Farmers' involvement in collective experimental designs in a French region, Rhône-Alpes. How do they contribute to farmers' learning and facilitate the agroecological transition?

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Abstract: *Agroecology is a promising concept for designing and managing more sustainable agrosystems, but it deeply questions how farmers learn to implement agroecological practices. The building of generic knowledge by scientists is quite insufficient and has to be completed with learning and innovation dynamics on farms. We assume that experimenting agroecological practices on farms is a way for farmers to simultaneously implement and assess new cropping and livestock farming systems, and that the involvement of peers or supporting actors, either scientists or extensionists, could help the experimenting process and favor agroecological transitions. Based on a French participatory research project, we present a cross-case analysis of seven farmers' networks carrying out experiments on crop production and livestock farming. Some experiments were implemented by the farmers themselves on their farms or within a farm network; others were led by technical advisors, veterinarians or scientists. They varied from very formal to much more informal designs and protocols, from individual to more collective experiments. By experimenting, farmers not only assessed the performances of the experimented practices, they also learned how to manage a complex system and observe animals or plants differently, they gained confidence to move to a trajectory of technical change, and in some cases, the experiments stabilized the network for a period by supporting the exchanges between peers. The synergy between individual and collective dynamics was analyzed. Peer-to-peer exchanges provided new ideas and a greater reflexivity on the experiments realized at the individual level. Complementary, the individual experiments were a way to acquire situated knowledge directly usable by each farmer.*

Keywords: *Experiment, innovation, multi-actor learning, knowledge, agroecology, participatory research*

Introduction

The environmental impacts of agriculture call for a large change in farming systems and more generally in agricultural knowledge systems. In particular, the use of agroecological principles for designing and managing more sustainable agroecosystems, although highly promising, is a challenge as regard knowledge building (Gliessman, 2007). Agroecology promoters call for the development of new ways of learning based on interactions in-between farmers, and with advisors and scientists (Francis et al., 2011). The reasons are twofold: first the ecological processes are uncertain, *i.e.* the speed and intensity of their effects on agroecological systems are not fully predictable. Second they are situated, *i.e.* very dependent on local situations. Therefore, the paradigm of generic knowledge built by scientists and its dissemination to farmers, which has prevailed for decades, has now to be replaced by a new paradigm, based on the development of farmers' learning and innovation processes on farms (Prost et al., 2016). On-farm learning may be a way for farmers to overcome problems related to uncertain and situated ecological processes by fitting cropping and husbandry practices to ecological situations, and by learning by doing. But this process is not so easy and could be supported by scientists and advisors.

Farmers mobilize a great diversity of sources of knowledge to imagine and manage crop and husbandry systems in an agroecological way. Besides traditional agricultural advisors' visits on farms, they find out information on agricultural newspapers or websites, during training courses or through peer-to-peer exchanges, experimentation, etc. (Ingram, 2010; Kummer et al., 2012). We assume that farmers' involvement in experimental designs is a key activity for them to learn how to implement and manage new agroecological systems. Historically, in agronomy, experimentation has been considered as a way to build credible knowledge for scientists. Knowledge on crop or herd functioning was generated by testing theoretical hypotheses in factorial experiments. In that paradigm, the repeatability of experimental protocols and the data traceability are considered as key elements to produce scientific evidences, hence leading to a simplification of the experimental agrosystem under study, as it is usually done in experimental stations (Murdoch and Clark, 1994; Ansell and Bartenberger, 2016). With the development of agroecology, repeatability is questioned: how to experiment a technique based on agroecological processes in several places: is it accurate to choose the same technical modality everywhere irrespectively of the local ecological situations? How to deal with the possibly contradictory information resulting from this choice? The usability of scientific experiments by farmers is also questioned: can the knowledge built with a situated experiment be re-used by farmers in other conditions?

Meanwhile, farmers experimenting activity is now recognized as a way to enhance agroecological transition (Kummer et al., 2012; Leitgeb et al., 2014). As these experiments realized in real conditions vary a lot, several typologies have been proposed, partially overlapping. Ansell and Bartenberger (2016) distinguish three experimental logics: "controlled experimentation", which is close to scientific approach, for analyzing a cause-effect relationship and test hypotheses; "Darwinian experimentation" which consists in gathering the largest possible number of individual experiments on a theme to identify success stories, and "generative experimentation" which consists in elaborating, testing innovative solutions to existing problems, and regularly adapting the system under study until it becomes efficient, as realized in agronomy with system experiments (Deytieux et al., 2012). For their part, Caniglia et al. (2017) identified 6 types of experiments in sustainability science, depending on two variables. The first one is the degree of control by scientists. It comprises three modalities: full control of the experiments by scientists, simultaneous control by scientists and actors, and no scientist control. The second variable characterizes the subject of experimentation. Either the experiments seek to understand *sustainability problems* and provide analytical knowledge on how practices could act on them. Or they focus on *sustainability solutions* in order to build actionable knowledge. It must be noted that the different types of experiments are not exclusive and rely on an ideal-typical categorization, whereas in practice, it can be considered that there is a continuum between all types. Anyway these typologies can be used to open the box of agroecological experimentations involving farmers.

Another key element in the literature for an agroecological transition is the development of local farmers' networks (Gliessman, 2009). Their number has been growing recently and they are now even encouraged by agricultural policies (*e.g.* EIP at the European level, GIEE[1] in France) to favor the agroecological transition. Collective dynamics are of great support for changing practices (Elzen al., 2012). Such networks enable farmers to share experiences and knowledge (Altieri and Toledo, 2011; Garbach and Morgan, 2017) and build technical innovations fitted to local conditions, such as reduced tillage systems in England (Ingram, 2010). The frame of agroecology brings an increasing recognition of local knowledge and the place of farmers in knowledge generation is largely reconsidered (Kloppenburg, 1991). Farmers' networks are a way to develop situated knowledge usable by farmers, but also to collect and compare information on a wider range of situations, helping farmers to be more

[1] French acronym for "Groupement d'intérêt économique et environnemental", farmers' networks financially supported by the French government since 2016 to favor agroecological transition on farms

reflexive. Klerkx et al. (2012) highlighted that knowledge generation in the networks has to be supported, by what will be called here a "supporting actor". This supporting activity can present a range of styles. It can be purely facilitation when the supporting actor is not involved in the experimentation but ensures "that partners connect, and that information flows and learning occurs" (Klerkx et al., 2009). In other cases, especially when the supporting actor is a researcher or an extensionist, he/she can be involved in the experimental design or even sometimes can be the leader (Duru et al., 2015).

Combining an experimenting dimension and a collective dimension could be a promising way for promoting agroecological knowledge and supporting the agroecological transition. Based on this assumption, the article focuses on farmers' involvement in collective on-farm experimentations of agroecological practices, whether the experiments are led by the farmers themselves or by external persons. The aim is (i) to describe and analyze a diversity of farmers' experimenting processes in relation to the network functioning (how and why did farmers initiate or contribute to experiments on agroecological practices or systems? How were the other members involved?), (ii) to understand how such multi-actor experimentations contributed to promote farmers' learning processes and finally to the agroecological transition.

As the object under study was the experimental designs, we only considered local networks, *i.e.* those where farmers were geographically close enough to visit each other's on-farm experiments. We adopted a large definition of farmers' network, considering not only the farmers' peer-to-peer exchanges, but also with agricultural advisors, vets or scientists who supported farmers in their experimenting processes or in some cases co-designed experiments, hereafter referred to as "supporting actors". As the term "farmers' experiments" is diversely interpreted, we considered that there is an experimenting activity if three activities are combined (Catalogna and Navarrete, 2016): (1) planning a design to solve an identified problem and test potential solutions; (2) monitoring the system under experiment to observe the potential effects; and (3) drawing conclusions on the practices under experimentation. If the three steps are mandatory, the degree to which each step is performed is open. For example, the monitoring phase may be limited to visual observations on plants or animals without writing any information, or the conclusive phase may consist in initiating a reflexive process on how the practices should be adapted the following year, even if no clear conclusion has been drawn from the trial.

Research approach

Seven farmers' networks engaged in agroecological transitions: The research is part of a French participatory research project, called COTRAE[2], studying how local farmers' networks are organized and how they build and exchange knowledge dealing with agroecology. The seven networks studied are located in the Auvergne-Rhone-Alpes region; they were all managing experiments during the study, on crop production (cereals, fruits) and/or livestock farming (dairy and beef cattle).

Interdisciplinary surveys of each farmers' network: The research project was based on a close interaction between scientists from biotechnical sciences (agronomy, animal science) and social sciences (sociology, geography) and with farmers and supporting actors (vets, advisors, scientists, etc.). It was based on an empirical survey and participant observation. Regarding the empirical survey, common guidelines were used to characterize the seven networks and the experiments realized. 48 farmers were interviewed (see the distribution per network on Table 1), the interviews taking place directly on the farms and lasting between one and two hours. As it was impossible to meet every farmer of a network, interviewees were selected to cover as far as possible the network diversity, *i.e.* farmers having a central *vs* minor place in the network organization (president, leader or simple member), more or less experimented in agroecology, and implementing experiments regularly or not for the collective. The supporting actors most involved in the seven networks were also surveyed, to understand their role in the network functioning and in particular in the experimentation

[2] "Collectifs en transition agroécologique", http://psdr.fr/PSDR.php?categ=103&lg=FR#ancre398

process. As far as possible, the surveys were completed by participant observation of key interaction moments such as annual meetings, collective farm visits, etc. All these devices enabled to collect factual information on (i) farmers' networks (aims and activities of the network, information and objects exchanged, nature and frequency of the meetings, supporting actors, number and type of farmers, long-term network dynamics, etc.), and on (ii) the experimental designs (technical objects under study, number and location of the experiments, actors' involvement, etc.). Qualitative information issued from verbatims was collected to understand how the experiments contributed to farmers' knowledge building, more generally to the agroecological transition of the farms.

Data analysis. The empirical data were first analyzed at the network level (Benmansour, 2017; Peureux, 2017; Ruiz, 2017; Venot, 2017). Comparing the actors' discourses with one another enabled to note possible discrepancies that were used to better question the network functioning. In a second step, a cross-case analysis of the seven networks was realized for a more generic interpretation of the data. An analytical framework was built on the literature on farmers' experiments and farmers' networks. We first analyzed how the networks were organized, what sort of objects or information were exchanged, and what was the role of supporting actors, from facilitators to leaders. Second we described the experiments: aims (understand a problem, find a solution…), nature of the experimental designs (referring to *controlled, Darwinian, generative experiments*) and organization (at the individual or collective scale). Finally, we identified the various ways the experiments realized within the networks helped farmers to learn new agroecological practices by building analytical *vs* actionable knowledge, local *vs* generic knowledge. Besides knowledge production, we identified various other ways the experiments engaged farmers in an agroecological transition.

Results

We now present major trends resulting from the cross-case analysis according the three dimensions (networks functioning, experiments, and their role in farmers learning and agroecological transition).

1. Characteristics and functioning of the farmers' networks under study

The size of the farmers' networks studied varied from 14 to 90 farmers. They differed in their organization and functioning, in their aim and in the role of experimentation (Table 1). SOL, GRB and CDA networks were organized around experiments. In the three cases, the networks did not pre-exist the experiment. In SOL and GRB, engineers were the ones who involved farmers in the experiment process whereas in CDA, experiment was initiated by the farmers themselves. In contrast, the farmers in CBR, CUP, COV and INS had a long history of practice exchanges, of sharing ideas and knowledge through farm and field visits, of training sessions and also of informal interactions. Experiment was only one activity among others.

The role of supporting actors varied from being a facilitator of collective actions to a referent devoted to the experiments. The most pro-active experiment referents initiated the experiments, elaborated the experimental design and the data recording protocols, analyzed data and were also responsible for the dissemination of the results among the farmers, inside or outside the network. In GRB, although the experiments were led on-farm, the engineers from the experimental organization were in charge of collecting and hierarchizing the farmers' needs and the potential solutions to be tested; then they identified the farms and plots most appropriate to carry out each experiment; and lastly they planned and monitored the trials. The SOL network was organized in the form of a participatory research; conducting the experiment was a collaborative work between pilot farmers and researchers through continuous interactions, even if each actor had a specific goal. Scientists facilitated the emerging of farmers' objectives and the collective design of innovative farming systems. Experiment outcomes were observed by the farmers but most data were monitored and collected by the researchers then shared, discussed and assessed altogether. In the COV network, one vet planned and facilitated the meetings devoted to experiments. He suggested some essential oil-based products and protocols to be tested and the data to record. He gathered information recorded by the farmers on their own farms and organized the final discussions on oil-based products' performances. Both CDA and CUP networks benefited from the support of two people: one was dedicated to facilitation whereas the other one coped with the technical aspects (monitoring experiments, collecting data, formalizing and sharing the outcomes). In only one network (CBR), the supporting actor had a very limited role in experimentation. The main reason it that she organized the network activities as a whole, in particular the training sessions where conservation agriculture experts were invited. But her activity as regards experimentation was limited to collecting the list of on-going experiments planned by each farmer, without significant contribution to their organization or monitoring. Accordingly, the farmers were willing to find external resources to help them to build and manage the experiments, and all claimed that *"[they] lack[ed] hands, brains, time, and money"*.

Table 1. The seven networks' characteristics (the number of farmers interviewed is indicated in italic characters)

Network	Farmer number and production systems	Organization of the network and supporting actor	Aim of the collective	Technical objects experimented
SOL	15 arable-crop farmers *(N=3)*	3 subgroups corresponding to different production systems. On each, one pilot farmer experimented a cropping system designed with the rest of the subgroup. The experiments were monitored by two scientists in agronomy	Experimenting to improve soil health and learn knowledge on soil functioning	Conservation tillage practices, crop rotations
GRB	15 organic fruit growers (apple, apricot, cherry, peach) *(N=13)*	An experimental organization led by organic farmers who develops on-station and on-farm experiments to help growers improve their practices. 2 engineers in charge of experiments.	Hosting agronomical experiments for the experimental organization	Fruit cultivars, biocontrol products, cropping practices for pest control
CDA	18 mixed crop livestock farmers *(N=2)*	2 persons supporting the network activities: one facilitates the collective action and one organizes and monitors the experiments	Testing old grain cultivars and being autonomous in seeds production, processing and selling the grains	Crop associations (legumes cereals), old grain cultivars
CBR	30 farms (near 100 farmers); mixed-crop-livestock farmers (the majority have dairy cattle, some beef cattle) *(N=9)*	A network with a long history (close to 50 years), in search for very innovative practices thanks to training sessions, farm visits, study trips and experiments. It is accompanied by an advisor from the Chamber of Agriculture	Historical aims: comparing work margins and practices to improve the systems. More recent aims: maximizing cover crops and minimizing tillage; improving animal feed self-sufficiency with on-farm experiments	Conservation tillage practices, animal feeding
CUP	14 livestock farmers formerly using maize silage and now changing for grass hay *(N=7)*	A network accompanied by 1 technical advisor in charge of the network animation and 1 animal science researcher helping to organize the experiments	Reducing the use of inputs and improving the level of feed autonomy on farm, sharing agricultural machines (hay harvest) and mutual helping for labor-demanding tasks	Alfalfa cropping, then mixtures of grass species best fitted to local soil and climate conditions
COV	About 90 livestock farmers *(N=11)*	Farmers organized in a non-profit association linked to a veterinary clinic (4 vets) by an agreement. One vet in charge of developing the use of alternative medicines in the network	A mutual responsibility for animal health between the farmers and the vets	Treatments based on essential oils and alternative medicines, care protocols to be used by farmers
INS	About 20 farmers. Fruit and vegetable growers *(N=3)*	An informal network accompanied by a technical advisor from the Chamber of Agriculture and a logistic animator from a local organic agriculture development association. Close relationships with entomologists from technical and research institutes	Increasing knowledge on functional biodiversity ; developing local pest control practices	Biological pest control, mostly towards functional biodiversity

2. Organization of experiments within the networks

Objects under experimentation

The experiments concerned either an individual technique (GRB: new fruit tree cultivars under organic farming), a new crop management (CUP: mixtures of grass species and the optimal crop management fitted to the local soil and climate conditions; CDA: optimal mix of old grain cultivars for each farmer), a new cropping system (SOL and CBR: new conservation tillage and crop rotation strategies), or new animal care protocols (COV) (Table 1).

Experimental designs

Among the farmers' networks surveyed, the experimental designs varied from very formal to very informal designs. In the *informal experimental designs* (*e.g*. CBR*)*, the aim was to find a solution to a problem identified by the farmers; the system under experiment was quite realistic, similar to the way the farmers usually manage their crops/animals except for the practices under experiment. Some elements of the experimental choices were anticipated, but others were decided or adapted during the course of the experiment, depending on the system functioning or real climate/soil conditions, and this on-going adaptation enabled farmers to learn how to manage the new system. They observed the system dynamic, collected rather qualitative information, and did not systematically record them. The conclusions sometimes remained implicit: each farmer could draw conclusions on his/her own experiment, but did not necessarily make it explicit at the collective level. In the most *formal experimental designs* (*e.g.* GRB), several practices were compared one to another or to a control, on several micro-plots as replicates. The hypothesis tested was that the new practices would be more efficient than the control or current farmers' practices. Although carried out on real farms, such experiments followed the scientific pattern. The farmers were involved to manage crops during the experiments and implement the cropping practices, but most of the experimenting activities were taken up by the supporting actor (*e.g.* GRB and SOL).

A combination of several types of experimental designs

Several types of experiments were combined at the same time in some networks: formal and informal, individual and collective, at the initiative of all farmers, of leader farmers and of supporting actors. For example, in the COV network, two main kinds of experiments on alternative medicines were combined. On one side, numerous informal experiments where realized by the farmers to assess the efficiency of a given treatment (product, dosage, method of administration…) in their own situations. They decided to do the test on their own initiative, or following vets' or peers' advice. On the other side, a more formal experimentation was organized by the vet to validate generic curative protocols, which had to be suitable for every farmer in the network: the vet organized four 2-hour meetings with 6-8 farmers already using alternative medicines on their farms. They collectively defined which essential oil-based products they would test for each disease, and what would be the appropriate protocol. They also defined how they would observe and keep track of the results obtained when applying the protocols, using an observation grid. In the INS network, three types of experiments were combined: (i) some were carried out by a very experimented leader farmer in both his own greenhouses and that of other farmers; he tried to acclimate poorly-known biocontrol agents, not yet proposed by the technical animator. (ii) Other experiments were realized by less experimented farmers who tested some practices suggested by the technical animator or the leader farmer. (iii) Some experiments were organized on several farms by the experimental station to assess an agroecological practice into different contexts and farm conditions in order to build generic technical references.

3. Experimentation in farmers' networks as a way to favor agroecological transition

Experiments within the studied networks enabled the actors to elaborate new knowledge, as in scientific experimentation, but they also played other roles at the individual or collective levels which intertwined to contribute to the collective learning process.

Generating and sharing knowledge on the performances of the experimented practices

Depending on the network and on the type of experiments carried out within a network, the knowledge generated varied from information specific to one farmer, providing him information on how to implement a new agroecological practice on his farm, to more generic information such as technical references usable by technical advisors in varied conditions. All farmers surveyed indicated they gained personal knowledge through on-farm experiments. For example, the second type of experiments in INS network (see Section 2) helped untrained farmers to discover the interest of biological pest control under their conditions and experiment practices already assessed in other farms. They progressively gained skills in entomology to better identify pests and natural enemies and learned about their life cycles. By contrast, more generic knowledge was built when a similar experimental protocol was deployed on several farms, or when complementary trials were carried out on different farms with similar monitoring: it concerned the generic sanitary protocols to cure diseases with alternative medicines for COV, the interest of mixed grass on various soil conditions for CUP, new pest control strategies for INS (thanks to the third type of experiments, see Section 2), performances of fruit cultivars under various climate conditions for GRB, and the efficiency of conservation techniques to improve soil health in SOL.

The cross-analysis suggests that promoting learning processes needs to be supported either by a scientist (SOL, CUP) or by peers (COV). For example, in SOL, to improve soil health, three small groups of farmers were organized within the network, each one having similar soils, climates, production systems and problems to solve. Within each small group, a new cropping system based on new soil management and crop rotation was co-designed between the farmers and the scientists. It was then experimented by a pilot farmer with the technical expertise of the other group members. The scientists in agronomy were responsible for recording and analyzing data. Then the three experiments were compared altogether to better understand how the new cropping practices affected soil health depending on local ecological conditions. The involvement of scientists in the trials was highly appreciated by the farmers, as it allowed them to benefit from scientific indicators of soil health (nematode numbers for example) and deepened their knowledge on soil functioning. In CUP network, the animal scientist helped building a common understanding of the problem by suggesting to consider other grass species in mixture beside alfalfa. Trials were designed during participatory meetings where the farmers, the animal scientist and a forage management advisor all decided on the location of the experiments, the mixtures to be tested, the technical practices to implement and the measurements to carry out. Once the experimental design was formalized by the researcher and the advisor, it was shared and approved by the network.

However, in other networks studied, the support did not come from scientists but peers, as indicated by a cattle farmer from COV: "I *had a problem with somatic cell count. I tried homeopathy and I had some results […]. I'm in a good relationship with A [another farmer in the network]. He likes testing things. He tries and then I try the same thing, and then we check. It's like that. It's between us."* In CBR network, there was a complementarity between few very innovative farmers having progressively assumed informal leader positions and the rest of the network. One of the leader farmers, who had always spent much time reading agricultural newspapers and discussing on web forums, was the first to start to experiment with cover crops. He gained information on how to implement them and how interesting it was in his own farming conditions. Then after inviting network members to come and observe the results on his farm, he convinced the rest of the network to join him in specific training sessions led by Chambers of agriculture and experts and to start working with cover crops. The other farmers experimented them on their own farms, which resulted in a larger assessment of the efficiency of the practices tested, in several soils and climate conditions, farm organizations, etc. The results, in turn, benefited the former farmer. In this case, although the objectives and protocols were planned and implemented at the individual level, the exchange of information at a collective level enabled to feed an essential need in the scope of agroecology, the search for the best-fitted practice in each location and situation.

Gaining information on related topics. Several farmers said that hosting an experiment was a way to benefit the expertise of the supporting actor on wider topics than the practice experimented, and in particular for the observation of natural regulations, a key element in agroecology. For example, some GRB fruit growers said that, during field monitoring and data collection with the supporting engineer, they learned a lot about natural enemies to control pests. Farmers of the INS network also learned to observe and recognize different pests and biological control agents with the help of the leader farmer and the entomologists accompanying the network. In the SOL network, farmers learned with scientists to use simple indicators to estimate the soil biological functioning.

Reassuring farmers' changes and improving their decision-making process. Because the experiment is realized on a limited surface area and/or because the farmer is accompanied by a supporting actor or peers, it enables him to implement a new cropping system without taking too much risk and to gain confidence. Experimentation by GRB engineers of new organic practices to control pests enabled farmers either (i) to adopt the new cropping strategy that had been experimented on their farm (when it was more efficient than the current practice), (ii) to confirm their initial cropping strategies (when the tested practice did not perform better than the current practice) and (iii) sometimes even to reconsider their system (*e.g.* a farmer understood that the only solution was to replant his orchard and to replace the cultivar by a low-susceptibility one because no satisfying control option could be found after several years of experimentation).

Fostering the network functioning. In CDA and COV networks, experimentation was a support for training sessions, field visits and even informal exchanges between farmers. The experiments reinforced the collective "innovation culture" within the COV network, the numerous meetings were also an appreciated opportunity for the participating farmers to exchange knowledge and experiences about alternative medicines. In CUP, which had strong historical habits of collective work in-between farmers, experimenting grass mixture on several farms and meetings organized to follow up the experiments were considered as key elements to foster the network functioning.

Discussion

Complexity around farmers' experiments

First of all, studying the experiments realized by the farmers is complex because even if conceptual categories can be drawn (see next section on intra- and inter-network variability), one experiment often falls into more than one category. For example, a farmer may be an experiment leader, a simple user or a facilitator for the others depending the experiment period or location. Moreover, there is a blurred frontier between experimenting or not. Some farmers belonging to the networks surveyed in the COTRAE project considered they were not experimenting. The reasons are twofold. First the term "experiments" has a heavy scientific dimension, which might scare some practitioners. Second, they considered they learned new knowledge by managing an agroecological system now and here instead of by planning an experiment (Renier et al., 2018). This rather shifts to adaptive management on real situations (Foxon et al., 2009). Anyway, both experiential and experimental dimensions contribute to the farmers' learning process, as indicated by Lyon (1996).

Moreover, the comparison of the seven case studies leads to the conclusion that the interaction between the individuals and networks in experimentation is much more complex than it could be initially thought from literature. Depending on the intensity of the collective dimension for building, managing and interpreting the experiments, as analyzed in the Results section, the resulting knowledge will be specific to one farming context or more generic. In particular, it depends on two dimensions: (i) Do the experiments try to answer a problem raised by one specific farmer or by the network as a whole? (ii) Do the networks aim at building actionable knowledge usable in specific local situations, to provide regional technical references, or even to build generic knowledge as in the scientific world? The different situations may interfere.

Intra- and inter-network variability of experiments

The experiments studied vary from very formal designs and protocols to much more informal ones. In the first case, the experiments are, at least partly, related to the scientific approach (*controlled experimentation* according to Ansell and Bartenberger, 2016). The supporting actors play a very active role, which refers to *full* or *partial control by scientists* according to Caniglia et al. (2017). The resulting knowledge is expected to be usable outside the network (e.g. regional technical references, standard animal care protocols, soil health indicators). Even if providing generic knowledge is the main goal, the fact that the experiments are realized on farms enables farmers to gain situated information on their own cropping or farming system. On the other hand, less formalized and only partly anticipated experimental designs, built by individual farmers, were identified. Such experiments are related to what Ansell and Bartenberger (2016) call *generative experimentation* in which the experiment aims at imagining and adapting a technical proposition in real time until it enables to solve the problem identified previously. The process often leads to situated knowledge easy to reuse for farmers. Difficulties to interpret the results may arise because of possible biases such as confounding factors, when some uncontrolled factors are responsible for the effects observed instead of the practices experimented. The cross-case analysis invites not to over-focus on discrepancies between farmers‘ experiments but rather argues for an in-depth analysis of the inner consistency of each experiment, between aims, practical organization and expected outcomes. Moreover a challenge is to imagine intermediate situations between the previous types, *i.e.* experiments specific enough to gain interest for individual farmers, but also shared enough among farmers to increase their capacity of analysis, by helping each farmer to make a diagnosis, understand his/her own crop or herd situation, or avoid confounding factors. One point must be highlighted, cutting across all experimental types: the experiment outcomes largely outreach the knowledge on the performances of the experimented practices: by experimenting, farmers learn how to manage a complex system or observe animals or plants differently, they gain confidence to move to a trajectory of technical change, which was also shown by Chantre and Cardona (2014). The experiment is also a support for exchanging between peers (Garbach and Morgan 2017).

Networks as a resource for experimentation:

As showed previously, it is quite important to maintain a balance between individual and collective dynamics. The collective dynamic provides new ideas and a greater reflexivity on what is realized at the individual level. Complementary, the experiments at the individual level are a way to acquire situated knowledge directly usable by the individuals. Such process is long since it requires a reflexive analysis on what to change, how to change (before experimenting) and then how much change is achieved, and about the performances and limits of the tested system. That is where the network dynamic, by offering a variety of situations to observe and knowledge exchanges, saves time compared to individual experimenting dynamics.

In all the studied networks where collective experiment occurred, farmers were involved in the three steps defined by Hocdé and Triomphe (2009) in the experimentation process: theme definition, protocol definition and results assessment. That refers to what the authors called *collegial experimentation*. But our cases showed a greater diversity of ways to involve farmers. In the first step, definition of the experimentation theme, farmers problems can be collected and farmers can be asked to agree on suggested goals or practices to test, or the experimentation theme can come from farmers‘ ideas. Regarding the second step, definition of the experimental protocol, the farmers surveyed often played a significant part in designing and planning the experimental protocol. But, only in a few cases, they were involved throughout the experimentation process and in particular when decisions had to be taken in the course of action (in SOL network, conducting the experiment was even a collaborative work between pilot farmers and researchers through continuous interactions). It must be noted that even when a strong collective experimenting process occurred, the last step (results assessment) always relied on the supporting actors. Monitoring the experiments, collecting data, formalizing the outcomes, disseminating results are very time-consuming activities in the long run which farmers usually cannot afford.

All our cases show that collective experimentation process requires facilitation activities. The supporting actors committed to knowledge production are not only researchers but also agricultural advisors from different types of organizations or engineers from an experimentation organization. These supporting actors play a key role for coordinating the networks and keeping collective dynamics. However, the term "Farmers" is not a homogenous category: some play a central role and help the others in the experimentation process because they have more time than the others to implement the trials, they are more familiar with the experimental approach, they accept to take more risks on their farms or because they are passionate to transfer knowledge to peers. Thanks to their experimentation leading activity, they can gradually embark others on experimentation. When taking farmers' involvement into account, one must question who the farmers committed and involved in experiment definition are and who they speak for.

Conclusion: Towards the combination of various experiments to favor the agroecological transition?

The article presents and analyses the diversity of experiments within seven farmers' networks experimenting agroecological practices. The diversity is described according several dimensions: role of scientists, technical advisors and farmers; nature of the experimental designs and protocols; nature of knowledge generated. It was shown that by experimenting, farmers not only assessed the performances of the experimented practices, they also learned how to manage a complex system and observe animals or plants differently, they gained confidence to move to a trajectory of technical change, and in some cases, the experiments stabilized the network for a period by supporting the exchanges between peers.

Based on the previous results, we assume that the combination between various types of experiments can be an efficient way for helping farmers to adopt and adapt agroecological systems. Such a combination was indeed observed on a few studied networks: some combined experiments designed by the farmers with others, on the same farms, leaded by an experimental station. Others partly planned experiments on several farm plots to be able to compare results. But the combination of complementary types of experiments has never been fully conceptualized in agricultural sciences. It raises several theoretical questions: how can the diversity of experiments be organized? by comparisons between farms the same year to explore the effects of several environmental situations and/or by comparisons along several years to capture long-term ecological dynamics? Which complementarity between on-farm and on-station experiments? How farmers can contribute to design and manage on-station experiments? It seems important to push forward researches that hybridize knowledge and ways of learning of both scientists and practitioners (Francis et al., 2011) to favor technical change and reach the large agroecological transition expected by both the society and public policies.

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References

Altieri, M.A. and M. Toledo (2011) The agroecological revolution in Latin America: rescuing nature, ensuring food sovereignty and empowering peasants. *Journal of Peasant Studies* 38: 587‑612.

Ansell, C.K. and M. Bartenberger (2016) Varieties of experimentalism. *Ecological economics* 130: 64-73.

Benmansour, S. (2017) Les processus de transition agro écologique dans les collectifs agricoles : étude de son appropriation et de sa mise en œuvre à partir de deux études de cas. Master thesis, AgroCampus Ouest, France, 95 pp.

Caniglia, G., Schäpke, N., Lang D.J., Abson, D.J., Luederitz, C., Wiek, A., Laubichler, M.D., Gralla, F. and H. Von Wehrden (2017) Experiments and evidence in sustainability science: a typology. *Journal of Cleaner Production* 169: 39-47.

Catalogna, M. and M. Navarrete (2016) An agronomical framework for analyzing farmers' experiments. Presentation held at the 12th Symposium of the International Farming Systems Association in Newport, UK, 12-15-07/2016.

Chantre, E. and A. Cardona (2014) Trajectories of French field crop farmers moving toward sustainable farming practices: change, learning, and links with the advisory services, *Agroecology and Sustainable Food Systems* 38(5): 573-602.

Deytieux, V., Vivier, C., Minette, S., Nolot, J-M., Piaud, S., Schaub, A., Lande, N., Petit, M-S., Reau, R., Fourrié, L. and L. Fontaine (2012) Expérimentation de systèmes de culture innovants : avancées méthodologiques et mise en réseau opérationnelle. *Innovations Agronomiques* 20: 49-78.

Duru, M. and O. Therond (2015) Designing agroecological transitions; A review. *Agronomy for Sustainable Development* 35(4): 1237-1257.

Elzen, B., Barbier, M., Cerf, M. and J. Grin (2012) Stimulating transitions towards sustainable farming systems. In: I. Darnhofer, D. Gibbon, B. Dedieu (eds.) *Farming systems research into the 21st century. The new dynamic.* Dordrecht, NLD : Springer, pp. 431-455.

Foxon, T., Reed, M. and L. Stringer (2009) Governing long-term social-ecological change : what can the adaptive management and transition management approaches learn from each other ? *Environmental Policy and Governance* 19: 3‐20.

Francis, C.A, Jordan, N., Porter, P., Breland, T.A., Lieblein, G., Salomonsson, L., Sriskandarajah, N., Wiedenhoeft, M., DeHaan, R., Braden, I. and V. Langeret (2011) Innovative education in agroecology: Experiential learning for a sustainable agriculture. *Critical Reviews in Plant Sciences* 30:226–237.

Garbach, K. and G.P. Morgan (2017) Grower networks support adoption of innovations in pollination management: The roles of social learning, technical learning, and personal experience. *Journal of environmental management* 204: 39-49.

Gliessman, S.R. (2007) *Agroécology : the ecology of sustainable food systems*. 2nd ed°.CRC press, 408 p.

Gliessman, S.R. (2009) Editorial: Community-based participatory action research with agroecology. *Journal of Sustainable Agriculture* 33(8): 799–800.

Hocdé, H. and B. Triomphe (2009) L'expérimentation en milieu paysan. In *Mémento de l'agronome*, Montpellier : CIRAD, 511-536.

Ingram, J. (2010) Technical and Social Dimensions of Farmer Learning: An Analysis of the Emergence of Reduced Tillage Systems in England, *Journal of Sustainable Agriculture* 34: 183-201.

Klerkx, L. and C. Leeuwis. (2009) Establishment and embedding of innovation brokers at different innovation system levels: Insights from the Dutch agricultural sector. *Technological forecasting and social change* 76(6): 849-860.

Klerkx, L., Schut, M., Leeuwis, C. and C. Kilelu (2012) Advances in knowledge brokering in the agricultural sector: towards innovation system facilitation. *IDS Bulletin* 43(5): 53-60.

Kloppenburg, J. (1991) Social theory and the de/reconstruction of agricultural science: local knowledge for an alternative agriculture. *Rural sociology* 56(4): 519-548.

Kummer, S., Milestad, R., Leitgeb, F. and C.R. Vogl (2012) Building Resilience through Farmers' Experiments in Organic Agriculture: Examples from Eastern Austria. *Sustainable Agricultural Research* 1:308–321.

Leitgeb, F., Kummer, S., Funes-Monzote, F.R. and C.R. Vogl (2014) Farmers' experiments in Cuba. *Renewable Agriculture and Food Systems* 29:48–64.

Lyon F. (1996) How farmers research and learn: the case of arable farmers of East Anglia, UK. *Agriculture and Human values* 13(4): 39-47.

Murdoch, J. and J. Clark (1994) Sustainable knowledge. *Geoforum* 25, 115‐132.

Peureux, A., (2017) Organization of farmer groups impacts farmer experimentation and learning for agroecological practices. Evidence from Southeast France. Master thesis ISARA Lyon France/ Norwegian University of Life Science, 39p.

Prost, L., Berthet, E.T.A., Cerf, M., Jeuffroy, M.H. and J. Labatut (2016) Innovative design for agriculture in the move towards sustainability: scientific challenges. *Research in Engineering Design.*

Rénier, L., Cardona, A. and E. Lécrivain (2018) New arrangements for an agroecological management of animal health. The case of French farmers learning homeopathy, 13th European IFSA Symposium, 1-5 July 2018, Chania (Crete, Greece).

Ruiz, C. (2017) Etude d'un collectif agricole, la COPAV. Fonctionnement et expérimentations en médecines alternatives, Master thesis VetAgroSup Clermont-Ferrand, France, 161p.

Venot, C. (2017) Rôles d'expérimentations en arboriculture fruitière pour la transition vers l'agroécologie des exploitations. Une étude en Rhône-Alpes. Master thesis SupAgro Montpellier, France, 77p.