we say that farmers who change soil tillage because of an extreme climatic episode one year are experimenting (or are they only adapting their cropping practices to unpredicted events)?

The topic of farmers' experiments overlays a large range in definitions and, consequently, in perspectives of analysis. Moreover, the importance placed on farmers' experimentations for building and learning more sustainable systems is very variable among articles, from a minor aspect to the main topic. Some studies reveal generalities on farmers' experiments (Bentley *et al.*, 2010; Quiroz, 1999) while others build typologies to describe the diversity among farmers' experiments (Kummer, 2011; Millar, 1994; Rhoades & Bebbington, 1988). Other articles review specific topics: meaning of a farmer's experiment, profiles of experimenters, factors stimulating or inhibiting experimentation, characterization of farmers' experimentation (Leitgeb *et al.*, 2008; Saad, 2002). But even in this kind of review, the individual process of experimentation is not so developed. Most articles have been written by social scientists or agronomists involved in development programs such as Farmers Field Schools (FFS) or Participatory Rural Appraisal (Angstreich & Zinnah, 2007; De Souza *et al.*, 2012; Defoer, 2002) who were more interested by the collective learning process than the concrete courses and procedures of the experimentation. As a result, little is known about the process of the experimentation itself. Today, to foster the transition to more sustainable farming systems, it is important to better understand how farmers learn how to change (Chantre & Cardona, 2014), and in particular how their own experiments can ease technical changes through learning.

Farmers' experiments are sometimes compared to scientific ones but the reference to science is too often reduced to a single kind of scientific experiment, factorial trials, whereas a much larger diversity exist (De Souza *et al.*, 2012; Debaeke *et al.*, 2009). In this communication, we propose to use the concepts, steps and diversity of methods used by scientists in experimentation to analyze farmers' experiments. We built a conceptual framework to describe farmers' experiments based on the agronomic methods of experimenting and on previous studies on farmers' experiments. Far from considering science as a compulsory reference, the aim is to use it as a heuristic tool to describe farmers' experiments. The article is organized as follows. We first draw the two main approaches in agronomic experimentation and present the conceptual framework. Then we illustrate it with farmers' experiments coming from literature. Finally we use it to fully describe 3 experimenting situations in our case study, implemented by some French farmers on arable and vegetable crops (Catalogna, PhD in progress).

2 Methods

2.1 Two approaches of scientific experimentation in agronomy

Scientific experimentation in agronomy has taken many forms during the development of the discipline. Starting from mono-factorial experiments (*e.g.* crop yield depending on the amount of N-fertilizer applied), it has been enriched by numerous forms of experimentation, having different objectives and complementary roles. We will not make an exhaustive list of them but rather focus on two fundamental approaches: factorial and system experiments, which we assume to be both useful to understand how farmers experiment.

Historically, factorial experiments spread with the development of chemical inputs and statistical analysis capacities in the 19th century (Maat, 2011). Their objectives are to identify the effect of one or a few factors on a system. The theoretical principle is to formulate hypotheses on the factors most impacting crop functioning, and to compare situations where different modalities of these few factors (called "treatments") are implemented, all else being equal. The treatments are set up on small plots and a careful attention is paid to the spatial plot arrangement, for statistical reasons. The treatments are often compared to a control, whose definition depends on the study aim: the most common situation, a situation with no input, etc. For statistical reasons, each treatment is replicated. Factorial experiments all follow a common pattern, *i.e.* the succession of three steps: designing the experiment in advance, managing it in real time, and analyzing the results. Despite their great contribution to knowledge building in the past, they are questioned by the evolution of farming context. They suffer from a major drawback: several cropping systems differing by the sole controlled factor(s) are compared without checking the consistency of each system (Debaeke *et al.*, 2009). Even when scientists multiply the factors taken into account and the replicates in different environments, multi-factorial experiments still suffer from a reductionist approach (Reau *et al.*, 1996).

To deal with this problem, some agronomists have developed a new way of experimenting called "system experimentation". It aims at testing the capacity of innovative cropping systems to attain the objectives for which they were designed (Meynard *et al.*, 2012), for example low-input cropping systems. The idea is to only assess the few systems in which the combinations of techniques seem relevant to reach the given objectives and fit local conditions. This enables to drastically reduce the number of combinations to set up, and to take into account a larger number of techniques than in multi-factorial experiments. Moreover, the crop management sequence of each crop is not entirely planned in the experimental design, as it is in factorial experiments, in order to face natural hazards. Scientists, instead, plan and assess decision rules, which become objects of evaluation as the effects of the systems themselves (Debaeke *et al.*, 2009). System experimentation thus partly questions the previous 3-step model of design/management/analyze. The main drawback for system experiments is how generic the results are, because the knowledge built, by nature, is closely linked to the specific situations. Deytieux *et al.* (2012) proposed to organize multi-site networks of system experiments to cover a larger array of situations and search for more generic knowledge. Since system experimentation aims at assessing cropping systems as a whole, one wonder if they are closer to farmers' way of experimenting.

2.2 Building a conceptual framework to analyze farmers' experiments

Derived from the previous analysis and previous studies on farmers' experiments, we propose a conceptual framework for analyzing farmers' experiments based on 3 phases: design, management and conclusions (Figure 1).

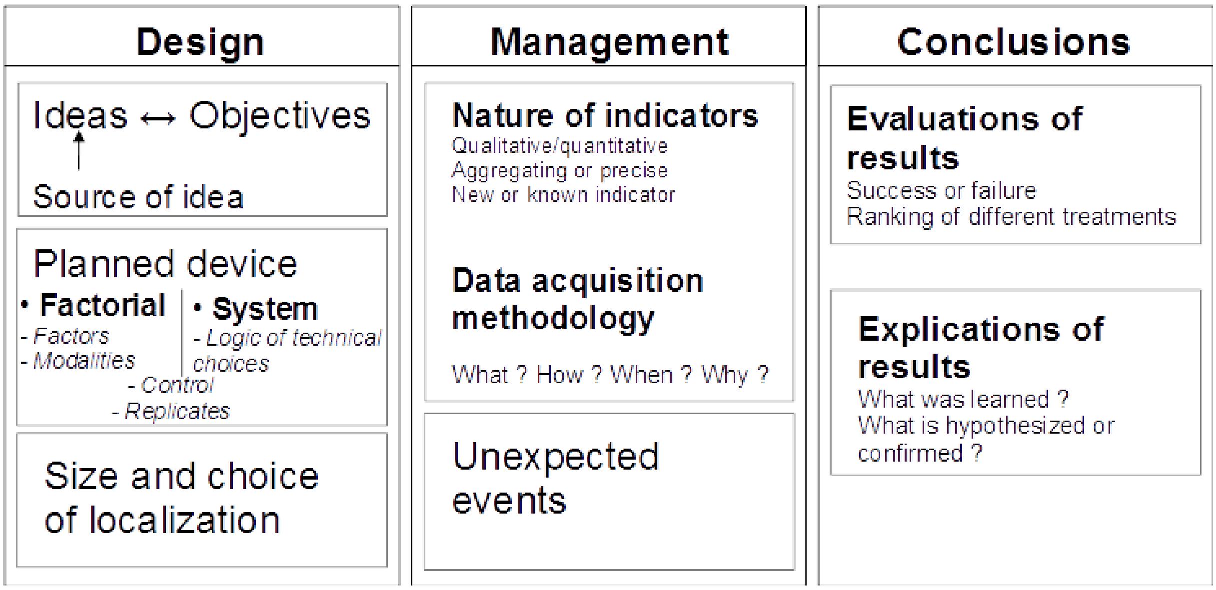

Figure 1 : A framework to describe farmers' experiments

Design phase: This phase describes how farmers formulate objectives (*e.g.* assessing the effect of different factors or assessing a system that seems coherent and suitable for their case), how they design the experiment and how they choose where to implement it. Depending on what is tested and how the experimental design is planned, farmers' experiments are classified either as factorial or system. Factorial refers to farmers' experiments that analyze the effects of the introduction/modification of one or a few factors. System refers to farmers' experiments that define overall objectives and establish a cropping/breeding system based on logical technical choices to achieve them. Even if control and replicates are more suitable to factorial experiments, they can be included in farmers' system experiment as well.

Management phase: This phase is focused on the nature of the indicators to describe the biotechnical system and on the methods for acquiring data for further evaluation. These methods can vary widely among farmers and they influence the nature of the information farmers memorize. Casagrande *et al.* (2012) showed for example that organic farmers elaborated information on weeds very differently each other. Agronomists do not manage unexpected events in the same way in factorial or system experiments (see 3.1). Moreover, Stolzenbach (1994) used Schön's theory about practitioners' experiment to describe farmers' experiment with 3 dimensions: hypothesis testing, exploration and move-testing. The two latter dimensions explain that farmers do experiment even if they are not able to predict what is going to happen and, thus, how they are going to observe it and react to it. The point is to understand how farmers deal with unexpected events during their experimentation.

Conclusion phase: Kummer (2011) showed that one of the most important output of Austrian organic farmers' experiments was new knowledge. We differentiated two levels of learning which both involve the use of comparison and indicators. The first one is an evaluation of the outputs of what Hoffmann *et al.* (2007) call a black-box experimentation– *e.g.* 'the colder stream water was bad for the early rice' (Bhuktan *et al.*, 1999). It constitutes a new pragmatic knowledge even if the causal mechanisms are not known in detail. Evaluation refers to the way farmers assess the success or failure of the experiment, or ranks different modalities (treatments or systems). The second type of learning refers to the explication of results, *i.e.* how farmers interpret the results. Understanding mechanisms is a way to avoid confusing effects in the agronomy theory, but is probably not the sole or even the main way of learning for farmers.

Despite the framework is split in 3 phases, they should not be seen as strictly successive: as a cook checks a meal when it is simmering, farmers may not wait patiently the ending of their experiments to assess the results. And yet, Millar (1994) showed that testing, validation and evaluation often occur simultaneously for farmers while Leitgeb *et al.* (2014) reported that one third of the 72 Cuban farmers surveyed adapted their methods during the course of the experiment.

2.3 Selection of scientific articles

Keywords used in the scientific review on Web of Science and Gscholar were: "farmers' experiment", ["farmer" + "trial"], [“farmer" + "experiment"], "expérimentation paysanne". We excluded articles in which farmers' experiments are not described precisely. We focused on experiments dealing with technical innovations or farming practices and excluded those dealing about commercialization, food processing or social organizations. At the end, we analyzed 47 articles or book chapters.

2.4 Case study

The case study is constituted of experiments realized by three vegetable and cash crop producers in the Drôme department, France. They are part of a larger survey for a PhD study (started on February 2015) aimed at describing and analyzing farmers’ experiments in a perspective of agroecological transition. At the moment, 19 farmers have been surveyed, who have experimented agroecological practices related to conservation agriculture and functional biodiversity. Experiments were spotted during both a first phone call and a face-to-face interview and discussed with open questions based on the framework (figure 1). In this communication, the three experimenting situations were selected because the description of the experiments during the interview was very precise and because they cover the two experimentation types: two can be related to factorial experiments (functional biodiversity and conservation agriculture) and the last one to system experiment (conservation agriculture). The first two farmers have a longer experience in agriculture than the third one. Farmer 1 is cultivating vegetables under greenhouses. Farmer 2 is cultivating arable and vegetables crops, and Farmer 3 only vegetables. Farmer 2 and 3 are organic farmers.

3 Literature analysis

3.1 Design phase

3.1.1 The objectives of experiments and their origins

Farmers' experiments emerge as soon as an idea relevant enough to be tested appears. Deciding to test an idea can be immediate (*e.g.* trying a new variety) or can take a few years (Scheuermeier, 1997). These ideas constitute farmers' hypotheses: by experimenting, they confront their ideas to reality and therefore, test their hypotheses. But the main difference with scientists is that the hypotheses are usually rather implicit. Anyway, we can distinguish two types of hypothesis. One is strongly linked to farmers' practical expectations: farmers want to see “if it works”. The other is less precise: something new is experimented but there are no clear expectations about it; farmers seek “what happens if...”. Leitgeb *et al.* (2014) noted that 68 % of the Cuban farmers surveyed had positive expectations about their experiments, while 6% had negative ones. 26 % had neither positive nor negative expectations and just wanted to see the feasibility of the experiment.

The source of idea can widely vary: it is brought by a neighbor – *e.g.* seeds (Bhuktan *et al.*, 1999), as part of a development program – *e.g.* modern rice variety extension in Cambodia (Mak, 2001), or from local observations and personal skills – *e.g.* in Nepal, new way of grafting to facilitate fruits picking up (Scheuermeier, 1997). Kummer (2011) identified 13 different sources of ideas for Austrian organic farmers, the most important ones being their own idea, the other farmers and the literature.

Objectives can be solving a problem when it is clearly identified, or simply improving farmer's livelihood. When problems are clearly identified, some authors classify experiment as a “problem solving experiment” (Kummer, 2011; Millar, 1994; Rhoades & Bebbington, 1988). Hocdé (1997) even said that farmers are experimenting to find practical solutions to problems. In other cases, Scheuermeier (1997) observed situations where farmers' problems are defined back once the experimentation is implemented.

3.1.2 Planned experimental design

In the literature, numerous examples of farmers’ experiments related to factorial experiments were found. Most of the time, it concerns a new variety or input with various number of treatments. For example, Rajasekran (1999) reported farmers testing dozens of banana varieties. In East Anglia, Lyon (1996) described farmers experimenting with various doses of herbicides or straw shorteners for cereal crops. In Nigeria and Guatemala, farmers experimented chemical fertilizers mixed with traditional organic ones in order to find effective low-cost fertilizers (Hocdé, 1997; Phillips-Howard, 1999). We also found cases where farmers were testing different environments for a new variety, for example from upper hills to low and swampy fields (Bhuktan *et al.*, 1999) or from pure culture to mixed with other varieties (Pottier, 1994). Farmers can also realize multi-factorial experiments (Bentley, 2006; Bhuktan *et al.*, 1999). In Nepal, a farmer compared two varieties (the traditional one and a new one), muddy and clear nursery water and spring vs stream irrigation after transplanting (Bhuktan *et al.*, 1999). Control and replicates, that are fundamental for scientists in the factorial experiment approach, were found in farmers' experiments mainly when they take part of a participatory research projects like FFS or Local Agricultural Research Committees (Braun *et al.*, 2000). In Lyon's study, however, farmers did not use replicates and mostly compared their experiment to their own fields in previous years, thus in time rather than in space (Lyon, 1996). In the same way, half of Cuban farmers surveyed repeated their experiment at a subsequent date, but very few used a control (Leitgeb *et al.*, 2014).

The farmers' experiments relating to the scientific approach of system experiment tested a coherent combination of technical choices instead of few factors. It concerned different subjects: a new way to cultivate a crop (Bentley, 2006; Quiroz, 1999; Wettasinha *et al.*, 1997), a new rotation or association of crops (Baars, 2011; Buckles & Perales, 1999; Millar, 1994), agroforestry systems (De Souza *et al.*, 2012; Millar, 1994), animals breeding (Kummer *et al.*, 2012; Scheuermeier, 1997) or animals and crops synergies (Mouret, 2013). In Sri Lanka, instead of burning straws, a couple of farmers experimented a new system by bringing back straws in paddy fields and reducing the amount of fertilizers they used (Wettasinha *et al.*, 1997). Another farmer tried to imitate the "environment" of cocoyam he had seen in a complex agroforestry system in southern Ghana and, thus decided to shade cocoyam by planting it under mangoo trees (Millar, 1994). He also associated it with other crops: cassava, ginger and palm plants. An Austrian farmer experimented free-range pig keeping and chose robust pig breeds as well as alternative fodder and progressively redesigned the whole system (Kummer *et al.*, 2012). Information on the presence or absence of a control and replicates is quite scarce in the literature. The only cases we found of farmers replicating a system experiment were correlated with a co-working with scientists (Baars, 2011; Buckles & Perales, 1999).

3.1.3 Size and localization of the experimental design

In factorial scientific experiments, the aim is to understand the effect of some particular factors. Thus many other factors are controlled and plants are grown in almost ideal conditions, often far from reality. On the contrary, farmers usually have to deal with heterogeneous conditions at farm scale, with some plots that can be far from ideal. Some of them choose to experiment in their worst conditions, where problems are the most important. A farmer tested deliberately a potentially root-rot resistant variety of cassava in his most infected field (Saad, 2002). Rajasekran (1999) reported that Indian woman farmers experimenting banana and coconut in poorly drained soils. In an agroforestry development project, Brazilian farmers started to experiment agroforestry at the most degraded sites of their properties (De Souza *et al.*, 2012). In other studies, farmers deliberately chose their most fertile field to try a new variety (Richards, 1994). It seems that the diversity in the location choice is linked to the farmers' objectives: in the first case, the farmers were testing the relevance of the practice / variety to tackle a problem, while in the second case, the farmers wanted to discover the growth potential of new varieties.

Most of the time, experiments are realized on small scale (Quiroz, 1999; Saad, 2002): a small plot for crop production or a few animals for breeding (Kummer *et al.*, 2012; Mouret, 2013). However, Baars (2011) described how a farmer implemented his experiments on large plots for ease of work, and how he also took account for specific interactions within on-farm management such as repeated grazing.

3.2 Management phase

3.2.1 Indicators

In the literature analyzed, farmers usually used a lot of indicators to assess their experiments. Most of them are visual (Kummer, 2011; Leitgeb *et al.*, 2014). Mexican farmers experimenting velvet beans in association with summer maize observed the evolution of soil fertility and structure, soil erosion, soil moisture, weed population, and damage to maize from soil pests (Buckles & Perales, 1999). Phillips-Howard (1999) reported that Nigerian farmers experimenting with chemical fertilizers used up to 22 indicators: growth performance – germination, growth rate, penetration of soil, leaf drying – and product form – size, shape, hardness, weight –, as well as market values – taste, smoothness, color, perishability, etc. – (Phillips-Howard, 1999). Quantitative indicators are less frequently used. Both can be used simultaneously. For example, in Java, farmers participating in a FFS about integrated pest management both observed pest behavior and counted the average number of pests and predators (Winarto, 1994). A Nepali farmer experimenting a new rice variety used both qualitative indicators such as germination rates, tillering rates, developing stage, size of panicles and number of grains and a quantitative one, yield (Bhuktan *et al.*, 1999).

Information about how farmers acquire their data is much scarcer. Sri Lanka farmers relate that they felt between their hands a smoother soil texture for assessing straw incorporation on paddy fields (Wettasinha *et al.*, 1997). They used both visual and touching indicators. They uprooted rice plants and observed tillering rates, green intensity and roughness of leaves, and root length and resistance.

Finally, we found few papers concerning how farmers record data. According to Lyon (1996), they may keep records but most of them remember results. Leitgeb *et al.* (2014) showed that three quarters of the interviewed farmers in Cuba confided in their memory and did not document their experiments. Leitgeb *et al.*

(2010), however, showed that 62,5% of the Cuban urban farmers interviewed took written notes. Kummer (2011) showed that more than half of the Austrian organic farmers surveyed documented their experiments as well.

3.2.2 Unexpected events

Unexpected events often occur during experiments as farmers are trying to cope with complex systems (Lyon, 1996). We consider as unexpected an event that is external (physically or conceptually) from the planned experiment and that influences conclusions in terms of evaluation or learning. However, we found few articles describing what events occurred and how farmers reacted. A farmer interviewed by Stolzenbach (1994) related how he decided to adapt his experiment: he saw that the fertilized groundnut he was testing grew very high; and he was scared that the gynophore would not be able to reach the soil. He decided to earth up these groundnuts, modifying his experimental design: he then compared fertilized and earthed up groundnuts to flat culture of unfertilized groundnuts. Baars (2011) reported how a farmer followed his intuition and discovered an adequate management of clover, *i.e.* an additional clover harvesting in November that was not planned at the beginning of the experiment.

3.3 Conclusion phase

3.3.1 Evaluations of results

Little information is available about evaluations of results, most of them being implicit in articles. Leitgeb *et al.* (2014) showed that 60% of the Cuban farmers surveyed made direct comparisons to assess the performance and the outcome of an experiment. Almost 90% of Austrian organic farmers interviewed by Kummer (2011) used comparison to assess their results, mostly with their own experiences and other farmers. When trying different modalities (for example varieties), farmers can rank them (Bhuktan *et al.*, 1999). Kummer *et al.* (2012) reported a farmer who classified plants between supporting and inhibiting wild plant species in vineyard. Counter intuitive fact can be verified, for examples that fewer seeds yield more (Bentley *et al.*, 2010). Evaluations may occur very soon during the experiment. In Nepal, a farmer quickly dropped a treatment 'muddy water' because he noticed very soon that seeds sown just after puddling did not germinate very well (Bhuktan *et al.*, 1999). Farmers can finally deny or accept an experiment in function of labor or capital intensiveness (Bentley, 2006; Stolzenbach, 1994).

3.3.2 Explications of results

Explications can result from a direct interpretation between indicators and evaluation. A Nepali farmer learned that a rice variety was more suitable in the lower altitude swampy land because it had "vigorous roots and sturdy tillers requiring ample water" (Bhuktan *et al.*, 1999). Explications can be rather affirmative or more hypothetical: "*the straw may have contributed to making the plants more hardy and less vulnerable to insects*" (Wettasinha *et al.*, 1997). Some explications can also be a base for a new experimentation. For example, a Punjabi farmer who was experimenting nursery for muskmelon explained some loss of seedlings because of the lack of nutrients and warmth. He then decided to experiment with sowing in cow dung (Bajwa *et al.*, 1997).

As an intermediate conclusion, our framework enabled to describe the farmers' experiments described in the literature, but few articles were precise enough to fully complete the framework. That was the issue assigned to the case study.

3.4 Case studies

The framework enables to investigate and describe the process of on-going experiments of three farmers (Figure 2).

3.4.1 Farmer 1: A seek for practical solution

Farmer 1 experimented a new biological control strategy against thrips, whiteflies and aphids under greenhouses in a mono-factorial trial. He chose to experiment it on all of his greenhouses. This could seem unsafe but he was already unable to control pests with insecticides. Moreover he trusted the biocontrol company because he was already using some of their predators. During this experiment, he and the company expert used different indicators. *"We were not looking for the same things; Macrolophus are not evident to see. We have a different approach: I was looking if aphids were multiplying, they were looking if Macrolophus were present, if they laid eggs".* At the end of the experiment, he could not be sure that the Macrolophus were entirely responsible for the good pest control because he noticed other predators. The company expert told him that Macrolophus took part in controlling pests. The farmer concluded that he had found an efficient combination of practices (introduction of Macrolophus associated to natural predators and no insecticide spraying) rather than finding if Macrolophus alone was better than chemical insecticide. This is an illustration of cases where farmers are first looking for a practical solution to a problem. They do not mind to prove initial statements; an unexpected event (in this case presence of other natural predators) is welcome if it creates a new and reproducible situation that solves the problem, even in a factorial experiment.

3.4.2 Farmer 2: Incomplete bi-factorial experiment which opens on new questions

Farmer 2 experimented in a bi-factorial way two clover mixes and two soils: white-purple clover on acid soil and limestone soil, and crimson clover on limestone soil. *"You cannot compare those fields, even yields".* As one treatment was missing, Farmer 2 extrapolated the growth rate of crimson clover in general, regardless of the type of soil, and he concluded that white-purple clover was better than crimson clover on acid soils, whereas in a scientific perspective, the conclusion would have been impossible. The conclusion is maybe influenced by practical reasons: is it possible that having only one type of clover mix to manage is more convenient and would be preferred in any case (white-purple clover developed well on both soils). Moreover, Farmer 2 was not able to measure the competition between wheat and clover because he did not compare it with a normal wheat field: *"Maybe I'm not compensating wheat competition with clover* [year1] *with the following crop* [year2]*.*"

3.4.3 Farmer 3: Results spread over time

Facing a huge problem of time with plowing, Farmer 3 experimented the permanent garden beds method. On the first cropping bed, he immediately had the confirmation that it was more effective and he implemented it on the whole area. A first objective (stop plowing) was immediately achieved and could explain he choose to experiment on a large area. A second result, concerning soil life activity was reached during the experiment, thanks to earthworms. After three years, he noticed more fungi. Other indicators concerned work ease and soil *"My fields are more and more easy to work […] When it rains, all fields are flooded except mines"*. Farmer 3 therefore told that he reached his objective as regards soil life after 5 years. While innovation has already been adopted by the farmer, this experiment still provides new indicators and results compared to the initial objective of solving a problem of time.

	Farmer 1	Farmer 2	Farmer 2
Experiment	Biological control : Release of macrolophus	Intercropping : Clover sown in wheat	Cropping method : Permanent garden beds
Design			
Ideas, source of ideas and objectives	A biocontrol company technician proposed Farmer 1 a generalist predator (Macrolophus pygmeus) that could control both aphids, thrips and whiteflies. He tested if Macrolophus was more efficient than chemical insecticides.	Farmer 2 wanted to direct sow clover in wheat in order to have an already standing green cover after wheat harvesting. A previous mix of 4 clovers was costly and success was quite hazardous. He tested more simple seeds mixes to look for the best clover type.	Already convinced by no tillage practices, F3 visited a french farm with no-plowing cropping method where crops were grown on permanent garden beds. He tested if permanent garden beds would allow both having more time and improving living soil on his farm.
Planned experimental design	One factor tested: Large spectral insect control technique Two treatments: biological (Macrolophus pygmeus) and systemic chemical insecticide (Karate) No control. Replication : NA	Two factors tested: clover species mixes (white and purple clover mixed and pure crimson clover) and soil types (acid one and common limestone-silty clay soil). Came up with 3 different treatments: Crimson clover on limestone soil (x 2), crimson clover on acid soil (no replication) and white-purple clover on acid soil (x 2). 4th treatment was not tested. No control	System tested: Shaping of beds with two new tools (rotovator and vibrocultor). Ridges for all crops except small ones such as carrots that were conducted on a flat bed. No walking on beds except for hard harvesting crops (potatoes). Control: previous system based on plowing. Replication : NA
Size and choice of localisation	All greenhouses : Half of greenhouses for each treatment	1 ha of crimson clover on acid soil on 1 hectare. 1,5 ha of crimson clover (x2) on limestone soil. 2 ha of white and purple clover mixed on acid soil. One 2m wide strip of white-purple clover (next to crimson clover).	Whole area (1 ha).
Management			
Nature of indicators and data collecting methodology	**Company experts:** Observed presence of Macrolophus during the whole season (adults, eggs and larvae). **Farmer 1** : Spotted outbreaks of aphids and oberserved their size evolution. In September hit a plant (tomato for example): checked if there was a cloud of whiteflies or not to estimate pest infestation level. He also observed damage on plants and length of harvesting period. No written data.	Indicators concerned mostly clover visual information collected after wheat harvesting: growth step of clover (growing or seed stage), height, color and biomass (he estimated dried organic matter produced by clover of 1,5-2T/ha). Only sowing rates were written.	Observed earthworms abundance (worms, castings) Soil color, stickiness (under shoes after a rain) and smoothness Time spent Felt during action : tools ease of use Heared earthworms moving when it rained and water getting back in their galleries (suction noise after jumping on wet soil) Each permanent garden bed was represented on Excel software to facilitate crop rotations.
Unexpected event	Other natural predators were noticed (encarsia, ladybug) under biological greenhouses.	After a first reaping of a crimson clover on acid soil, he plowed quickly (August) and sown rape. But, on the other crimson clover fields that were reaped, it was plowed later because the following crop was wheat (November). On those fields, crimson clover seeds germinated after a rain in late August and densely covered the soil.	
Conclusions			
Results and conclusion	On short term, there were fewer aphids under chemical greenhouses. On long term (season), biological greenhouses were less overrun by aphids. There was little damage on plants under biological greenhouses. Aleurods developed less under biological greenhouses. Tomatoes were harvested until November for the first time. **Macrolophus pygmeus is more efficient to control both aphids, thrips and whiteflies on long term than the chemical insecticide.**	After wheat harvesting, crimson clover was dried and went to seed although white-purple clover was still green and alive. Moreover, there were less white-purple seeds in wheat: those clovers were lower and grew slower than crimson clover. **White-purple clover seems more interesting.**	This system took one third of time compared to plowing methods. Soil was easy to till on permanent garden bed, softer and not sticky. Permanent garden beds combined with ridges were darker and exhibited more microfauna. **Permanent bed cultures are more suitable than the plowing system.**
Explication, what was learned	Whiteflies and thrips are controlled on long term by Macrolophus because they need time to develop. It is possible that other natural predators that were already here helped to control pests under biological greenhouses.	Crimson clover reaches flowering and seeds steps faster than white-purple clover.	Keeping fine soil on surface stimulate soil life. Ridges increase surface so increase oxygen exchanges so enhance soil life. Moreover, furrow between ridges creates, because of shadow, a wet and fresh climate that suits soil organisms better.

Figure 2 : Description of 3 farmers' experiments using the Design, Management, Conclusions framework

4 Discussion and conclusion

We now discuss the capacity of the framework to describe and understand the farmers' experiments from the literature and the case study.

First in both cases, it was possible to classify a specific farmer's experiment to the factorial or system approaches. But farmers' experiments do not necessary belong exclusively to one approach. For example, the Malian farmer who tested groundnut with and without fertilizer in Stolzenbach's study (1994) started to experiment in a factorial way. In retrospect, we can also consider that he experimented in a systemic way: adapting the other cultural practices to the situation resulted in a new coherent system. On the same way, system experiments on individual farms can sometimes be analyzed as a multifactorial experiment in a collective perspective, in which each farmer situation was reduced to a sum of factors and constituted a treatment (Buckles & Perales, 1999; Coulibaly *et al.*, 2012). Moreover the degree of complexity in farmers' experiments varies greatly (Hocdé, 1997; Kummer, 2011) from « simple trial to see, to […] experiments with scientific requirement » (De Tourdonnet *et al.*, 2013). Classifying farmers' experiments as factorial or system can be difficult when farmers do "simple trials" in an exploratory phase: as they first test only one new thing (e.g. a variety) and progressively solve the new problems arising in a more systemic way.

Second, replication was a notion quite difficult to recognize in farmers' experiments. For instance, in the case study, we do not know if Farmer 1 used each greenhouse as a replicate or if he compared each group of greenhouses treated as a whole. The same question arises for Farmer 3: is each permanent garden bed used as a replication or do they constitute a whole? Probably the difficulty for addressing the question of replication is that farmers consider them less useful as they do not try to statistically prove their experiment; the only cases of farmers replicating a cropping system experiment were correlated with a co-working with scientists (Baars, 2011; Buckles & Perales, 1999).

Third, we noted in the literature and the case study that farmers are using a lot of indicators both in factorial and system approaches. Simple aggregating indicators (*e.g.* yield) are hard to interpret alone; more precise indicators only inform of a particular aspect of the experiment (*e.g.* root length, earthworm population). Farmers usually combine both. They use a lot of qualitative and tacit indicators during the experiment, as they do for managing their crops (Casagrande *et al.*, 2012; Navarrete *et al.*, 1997). Rich qualitative information is acquired, that and help farmers to interpret the experiments and build new knowledge. Contrary to what scientists usually do, farmers do check every element that may impact the farm, from the field to the market. Some indicators are planned at the beginning of the experiment, while others are discovered during the experiment. The reason is that it is nearly impossible to anticipate all the interactions resulting from the implementation of a new practice. Therefore, we agree with Seamon and Zajonc (cited by Hoffmann *et al.*, 2007) that the way farmers create and use indicators belong to phenomenology, *i.e*. is grounded in direct experience.

Finally, the literature analyzed is mostly implicit on what was learned during the experimentation process. Learning is rather studied in a long term perspective (Chantre, 2011; Mak, 2001). Chantre (2011) studied learning on a long time scale through the combination of multiple experiments and other ways of learning. An interesting point resulting from the case study is that new knowledge resulted not only from the planned experimenting process, but also from unexpected events that were source of serendipity. For example, Farmer 1 finally concluded that a combination of two predator species could control the main pests whereas he just wanted to test if one of these species could do so. Farmer 2 discovered an unexpected behavior of the crimson clover.

Our framework must be regarded as a tool to survey and describe farmers' single experiments and to compare them in a more systematic way. Based on this characterization, it is possible to initiate reflections with farmers, on how to select information to record or why the farmer did not manage to conclude. It is also possible to discuss the conclusions with other farmers' knowledge and scientific results: for example, what conditions would be necessary to reach similar results or how to adapt the tested practice to other conditions? The framework could be used in farmers' group as a participatory tool to exchange on the on-going technical changes and to facilitate mutual learning. This potential use is being tested in a participatory project studying the social and technical innovations of farmers groups in agroecological transition (COTRAE project, http://www.psdr.fr/PSDR.php?categ=103&lg=FR#ancre398). Nevertheless, as the framework focuses on single experiments, it should be completed by a larger analysis of the farmers' change and learning processes which are not linear (Kummer, 2011). Each experiment should be regarded as a reflexive support for further ones and an element in a larger learning process. Middle-term phenomena like experiment scaling-up (Millar, 1994; Mouret, 2013), incremental improvement of an experimented practice (Bajwa *et al.*, 1997; Bhuktan *et al.*, 1999) or nestedness of experiments (Kummer, 2011) are based on spatial and temporal combinations of single experiments. They should be studied to better equip the agroecological transition.

5 References

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