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Diverging and Converging Pathways

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Workshop 1.5: Pathways towards sustainability in the agricultural knowledge and innovation system: the role of farmers' experiments and innovations

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Currently, innovation is seen as the key concept for supporting the urgently needed transition towards sustainability in agro-food systems. Recently, clear evidence has been presented that innovation is a dynamic, social, and multi-stakeholder process that implies the participation of a diversity of stakeholders. Participatory action research, citizen science or transdisciplinary research are pioneering approaches for ensuring that not only local knowledge, but also the creativity and enthusiasm of different stakeholders are involved and taken seriously in the related research and innovation pathways. In the agricultural sciences and agroecological sectors, the debate on the role of stakeholders' participation has been framed in various models in the Agricultural Knowledge and Information System (AKIS) or the Agricultural Innovation System (AIS). Nevertheless, the creative process that leads to farmers' innovations is rarely studied nor described precisely in agricultural literature. In the context of innovation research, experimenting is considered a dynamic process that runs for a certain period of time to test an innovation. Farmers' experimentation is the process by which farmers conduct trials or tests that can result in innovative management systems and/or new knowledge suitable for their specific agro-ecological, socio-cultural and economic conditions. Farmers' experiments refer to trying something new at farm level and learning from the results. Innovations and experiments are different but complementary processes. Experiments contribute to the creation of new knowledge, practices or processes – a precondition for the development or adoption of an innovation. There are two reasons why it is particularly interesting to explore farmers' experiments in the context of organic farming and the agroecology movement. First, sustainable land use practices are knowledge-intensive. While conventional farmers can use external inputs to handle adverse dynamics in their agro-ecosystem, organic farmers and other sustainably working farmers need to develop specified agro-ecological knowledge to be able to manage their farms successfully. Second, organic farming in Europe was developed by farmers and farmers' grassroots organisations and by practical experiments and trials of farmers and practical researchers. Academic science and research only played a minor role. The lack of advice and formal research in the pioneer phase of organic agriculture leads to the assumption that organic farmers have nurtured a culture of experimentation. However, it was not only the pioneers of organic farming who experimented. Many organic and agroecological farmers worldwide are presumably actively experimenting to answer questions, to address farm-specific problems and/or to improve their farming system. Based on the multi-stakeholder perspective of innovation development, we encouraged contributions that integrate farmers' knowledge and farmers' research approaches into scientific research and development. We sought contributions from different angles such as participatory action research, citizen science or farmers' experiments and innovations either interrelated to scientific research or done independently by farmers. The workshop acted as a space for multi-stakeholder exchange, where farmers, advisors and researchers could meet alongside each other and share experiences and knowledge about agroecological practices. We also invited papers beyond the farm perspective, looking at experiments of other actors along the whole supply chain of agricultural products or products developed in a certain region. The workshop addressed the development and dissemination of innovation within the farming community at local, regional, national and global level through knowledge networks, like training courses, social media or other dissemination platforms. The overall aim of the workshop was to identify pathways on how to facilitate farmers' experiments and innovations, as well as the experiments of other related stakeholders, and their significance for increasing the farming system's and regional resilience.

Experiments in animal farming practice: the case of decreasing the use of antimicrobials in livestock (France)

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Abstract: Many farmers are engaged in activities that can be considered as experiments, but until recently few of their practices were studied. This paper offers a first characterisation of experiments by dairy, pig and poultry farmers working in organic, labelled or conventional systems. Data (40 interviews) were collected during an interdisciplinary research project on antibiotic use in livestock farming in France. First, we discuss the literature. In line with D.A. Schön's "reflective practitioner model", we agree that farmers mainly carry out informal experiments. Second, we provide an overview of the experimental process (type of farmer's experiment (FE), period, topics, targets and length) and the outcomes (efficiency, transfer, possible impact on antimicrobials use, renewal), drawing on farmers' subjective valuation and qualitative interview data. We find that farmers carry out multiple tests, mainly with alternative medicines. There is a clear tendency of transferring positive tests for a given pathology to one another. Third, we present seven portraits of farmers to shed light on complementary dimensions of experiments: the appeal of novelty, the role of veterinarians and technicians, and the role of farmers' groups and training. Finally, we argue that much can be learned from ethnographic investigation in order to grasp what farmers are experiencing when they endeavour to solve animal health problems.

Keywords: Farmers' experiments, trajectory of change, animal health, antimicrobial use, livestock in France

Introduction

For a long time on-farm experiments were ignored or considered as unreliable (Sumberg et al., 1997; Saad, 2002), but for over two decades now the scientific literature has been highlighting the creativity of farmers in innovation processes. Farmers are currently of interest to academic researchers, who study the concrete modalities of these on-farm experiments and stress how more participative forms of innovation are preferred to the classical top-down innovation regime (McIntyre, 2007). Endorsing the challenge of developing “resource-poor” agriculture - identified by the Bruntland Commission in 1987 (cited in Chambers et al., 1989) as a “complex, diverse and risk-prone” type of agriculture - offered a key contribution by putting small farm families’ agendas and needs at the heart of agricultural research and extension. While the popular Farmer First Movement has not challenged scientific practices as much as expected, the idea of farmer-centred innovation has advanced considerably in recent decades. In a wide range of agricultural contexts and countries the issue no longer revolves around the reliability and reproducibility of farmers’ empirical experiments, but rather around the understanding of their logic and process in a ‘co-learning’ perspective between scientists and practitioners.

The existing literature devoted to small farmers’ creativity draws particular attention to farmers engaged in agro-ecological transitions. To manage their specific agro-ecosystem these farmers carry out numerous experiments, repeated over long-term scales, that constitute factors of resilience (Vogl et al., 2015; Kummer et al., 2012; Chantre & Cardonna, 2014). Experiments related to animal husbandry have lower visibility than those related to cropping and to soil, seed, pest and fertiliser management, although they may be very frequent. For instance, animal experiments appear in second position in the analysis of frequency of topics for Austrian organic farmers’ experiments, as presented by Vogl et al. (2014) (according to thematic clusters on 134 experiments discussed and 123 interview corpuses). However, little is known of farmers’ experiments in animal health management, which might be as widespread as they are in human medicine (Vornax et al., 2010). For example, when farmers adopt alternative medicine for themselves, they often do likewise for their animals.

This paper aims to provide the first characterisation of experiments by dairy, pig and poultry farmers working in organic, labelled or conventional systems. Data (40 interviews) were collected during an interdisciplinary research project on antibiotic use in livestock farming in France (INRA/TRAJ-GISA and CASDAR programmes). First, we discuss the literature. In line with D.A. Schön’s “reflective practitioner model”, we agree that farmers mainly carry out informal experiments. Second, we provide an overview of the process of experimentation (type of FE, period, topics, targets and length) and the outcomes of such a process (efficiency, transfer, possible impact on antimicrobials use and renewal), drawing on farmers’ subjective valuation and qualitative interview data. Third, we present seven portraits of farmers to shed light on complementary dimensions of experiments.

Farmers as reflexive practitioners embedded in socio-technical organisations

Many definitions of on-farm experiments have been given and we may consider them from two different perspectives. Inspired by a “scientific-centred model”, some authors have defined criteria against which an activity may or may not be labelled an experiment. As Vogl et al. (2015) pointed out, the pioneering work of Sumberg and Okali (1997) insisted on two definitional attributes: “the creation and initial observation of conditions and the observation or monitoring of subsequent results” (2015: p. 141). In this perspective, authors make a distinction between *proactive* and *reactive* research. They expect not only discrete actions, but a whole process in which “experiments run first on a small scale and expand if the outcome of the experiments is satisfactory”: a process that requires “regular monitoring” and an “explicit mental or written plan before starting” (Vogl. et al., 2015: p. 140). Adopting a broad view of innovation (“a farmer who is for the first time using a new land preparation method, crop rotation, crop variety etc. is an innovator”). Saad (2002: p. 3) considers likewise “that experimentation is the process by which the innovator generates, tests and evaluates an innovation".

Departing from this scientific approach, a "practice-centred perspective" claims that all practitioners do experiment to a greater or lesser extent, albeit not necessarily consciously. For example, Bentley (2006: p. 458) suggests that people experiment "naturally", that is, "compulsively, effortlessly, without achieving dramatic results, at least not every time". He admits that some experiments are original, while "others simply copy innovations that farmers have seen somewhere else" (*ibid*: p. 451), and stresses the idea that "a few folk experiments will be of interest to scientists" (*ibid*: p. 452). Bentley nevertheless considers that experiments are crucial for smallholders - particularly those of developing countries -who find ad hoc solutions on a daily basis in order to save labour or capital.

This second perspective echoes Schön's reflexive practitioner model. In the 1980s this philosopher and scholar gave further thought to the kind of knowing inherent in professional practice. He brought to light how practitioners solve problems in situations, drawing attention to every detail and abandoning theory to try something new, reframing the situation "in a spiral process of evaluating-acting-re-evaluating" via a "self-reflexive conversation" (Schön, 1963: p. 169). This shift from technical rationality in order to cope with the messiness and uncertainty of practice is key to understanding on-farm experiments. As Schön suggested, the practitioner is not only interested in solving problems; he or she is also interested in the unpredicted effect of his or her experiments. He or she also makes partial interpretations, being able to test several hypotheses simultaneously. We may conclude that practical situations are not very suitable for controlled experiments. Bentley comes to the same conclusion, referring to Latour and Woolgar's study of *Laboratory Life* (1986): while scientists essentially work with "inscriptions", folk knowledges are by contrast poorly "inscribed". Bentley notes with humour that "an invention that took a few moments to create and a few field visits to document ultimately took a whole PhD thesis to validate" (2006: p. 459).

In line with D. A. Schön's "reflective practitioner model" (1983), our multidisciplinary research conjectures that livestock farmers are coping with sanitary issues by predominantly setting up informal experiments. Instead of establishing *a priori*, and hence arbitrarily, a definition of experiments in health management, we seek to draw attention to the ways in which the use of antimicrobials is moving from the 'outside', in the wake of policy or market regulations and in response to social demands, as well as from the 'inside', according to farmers' needs and aspirations. From this point of view, experiments constitute part of the practical tool kit that farmers apply to their animal health management. We assume that farmers are engaged in an ongoing process of testing new practices with the objectives of saving labour and reducing medical expenditures. But we also consider that other factors shape their experiments, such as animal welfare, workplace wellness, sanitary quality of products, and civic involvement to fight against antibiotic resistance: all dimensions that have recently been a focus of criticism in France. Lastly, we consider it important to integrate collective actors and organisations into the experimental process. These represent two analytical standpoints that both the science-centred perspective and the practice-centred one tend to underestimate, in favour of an individual cognitive approach. In fact, the definition of "trajectories of change" is grounded in two postulates: first, change in farming practices is based not only on technical and economic factors but also on social and organisational ones; and second, change is the responsibility not of any single actor - in this case the farmer - but of the network of relations that the farmer weaves with technical and health advisors, feed or medicine distributors, and neighbouring farmers (Fortané et al., 2015).

A qualitative study: from an overview of farmers' experiments to some portraits

To this end, we carried out semi-structured interviews with farmers and key actors of their social network. Farmers' experiments were not a specific topic on our interview grid but they do appear as a striking result. Livestock farmers clearly give much more importance to experimentation than we expected. The sample was composed of 40 farmers (27 dairy, 9 pig, 4 poultry).

In this research we distinguish 5 types of Farmers' Experiment (FE) described by the farmers themselves, that we rank in order of importance of the farmers' initiative and autonomy in experimenting: i) experiments stemming from external recommendations (veterinarians, technical advisers, feed or medicine distributors, professional press, etc.); ii) experiments developed for solving urgent or major health issues; iii) long-term experiments that farmers conduct to increase their autonomy or the farm's performance or to reduce input costs; iv) collective experiments developed in an autonomous and informal environment; and v) collective experiments driven by agricultural extension services.

Regarding the topics of experiments, we take the farm as the unit of analysis. Farmers often try a wide range of substitutes to antimicrobials (vaccination, technical device, alternative medicines, etc.), sometimes combining several of them for the same pathology. In this case, we add the different combinations we identify on each farm, what we call "mixed cases". For example: V (Vaccination) + AM (Alternative Medicine); A (Alimentation) + TD (Technical Device) + V (Vaccination) + AM (Alternative Medicine), and so on. Finally, we have 65 topics of experiments for 40 farms.

We also characterise FE modalities, the starting date and the period of time for which they are conducted (see codification in the tables below). We take into account their concrete target (the herd, baby animals, severely infected animals, a sample).

The farmers' points of view on their experimental outcomes and the decisions they subsequently take are mostly a matter of intuitive valuation. Codification is thus based on subjective farmers' assessments. Researchers put to one side their own judgments on the reliability of the information, especially with regard to the efficiency of the FEs or their impact on the decrease of antimicrobial (AB) use. FE Efficiency and FE Impact on AB codifications are given in the table below. We also characterise FE Transfer (Same Pathology, Other Pathology, No Transfer), and FE Renewal (Yes, Probably, No more).

Along with this broad description, the seven portraits we propose aim to highlight farmers' logics of action. The cases have been selected to include every form of production, and a diversity of contexts and techniques or devices experimented with: vaccinations, food supplements, essential oils, homeopathy, etc. In several cases they lead to important and sustainable change. Some farmers implemented and tested solutions with the help of their veterinarians and advisors or within professional organisations.

Experiments to cope with a growing injunction to change: some results

Livestock production is one of the main targets of public policies to limit antimicrobial medicines in France, in particular medicines that are essential for human health (ANSES 2014). This reduction would meet consumers' demands and would be beneficial to the image of farmers that is regularly tainted by critical media coverage. Antimicrobials are moreover relatively expensive and farmers could stand to gain financially by cutting treatment costs. Many are therefore experimenting with new approaches to the animal health management of their flocks or herds, especially for the prevention and treatment of infectious diseases.

FE Modalities

Table 1 shows that the experiments frequently stem from external recommendations by veterinarian practitioners or other key actors of 'animal health' farmer organisations (14) that conduct pilot studies in the pig and poultry sectors (5). In a similar way, FEs are self-conducted by farmers in a long-term perspective (9) or to solve emergency cases (7). A few particular FEs conducted in 'informal' (non-institutional) farmer groups were identified during the inquiries. They mostly concern organic farmers experimenting with treatments based on unicist homeopathy. Table 2 is congruent with Table 1: FEs take place mostly after the visit of a sanitary adviser or retailer (15+8 mixed cases=23). FEs related to disease incidence are in second position (6+6 mixed cases=12 farms). It is interesting to note that almost one third of the farmers also use their free time to experiment (4+8 mixed cases=12). We may conclude that FEs constitute more than a problem-solving approach. Basically, they are part of the farmer's animal health management strategy.

Table 1. Types of FE

1 = External recommendations, **2** = Urgent health problems, **3** = Long-term FE, **4** = Institutional FE groups, **5** = Informal FE groups.

TYPE OF FE	Farm Number
1	14
3	9
2	7
5	6
4	2
1-3	1
2-4	1
Total	40

Table 2. Period of FE

E = Emergency situation**, D** = Disease incidence, **F** = Farmer Free time,
V = Experiments following the Visit of health advisors or sellers.

PERIOD	Farm Number
D	6
D-E	1
D-F	2
D-F-V	1
D-V	2
E	3
F	4
F-V	5
V	15
Default value	1
Total	40

Table 3 illustrates the variety of FE topics and the importance of multiple tests. In total, 65 experiments were carried out within the sample: 18 farmers carried out multiple tests with 7 different combinations of tests. This table also shows that alternative medicines are frequently explored in the FE (10 + 12 mixed cases = 22 farmers). About one third of the FE concerns alternative medicines (22/65 FE). If we consider the 18 "farmers' multiple tests", we can see that 17 of them experiment with alternative medicines. The FEs using technical tools (such as metering pump in pig production or internal teat sealant in dairy production) are also frequent (7 + 12 mixed cases = 19 farms). Finally, FEs using vaccines concern just under one third of the sample (3+9 mixed cases = 12 farms). These are initial findings that need to be compared to farmers' discourse provided in the portraits below. Even if we adopted a non-normative approach to the definition of an experiment, certain cases have been excluded from our inquiry: cases where experimenting is ‘doing nothing’ while waiting for the animal to recover on its own. This modality is also frequent in human medicine. The idea of “letting Nature” solve the problem and counting on the animal’s immune system is often found in interviews with organic farmers, but this type of farmer is under-represented in our sample. Table 4 indicates that the FEs are mainly run on a long-term basis (19 + 8 mixed cases = 27 farmers). The modality “Regularl” appears for 7 farmers (3 + 4 mixed cases). These two results confirm the main role of FEs in the management of health on farms in our sample.

Table 3. FE Topics

TD = Technical Device, **V** = Vaccination, **AM** = Alternative Medicine, **A** = Alimentation, **O** = Other

TOPICS	Farm Number
AM	10
TD	7
TD-V	5
AM-O	3
V	3
A-AM	2
A-AM-TD	2
AM-TD	2
AM-TD-V	2
A	1
AM-V	1
A-TD-V	1
O	1
Total	40

Table 4. FE Length

O=Once, **S** = Sometimes, **R**= Regularly, **L** = Long term scale

LENGTH	Farm Number
L	19
O	5
S	5
L-O	3
R	3
L-R	2
L-O-R	1
L-R-S	1
L-S	1
Total	40

Concerning the other descriptors, on 19 farms the FEs concern the herd as a whole or the flocks (poultry) and on 14 farms, animal samples (7 + 7 mixed cases = 14 farms).

FE outcomes

Table 5 shows that the FE outcomes range from “good”(14 + 7 mixed cases = 21 farms) to “variable” (13 + 5 = 18 farms). On only 5 farms are FE outcomes said to be “weak”, and “no effect” is mentioned in 5 cases. FEs result in a “small decrease” of antimicrobial use for half of the farmers (16 + 9 mixed cases = 25) and in “no decrease” for 7 of them. In a few cases it seems that FEs result in a slight increase in the use of antimicrobials, when a failure has been followed by an over-use of antimicrobials for safety’s sake. Conversely, 15 farmers (11 + 4 mixed cases) estimate that they experienced a steep decrease of the use of antimicrobials thanks to their experiments.

Table 5. FE Efficiency

G= Good, **V** = Variable, **W** = Weak, **Z** = Zero

EFFICIENCY	Farm Number
G	14
V	13
G-V	3
W	3
Z	2
G-V-W-Z	1
G-V-Z	1
G-W	1
G-Z	1
dv	1
Total	40

Table 6. FE Impact on AB Use

H = High decrease, **S** = Small decrease, **N** = No decrease

IMPACT ON AB USE	Farm Number
S	16
H	11
H-S	3
N	2
N-S	2
N -S	1
N-S	1
S-H	1
S-N	1
dv	2
Total	40

Concerning FE transfers, there is a clear tendency to transfer positive tests run for a given disease to another disease (21 + 5 mixed cases = 26/40 farms). For example, when a farmer gets a “good” result for the use of an essential oil complex to prevent mastitis, he uses the same product for lameness disorders. However, in one third of the cases there is no transfer (8 + 5 mixed cases = 13/40 farms). The renewal of FE is planned in more than half of the farms (22 + 4 mixed cases = 26/40 farms) and is considered as possible on 9/40 farms (5+ 4 mixed cases).

These results concern a restricted panel, with a heterogeneous representation of the different types of animal production. It is therefore hardly possible to test some of the hypotheses, such as the existence of sector specificities regarding farmers’ experimental modalities or outcomes, or even their effects on antimicrobial use.

Trajectories of change and experiments

The aim of these portraits is not only to embody our data. They are intended to shed light on complementary dimensions that could not be taken into account in our descriptors (which remain necessarily simplistic). Three dimensions appear: i) the articulation between farmers’ motivations or interests and the advice that they may find through training, farmers’ collectives or their technicians and veterinarians; ii) the “taste” for experimentation, the appeal of novelty, the “handiwork” (in an anthropological sense); iii) the global thinking about farming practices in which experiments take place and sometimes lead to a reconsideration of their usual techniques.

Portrait 1: A conventional dairy farm (in the Maine-et-Loire French département*), around 75 cows, 2 partners. Individual experiment.*

Tests implemented on this farm focused mainly on essential oils used to treat mastitis without using antimicrobials. These tests started in 2014 after the farmer attended a training course on essential oils. He took the initiative to undertake this training with the Ile-et-Vilaine CIVAM because he could find no help on these subjects in his own local environment. Among this farmer's motivations for using essential oils, he highlighted not only the natural aspect of the treatment but also the fact that it was less invasive than an injection of antimicrobials.

Moreover, the farmer pointed out that having less mastitis on the farm enabled him to perform tests on one or two cows without taking too much risk. As soon as he reached 4 or 5 cases of mastitis at the same time, he treated them directly with antimicrobials. The farmer explained that when using essential oils, the disappearance of symptoms and the recovery did sometimes take more time than when antimicrobials were used, but according to his tests the efficacy of oils and antimicrobials was similar. In the cases of relapse or *E. coli* mastitis, he nevertheless used antimicrobials systematically.

Naturally curious, this farmer enjoys using different oils, which he chooses according to each cow's characteristics and applies on different areas. In addition to being curious, this farmer has quite a systemic view of herd health management, and is vigilant as regards milking hygiene, cows' positions or the genetic selection of cows with an index of positive "cells". There are many techniques in preventive treatments for mastitis.

Portrait 2: A conventional dairy farm, 40 cows, father and son family business with the grand-father's help.

According to this farmer, the key to keeping cattle in good health is to adapt the production level. His professional objectives are now geared towards a good technical-economic balance rather than pure technical performance. This choice has led to changes in his farming practice. At the moment he is generally satisfied with the sanitary situation on his farm. He has a preventive approach and pays special attention to feed, the cowshed and hygienic milking practices.

One of the main changes he made was the implementation of selective treatment during the drying-off period. It started quite by chance, just because of a stock shortage in antimicrobials on his farm. As the results were conclusive, he applied the selective treatment (no antibiotics, only a teat obturator) on more cows, even on infected ones, which is not recommended. He then developed a more successful protocol taking into account somatic cell concentrations and production levels.

Today, he has scaled-up the selective treatment in the drying-off period. He uses no treatment in the case of cows that have a very low level of production especially when they are about to be fattened and slaughtered. Aware of the risk, he accepts it because he is able to assess risk factors and to adapt his practices if necessary.

He developed this new practice alone, autonomously, without discussing it with his veterinarian. This farmer feels concerned about antimicrobial reduction, which he sees as an imperative new challenge for all farmers. He is getting ready… and would like to acquire methods or new techniques to ensure successful change and to enhance his preventive approach. He does nevertheless still consider that antimicrobials have their role to play in a curative approach.

Portrait 3: An organic dairy farm. Brittany. About 50 cows, transition to organic farming in 2002, family farming.

Experiments that have been set up on this farm mainly concern homeopathy, but also some solutions that existed before the 'antibiotic era', such as traditional remedies (for example oil or cider vinegar). The farmer learned some principles from his homeopathy training in 2002, such as the importance of watching animals and considering animal health "as a whole". Regarding treatments, he likes to develop his own recipes. He therefore buys ingredients to make his own homeopathic mixes, following some indications in the 'Boiron revue'. When he tests a treatment, he watches the animal much more closely than usual and usually waits some time before calling the veterinarian (if the problem remains unsolved). Usually his wife does not agree with him on that. The philosophy of these experiments is to try them on just a few animals and spread them slowly to others (this includes "doing nothing", which can also yield results).

Portrait 4: A dairy farm with labelled raw cheese production, with 4 associates and 4 employees in Burgundy

Milk quality is an essential issue on this farm which produces raw cheese. The animal food system was entirely renovated a few years ago with a drying process in a barn, to improve the quality of the cheese and to acquire more autonomy. Watching and touching animals is very important to detect mastitis early. Phytotherapy (herbal medicine) is used as a preventive medicine: "*for us, animal health is observation so there are things that we are being able to treat with phytotherapy… when we see that there is a mastitis, we work with herbal medicine before using any antimicrobials*". This farmer uses treatment that he buys at a retailer but his intention is to learn quickly how to prepare his own treatments. The farmer in this case study used phytotherapy for the first time in an emergency situation (*Staphylococcus* that antimicrobials could not eradicate) that was impacting the farm's profitability. He did some research on the internet in order to find new solutions: "*so we immediately stopped antimicrobials and we started to sort our herd into three groups, from the most infected to the least infected. And then we started to search for some information about herbal medicine and we got lucky 'cos someone… it was just by chance, but someone came, from a commercial organisation, that was doing phytotherapy. So we started like that and in about 6 months, the problem was solved, all of our cows became healthy again*".

Portrait 5. A multi-activity farm with vines (40 hectares) and poultry breeding (22 pens), run by a 50 year-old man and 2 employees. Collective tests on Label Rouge "yellow" broilers

The main purpose of the tests was to identify technical improvements to be made: food intake, less antimicrobials use, water quality, etc. The farmer was on the board of directors of the farm organisation. He had been running the farm since he inherited it from his father. He was breeding free-range poultry in pens, what are known as *"cabans"*. The farmer organisation was running tests on the feed quality by changing/adding some components, and it needed the farmers who were members of the organisation to test the feed on a flock. That was how the farmer became involved in the testing, which could be considered as teamwork initiated by the farmer organisation. To him, this was a source of personal pride.

Portrait 6: A free-range poultry breeding in poultry house, Label Rouge, in the Landes region

This multi-activity farm had 5 poultry houses of 400 m² each. Run by a 50-year-old man who had inherited the farm from his parents, it bred and force-fed various types of "label rouge" poultry (ducks, broilers, guinea fowls, turkeys) for the foie gras industry. The farmer's experiments aimed at decreasing the occurrence of digestive diseases in chickens, in the hope that this would in turn result in decreasing the use of antimicrobials. It provided a very interesting example of cross-learning between species. This farmer diversified by breeding different types of poultry. He transferred what he observed from one species to another by running tests. He solved health issues on ducks by analysing the water and setting up a system to control the pH of the water. In particular, he wanted to see how the water's pH could improve the digestive health of broilers and guinea fowl. He also transferred the idea of a higher temperature from turkeys to broilers.

This farmer developed his own tests, without any collaboration with the technical staff of the farmer organisation, but he did also exchange breeding experiences with other farmers. One of his neighbours learnt from him how to lower the pH of water. This shows how learning passes from one farmer to another. The salespersons working for agricultural hygiene companies also played an important part in that process, by offering technical alternatives to farmers.

Portrait 7: A family farm with 310 sows in Brittany. Farrow-to-finish. Installation in 1994.

This farmer took over the family farm in 1994. At the time it had 230 sows but he increased the herd up to 310 in 2006. Almost all the farm buildings had been renovated just before he arrived. This farmer had never changed his cooperative and had had the same technical adviser since 1996. He had also had the same veterinarian (who worked with the cooperative) for many years. He considered economic performance to be very important, and health management to be one of the main parameters of profitability. He did not however consider himself to be someone who was willing to test everything just to try to increase his performance. So the experience of his colleagues (other farmers) that he shared in some collective groups like the CETA or training courses organised by his cooperative were almost more important than 'just' the advice of his veterinarian and technical advisor. Related to his economic motivation, he also valued his cooperative's technical and commercial strategies (he was involved in several bills of specifications) to value certain breeding practices, especially those promoting animal health and welfare:

"*This is a whole set of things. When you have projects like that, you have to get some information. You check with your veterinarian and your technician, you ask questions. Right now, I want to renovate my boarding dock, so I asked my technician, I asked my veterinarian. But I also belong to a working group, with some colleagues of mine. So we do a kind of a brainstorming and so you see if you're right or wrong. But it depends on our characters too. Some are more pioneering than others, they always rush into tests and innovations. Others have more of a wait-and-see approach, they do something only when they're sure it will work. I'm more in the second category*".

Conclusion: a call for further in-depth investigation

This characterisation of FE in the case of decreasing the use of antimicrobials in French livestock farming brings to light a wide range of practices that are often overlooked by veterinarian practitioners and sanitary advisers. It could serve as a starting point to extend the investigation in order to obtain a fuller picture of these FEs in health management, as in the example provided by researchers for organic production (Vogl et al., 2015). Other methods are likely to be used and we assume that other issues would appear. In particular, a questionnaire survey completed by farmers would face the tricky issue of health norms and answers would be those expected by scientists and advisors. We nevertheless consider it to be of great interest to push forward this perspective. At the same time, we are convinced that much can be learned from ethnographic immersion if we wish to gain more insight into what farmers are experiencing when they try to solve health problems.

We have found that many farmers are using alternative medicine together with antimicrobials and that a large number of them do not think that essential oils or homeopathy work as well as antimicrobials. That is why they use both kinds of medicine. In some cases this contributes to incremental change in health management, while other farmers choose to redesign their whole herd management system and to stop antimicrobial use altogether. The combination of different kinds of medicine has likewise been observed by Bentley (2006) in Western Salvador. He found that smallholder farmers were using botanic and chemical pesticides alternately for managing pests. Such a strategy of association between conventional and alternative medicine should be investigated further because it seems to be at the core of many farmers' experiments.

Overall, a majority of the farmers surveyed, whether conventional, labelled or organic, try different combinations. French dairy farmers sometimes use essential oils with local antimicrobials to prevent mastitis. This kind of practice is also found with free-range chicken farmers, even though it seems in their case that experiments are more collectively designed because of the importance of health and technical advisors in labelled production. These experiments are often designed to save on cash expenses but that does not mean that do not have other motivations for changing their practices (such as environmental or public health considerations). Farmers' experiments leading to a reduction of antimicrobial use should therefore not be analysed as a response to a political, social or professional injunction to remove those pharmaceuticals from animal health practices. In fact, some farmers still use antimicrobials and, in the worst cases, their consumption even increases a little. Most experiments are actually driven by a (changing) way of considering farming and animal health in particular. A reduction of antimicrobials could be a consequence of these experiments but should not be considered as the only or even the primary motivation. The same conclusion can be drawn from the study of conventional pig farmers. Even though the kinds of experiment they carry out are quite different because of the socio-technical and socio-economic configuration of industrial pig production (importance of building management, feed or vaccination choices), and because of the long-term nature of their changes in practices (they not only run "tests", they also plan them over months or years), their way of constantly re-inventing herd and animal health management is clearly determined by this overall conception of farming. The question that arises here is not whether farmers should reduce antimicrobials or whether they should de-intensify their farming practices, but rather how they are trying to re-appropriate some injunctions, recommendations, and technical and scientific prescriptions in their overall activity of pig, poultry or dairy farming, that fit with their conception of their work.

Ethnographic investigation would certainly more adequately document this aspect of farmers' experiments.

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From seed to bread: co-construction of a cereal seed network in Wallonia

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Abstract: After losing its artisan character after World War II, bread is now commoditised as the outcome of an increasingly globalised seed, cereal growing, milling and baking industry. Yet, alternative pathways are emerging to develop a more resilient and locally-adapted cereal system. Our case study focuses on exploring the emergence of a cereal seed network in Wallonia, which gathers farmers, millers, bakers, households and researchers. In this paper we look into the creative process of co-construction of this network, after 3 years of participant observation. We explore how group objectives and personal motivations evolved along with internal and external events. The main objective of this network is to conserve and breed a diversity of cereal varieties adapted to local agroecological food systems. Our results show that: (i) novelties are being produced and tested in farms; (ii) opening up a safe-learning space favours networking of these isolated novel actors; and (iii) collaborative management of cultivated diversity entails opportunities and challenges. We discuss these results in the light of similar experiences of seed networks in Europe and outline questions raised by challenges faced in participatory research on seed. Our conclusions suggest that in order to improve the nutritional quality of bread and develop a more resilient cereal system, collective management of seed and participatory plant breeding programs should be fostered. This will need a reversal of agronomy research approaches and of priorities in food policy.

Keywords: Seed network, participation, co-construction, agroecology, bread, cereals, Wallonia

Introduction

From seed to bread: consequences of the modernisation of the cereal system

In Europe the post-World War II food system established firstly a formal seed system creating pure-line standardised varieties that gradually substituted landraces and excluded farmers' seed selection practices and knowledge. Another consequence of this evolution was the continuous decline of cultivated diversity, both inter- and intra-specific, resulting in genetic erosion (Bonnin et al., 2014). Losing cultivated diversity also involves loosing associated knowledge, which can be termed as cultural erosion (Vára-Sanchez & Cuellar-Padilla, 2013). This loss in genetic and cultural diversity reduces options for adapting to changing conditions and thus threatens the resilience of farming systems (Hajjar et al., 2008). Because low-input farming has to adapt to greater environmental variability than high-input farming, it needs heterogeneous varieties that have a capacity to evolve and adapt to these changes (Rivière et al., 2013). Yet today most organic and agroecological farmers sow pure-line (homogeneous) varieties bred for high-external input farming, which are inadequate in the light of the challenges they face (Bueren & van Myers, 2012).

Farmers are not the only actors of the food chain affected by changes in the cereal seed system. Although modern wheat breeding enabled substantial yield gains, almost unilateral focus on this criterion led to downside effects such as decrease of mineral density or selection of a type of gluten, which may produce non-coeliac hypersensitivity. Changes downstream also impacted bread quality: industrial milling and baking practices have favoured white airy bread, with high salt content and low nutritional value, based on standardised flour mixes from cylinder-type mills. In classic bakery training programs, students no longer learn to bake with sourdough or without flour additives (Rémésy et al., 2015).

Emerging alternative networks and accompanying research

The global food system is in crisis but due to mechanisms related to path dependency and lock-in, promising alternative pathways towards sustainability struggle to gain legitimacy (Sutherland et al., 2012). Nevertheless, some of these pathways are gaining momentum. On the farmers' side, a groundswell of change is driven by a quest for more autonomy, through better use of internal resources and lesser reliance on global markets. On the households' side, a similar change is driven by a desire to reconnect with the land, find local food of better nutritional quality etc. Both sides are connected through the process of repeasantisation and the emergence of novel food markets linking farmers directly to households (van der Ploeg, 2008).

Institutional and research discourses (and practices) are also shifting. Participatory approaches are now acknowledged as an asset to foster innovation. Still there are various types of participation ranging from passive participation to more active forms like self-mobilisation. In more passive forms, the first-concerned actors are not included in co-producing knowledge or in decision-making. Active forms of participation rather try to enhance the skills of rural actors and encourage them to develop and promote their own processes (Cuellar-Padilla & Calle-Collado, 2011). This is the type of participation adopted for example by agroecology, in which we ground our research approach. We refer here to the specific concept of agroecology, defined as an intermediary action concept at the crossroads of science, practice and social movements (Wezel et al. 2009; Stassart et al., 2012). Agroecology seeks to establish a "dialogue of knowledge", which Rosset and Martinez-Torres (2014) summarised as a "*dialogue among different knowledge and ways of knowing*" which can "*form the basis for construction of new processes*". Other research traditions fuelled the debate on participation, like Farming Systems Research (Darnhofer et al., 2012) or Participatory Action Research (Reason et al.; 2006).

Regarding the seed question, numerous authors underpin the importance of farmers' contribution to the management of cultivated diversity (e.g. Osman & Chable, 2009; Pautasso et al., 2013). Technical and social innovations have appeared over the last 20 years - e.g. on-farm evolutionary plant breeding (a method based on genetic diversity and natural selection to develop locally adapted populations) (Döring et al., 2011) or participatory plant breeding (PPB). PPB can be defined as the participation of several actors (farmers, consumers, researchers…) in the breeding process and is based on the complementarity of knowledge and know-how of each participant (Cecarelli, 2012). Rivière et al. (2013) suggest a methodology for co-constructing a PPB project between farmers, local organisations and researchers: each step is collectively defined and evaluated. They outline that co-construction demands time and trust-building.

Aforementioned scientific and societal issues can also be found in the Belgian research and extension landscape, where until today alternative pathways for managing cultivated diversity remained hidden. Very little research has been carried out to understand and appreciate the dynamics, motivations, knowledge and strategies of farmers (and their networks) regarding varietal innovation within the cereal system. It is our assumption that this should be the first step when co-constructing any participatory research project (e.g. PPB) and to developing a sustainable and locally adapted cereal system in Belgium. Therefore we wish to contribute to the debate on the elements needed while conducting research that seeks to understand and support alternative pathways laid out by food networks.

We do so in this paper by looking into the creative process that led to the emergence of a cereal seed network in Wallonia. We also provide some first reflexive thoughts on our role as researchers in this process. First we briefly explain the method used to analyse the co-construction and make explicit our role. Second we present results about the trajectory of the network. We then discuss main outcomes, key challenges and the questions they raise. Finally we conclude with some perspectives on changes needed in order to foster innovation throughout the cereal system.

Case Study and method

In Wallonia, although cereals are the second most important crop in terms of land area (wheat representing 70% of cultivated cereals), bread wheat cropping declined to the point where most farmers grow low-quality forage wheat[1] and most bread grain is imported for an increasingly large-scale and globalised bread baking industry (Delcour et al., 2012). Within this context, different actors of the cereal system are reclaiming an active role in defined seed and bread quality (Louah et al., 2015)

Field research started in 2013 by carrying participant observation in farms developing alternative pathways for bread wheat seed, in southern (Gaume) and western (Hainaut) Wallonia. From then on we participated in all meetings and activities of the emerging network (Table 1), whose evolution is described in the results section. As the network grew and consolidated, our research approach evolved alongside and became more action-oriented in order to co-construct this regional seed network.

Grounded in agroecological participatory approaches we look as much on the improvement of the situation as on the process for this improvement. In this paper we focus on the process itself. We conducted a content analysis on meeting reports, notes taken throughout the whole process (group and individual meetings, field trips, workshops etc.) and email exchanges. This enabled us to build a narrative of the trajectory from isolated individual initiatives to the emergence of the network. We then draw on the framework developed by Combette et al. (2015) to illustrate the history of collectives working on cultivated diversity in France, adapting it to our case study. We used a timeline (Table 1) to organise data in order to visualise the chronology of the process and show that the networks' functioning and activities are continuously evolving. We synthetised and classified data in five categories: group objectives, internal events, evolution of the core group, individual motivations and reflexion, external

[1] As it is easier to obtain high yields and less risky, farmers generally prefer to sow varieties destined to become animal feed or to produce biogas.

events. Lastly we focused on examining challenges faced in regard of the growing dimension of the network and questions raised, in the light of scientific literature.

Results

Varietal novelties are being produced in distinct farms

While carrying participant observation in farms developing alternative pathways for bread wheat seed, we identified two distinct local initiatives. Benjamin[2] is a farmer-miller from southern Wallonia (Gaume). Among other experiments, he takes part in a French participatory plant breeding (PPB) program, which developed an innovative methodology for on-farm breeding (Rivière et al., 2013) in response to the demand of farmer-bakers from the Réseau Semences Paysannes (RSP, French seed network). Benjamin's motivation is to develop bread wheat peasant populations adapted to his "*terroir*"[3] and artisan bakery. On his farm, seed-related work is collective. It is both a political choice and a necessity in order to overcome the big amount of work to be done: sowing, harvesting, threshing and seed cleaning and sorting. These collective action moments are also an opportunity to exchange seed, knowledge and know-how. A supportive group of "eaters" helps with work organization.

At the same time, at the other end of Wallonia (Hainaut, Western Belgium), other farmers were also reflecting on agroecological solutions for production and processing of cereals. They gathered together in a very local network of "outsiders" to form the agroindustrial modernisation project: the *"Réseau des fermes novatrices"* (RFN) which means "innovative farms' network". They spontaneously chose to change their practices and establish new relations with other spaces (consumer groups, schools, restaurants…), thus producing novelties (Louah et al. 2015). Among other subjects, they started working together on bread cereals and were particularly interested in testing old as well as modern population varieties of cereals (e.g. the Composite Cross Populations developed by the Organic Research Centre in the UK). This dynamic group organised meetings and field trips to foster exchanges between them but also with other rural actors and researchers. Their wish is to develop new partnerships with scientists (in particular agronomists) that differ radically from the most common linear knowledge transfer model.

Due primarily to geographical distance, these local initiatives were evolving in parallel, with few contacts with each other.

Isolated initiatives join into a regional cereal seed network

Farmer-researcher interactions played a key role in triggering a regional network dynamic. Concomitantly to the start of this PhD research project, a growing interest in traditional varieties was arising from actors of the non-industrial cereal chain. People who came to help Benjamin with seed-related work started going back to their farms and gardens with a bag of seed from his population of landraces. They started calling themselves "ancient wheat sowers". In the autumn of 2013 we suggested structuring a learning group gathering farmers (4), millers (2), bakers (2) and gardeners/consumers (3) from the South-East of Wallonia. The aim was to create a space for knowledge sharing and collaborative learning "from seed to bread" between "ancient wheat sowers" as well as other stakeholders.

[2] This fictitious name is used in order to preserve anonymity of participants.

[3] Not translatable French word for local land.

This group progressively expanded and transformed into a cereal seed network (now with 82 members) that aims at reconnecting stakeholders from the non-industrial cereal chain and collectively reclaim seed sovereignty. One of the turning points happened in November 2014 when Benjamin induced a meeting between the researcher and two bakers willing to spend time on the seed question in cereals, particularly by favouring knowledge exchange and networking farmers and bakers. The agreement was to start first with a core group that would set a basis for a future network, and secondly to broaden it to actors interested in joining in. A series of observations and objectives were co-defined. The time was judged right to provoke a first wider meeting to confront these to other identified actors.

Thus the networks' launch meeting was held at the beginning of January 2015. The main criteria for participant selection was trust, guaranteed by peer recommendation. There was also a will to have a strong representation of farmers, thus efforts were made to personally contact potentially interested ones. Mostly bakers came and this has proven to be a continuous challenge throughout the process; while a lot of farmers claim to be very interested in the subject, time is clearly a constraint to their active participation in meetings and group dynamics in general. Bakers, however, generally have more time and it is only one of the few reasons why this collaboration between stakeholders can be so interesting and fruitful. A series of observations were shared with participants as a starting point. These were mainly (i) local initiatives are emerging, from farmer to baker, to develop a non-industrial cereal system, but they are disconnected; (ii) interest in other varieties (landraces, populations, ancient species) is rising but faces the challenge of learning (forgotten or new) knowledge and practices. Participants were then asked to present themselves, their **individual reflexions and motivations** regarding the network and whether they agreed with the observations made. All of them agreed but some debated the need to formalise a structure, which involves a substantial amount of administrative work. It was also noted that initial **group objectives** were very large (Table 1). Thus it was agreed to start with concrete actions, which would create knowledge exchange opportunities but also enable actors to get to know each other. This would also nourish further reflexion to progressively refine group objectives. In order to do that, simple communication tools were to be created. Finally it was stated that this regional network does not replace local initiatives and networks, rather it is complementary. Later a name was decided for the network: *Li Mestère*, meaning in the Walloon dialect a mixed cereal crop, often wheat and rye.

Among actions undertaken until now (**internal events**) are farm, mill and bakery visits, experience-sharing meetings, technical and practical workshops on sourdough bread making, wheat landraces selection criteria etc. In 2015, after searching several public and associative seed banks for material, *in-situ* collections of wheat, spelt and oat landraces were set up in several locations of Wallonia. *Li Mestère* also became a member of the Réseau Semences Paysannes (France). This allowed 6 farmers and 3 gardeners to participate in the French PPB program (with the RSP and INRA-Le Moulon) and thus get familiar with its technical and organisational aspects (Table 1).

External events (Table 1) have also stimulated individual and group motivations and reflexions. These include seminars, workshops, field trips organised by other actors (e.g. other farmers' associations), but also national and international networking of seed initiatives (not only cereal, but also vegetable seed). In parallel, biannual network meetings were times to refine and prioritise **group objectives** (Table 1). In September 2015, 3 short-term objectives were identified: (i) favour better access to information and technical training (conservation and breeding, cropping, milling, baking); (ii) set-up a dynamic *in-situ* collection of wheat, spelt and oat landraces (in several locations); (iii) consolidate the PPB project. Long-term objectives (communication and awareness raising, legal and political support) are to be addressed in a second time according to the process' evolution.

The **evolution of the core group** (Table 1) was in parallel to the objectives' refinement. Until recently, the original driving force (two bakers and a researcher) assumed secretarial tasks and co-facilitation. They also co-constructed information and communication tools to support group objectives: mailing list; shared file storage; flyer; and training material (technical forms). The network is at a new turning point, where it seeks to evolve into a more horizontal structure; for each priority objectives 2 or 3 persons are responsible for its operational framework and implementation. Again it raises the question of whether it should formalise a legal structure in order to appoint a group facilitator.

In the co-construction process presented here, we are both researchers and participants. This increases even more the need for reflexive thinking on our role in this process. As researchers, our role relies on 3 specific contributions within the core group:

(i) Providing technical support for optimising practices of in-situ dynamic management of cultivated diversity (e.g. giving advice on how to sow and manage experimental microplots and how best to conserve seed…);
(ii) Supporting the learning process in order to foster emergence of conditions for knowledge exchange and production. A significant part of our time is dedicated to creating a safe-learning space and co-facilitating the network's life and activities - the organisation and facilitation of meetings, field visits, training; maintaining personal contacts with members; connecting with other associations/networks etc;
(iii) Understanding the learning process: assessing learning outcomes from the content (of the process) and the process itself.

The emergence of the network was favoured by our involvement and expertise, but co-construction was made possible by the already latent dynamic - in other words, the timing was right.

Table 1. Co-construction of Li Mestère, a cereal seed network in Wallonia (Belgium)

Group objectives	Internal Events	Evolution of core group	Time	Individual motivations and reflexions	External events
	Collective harvest and threshing of on-farm wheat trials "From Bread to wheat" on-farm workshops	Informal group of ancient wheat sowers	2013	What is a good wheat? How to breed it? Political act to spread seed Bakers' acknowledgement of cereal quality Collaborate with research	Participatory film on wheat landraces PhD start – participant observation
Link farmers and bakers around seed through knowledge sharing Better cereal and bread quality Fair commercial relations between actors	"Ancient wheat sowers" tour Collective harvest of on-farm wheat trials Experience and knowledge sharing meeting Pre-definition of group objectives, identification of stakeholders and pre-selection of participants for potential network	Informal group of ancient wheat sowers and RFN 2 bakers + 1 researcher	2014	Find varieties adapted to "*terroir*" and test best practices Knowledge on landraces and populations Multiply "seed that matters" Find processing and marketing outlets Peasant-baker status recognition Concrete change happening	PPB seminar in France ECVC seed workshop in Brussels RFN farm visit
Create knowledge exchange opportunities	Network creation and objectives refinement Sourdough bread workshops	2 bakers + 1 researcher	2015	(Need for) structuring network – divergence of views on how Need to expand core group	"Agroecology in Action" –mill visit and experience

Better access to information Technical training Set-up of seed collection Consolidate PPB dynamic Find varieties adapted to farmers and bakers	Field visit Study trip to North of France (on PPB) RSP membership Peasant Cereals Feast (workshops and seed exchange) Network meeting: update of objectives Seed prospecting and collection set-up 9 members engage in PPB program (national and pre-sowing meetings) Development of communication tools				sharing workshop in Flanders 2 watermill takeovers On-farm experiment on SWI (with INAGRO)
Map initiatives and needs Networking (other actors) Long term: awareness raising; legal and political support	Network meetings (detail subtasks) Workshops on sourdough and landraces Study trip to South of France (PPB, gluten) Field visits (collections & PPB)	2 volunteers for each of the 3 priority themes	2016	More training on criteria for choosing landraces	MAP work on alternative bread sector Coordination of seed initiatives in Benelux

Collaborative management of cultivated diversity entails opportunities and challenges

Today *Li Mestère* remains an informal cereal seed network but gathers around about 82 farmers, bakers, millers, gardeners, citizens and researchers. Within this bread/cereals renewal and accompanying research, a collective management of cultivated diversity is arising. Field trips, meetings and workshops strengthen interactions between actors, intensify seed and knowledge exchanges (between practitioners as well as between the researcher and them), foster on-farm experiments and initiate co-construction of a collaborative research. Finding seed to start this process also required collaborating with others: *ex-situ* seed banks but also existing groups or seed networks. A couple of French associations that maintain collections of landraces helped *Li Mestère* by providing seed samples (in larger amounts than seed banks). Networking also made visible hidden novelties being produced on-farm that are orphaned by conventional agronomy research and extension. Some of these novelties tackle problems at the food system level. For example, a young farmer created the first Community Supported Agriculture system adapted to cereals in Belgium, experimenting in this field also created a social and solidarity economy. Other farmers tested novel farming practices. Regarding wheat cropping, one innovative agroecological practice which comes to the fore is the System of Wheat Intensification (SWI). Several farmers of *Li Mestère* are testing it at the moment. We are co-constructing research with them to assess the potential of these innovative practices, in the light of objectives collectively defined inside the network but also within this parallel collaboration (Table 2).

Table 2. The System of Wheat Intensification: an innovative wheat cropping practice

The System of Wheat Intensification is named after the System of Rice Intensification (SRI), which was discovered in Madagascar and first described in 2002. Since then, farmers and researchers have begun adapting and extrapolating its principles to a range of other crops, so that we can now speak of a general system of crop intensification (SCI) *(*Abraham et al., 2014).

SRI has been reassessed while insisting on aspects of basic plant husbandry and soil life, challenging a series of blind spots of the mainstream agronomy and plant breeding that underpinned the Green Revolution. In a nutshell, the SWI consists of a set of interrelated practices based on considerably reduced seeding density to lower intra-crop competition (from the conventional 150-200 kg/ha to 20-40 kg/ha). Together, these practices work synergetically, stimulating intensive tillering, maximal ear development and minimal tiller death. In all, individual plant vigour and total grain yield are improved with minimal cost or external inputs, therefore addressing the need for ecological (re)intensification and having a positive impact on farm autonomy. Interestingly, the low densities also change the phenotypic expression of the genotype, which has huge consequences for plant breeding. Some (conventional) plant breeders now challenge the standard practice of high seeding density in wheat that became entrenched during the twentieth century as there is a trade-off between yield potential (through tillering) and competitive ability.

The obvious question then is: what if this practice is combined with evolutionary breeding? Can the local adaptation process of populations be enhanced through selection within an SWI environment? In order to explore this, a master thesis student is carrying out an on-farm experiment. In this trial we compare how a pure-line vs. a population behave under SWI vs 'normal' density (following the farmer's usual practices). This work also includes a survey of farmers practising different variants of this system.

The encouraging rapid growth of this network broadens out the realm of the possible but also raises new challenges and *in fine* questions to be examined. Two main challenges are currently being experienced within the network. The first one is linked to legal issues. From the beginning, the question of (il)legality was raised. Formalising a network means at the same time enhancing visibility of 'hidden' practices (thus exposing members) and creating a strong solidarity web (reaction and claim power). It is also a means to legitimise the existence and purpose of these practices. Yet recent evolution of (inter)national legal frameworks and seed property rights jurisprudence have enhanced concerns on farmers' rights in general, and in particular related to seed sovereignty. This situation breeds distrust regarding collaboration with research or private seed industry or even seed artisans, fearing predominance of individual or commercial interests, or even biopiracy. This raised the question of how to collectively define and agree upon rules for the use and circulation of seed. The second main challenge faced today by the network is its long-term durability perspectives. Indeed it could be hindered because of the voluntary nature of most work done. To systemise and possibly legitimise this kind of action-research, a longer-term financial security could be necessary - for a network facilitator and for research partners, including farmers. This could generate a leverage effect for a regional PPB project or new and fruitful collaboration between different research areas (eg. social and natural scientists), in order to lead transdisciplinary systems research - from seed to bread. However funding has proven difficult to obtain for such a transversal approach because most funding goes to highly specialised object-oriented research. This raises the question of how to legitimise this type of research.

Discussion

This case study of co-construction of a seed network is limited to a specific crop and region. However our results have a broader significance when put in perspective with other research found in literature. Firstly we link up with other similar studies on seed networks in Europe. Secondly we discuss challenges for participatory research and on-farm management of seed.

Experiences from other seed networks in Europe

The main outcome of our work is that it highlights that ever more farmers, but also other stakeholders, are reclaiming an active role in the cereal system and leading their own experiments. Informal local networks are emerging in Belgium with different starting points (e.g. find cereal seed adapted to organic farming practices vs. find market outlets for organic cereals) yet joining in a broader regional movement. Combette et al. (2015) claim that the generation gap in seed and associated knowledge transmission, very marked in western Europe, is one of the reasons why collaborating is almost a necessity for anyone willing to start working towards seed sovereignty. According to their experience with a French seed network, creating knowledge exchange opportunities can result in co-producing new knowledge and practices. Also collectively tackling a problem induces a faster (and eventually more lasting) progression than when facing it alone. According to Pimbert (2011), farmer networks and other types of platforms are *"key for mobilising capacity for social learning, negotiation and collective action for research into the management of agricultural biodiversity"*. Indeed food systems' modernisation generated disconnection and disembeddedness resulting in a loss of autonomy and identity (Milestad et al., 2010). In these *"safe spaces"* the unvoiced can gain confidence to dialogue, frame alternatives, build alliances and act upon their food system. However, authors have pointed out that such spaces can also reproduce certain forms of exclusion (e.g. gender) or power issues if some precautions are not taken (Reason & Bradbury, 2006).

Challenges for participatory research and the on-farm management of seed

The young network on which our study focuses faces challenges, even more acute in the light of its rapid expansion. Can different perspectives and insights still be equally integrated when the number of involved members or geographical distance grows? This also demands a continuous self-reflexion on the way the network integrates with the real world and how it develops and communicates within it (Combette et al., 2015). At this point challenges faced by the network bring forward two main questions: i) how to collectively define and agree upon rules for the use and circulation of seed; and ii) how to perpetuate the network and how to legitimise this type of action-research, in a context where funding is difficult to obtain. Lack of investment in variety breeding has been recognised as one of the factors hindering the development of organic farming in Europe (Chable et al., 2012). But it is not the only barrier. Even when agricultural innovations do exist, they are not necessarily acknowledged and adopted. In Belgium, where our case study is located, low adoption of low-input disease-resistant varieties of wheat has been explained as a consequence of the locked-in situation of the cereal system: the system is in a path-dependency due to factors existing at all levels of the food chain, from farmers to extension services and European policies (Vanloqueren & Baret, 2007).

Another question that arises from this co-constructed process is how can researchers support varietal novelty production, and which change of approach does it involve? Identifying pathways on how to facilitate farmers' experiments and innovations involves reflexive thinking on the role of the researcher. Based on our findings and literature (Cuellár-Padilla & Calle-Collado, 2011; Louah et al., 2015; Pimbert, 2011) we argue that, in order to formulate farmer-relevant research questions and carry out research aimed at solving real problems, a radical reversal in the relative positioning of researchers towards farmers (and other actors of the food system) is required. As Pimbert states *"this form of co-operative inquiry and participatory knowledge creation implies a significant reversal from the dominant roles, locations and ways of knowing".* In other words: since they are the only "experts by experience", farmers take the lead and researchers accompany their quest for answers to their questions thanks to their access to tools and scientific knowledge. We no longer seek to integrate practitioners' knowledge to scientific thought through diverse forms of 'participatory research'. We rather seek to contribute to the development of safe-learning spaces that produce new knowledge for action. However adopting this collaborative research approach does have its challenges, in particular for young agronomists: gaps in academic education related to systems and collaborative research, time discrepancy between field and academic research, dealing with uncertainties and reflexivity etc. The researcher-facilitator needs to be comfortable with diversity, surprise and the unusual (Pimbert, 2011). Nevertheless, if we can overcome these difficulties and find new collaborative ways, co-constructed research offers great potential as novelties are directly produced (thus adopted) by actors involved. Results from participatory plant breeding programs in Europe and around the world are encouraging and provide valuable methodologies and tools (Cecarelli, 2012; Rivière et al., 2013).

Our findings corroborate the 3 key challenges identified by Pimbert (2011) for participatory research and the on-farm management of seed in the European Union: (i) transforming knowledge into more holistic and transdisciplinary ways of knowing; (ii) scaling-up and institutionalising participatory plant breeding and agroecology; (iii) reversing policies and legal frameworks for equitable rights of access, use and control over seed. Regarding our case study of bread cereals, policies should foster community-oriented research and development to respond to the existing demand of both farmers and the artisan bakery sector, which is directly linked to household demand. This involves a systemic approach to quality to increase the nutritional value of bread via health conscious choice of varieties, higher quality of flour type and improved baking processes.

Conclusions and perspectives

Our case study focused on the co-construction of the first Belgian cereal seed network as an example of one alternative pathway with regard to cereals for human nutrition (bread cereals in particular). This incipient seed network seeks to reintroduce diversity in cereal cropping (seed and practices) and answer the bread quality concerns of artisan processors and households. To achieve these goals, seed and knowledge are exchanged within a safe-learning space gathering different actors of the cereal system: farmers, bakers, millers, gardeners, citizens and researchers. In order to improve the nutritional quality of bread and develop a more resilient cereal system, we suggest fostering collective management of seed and participatory plant breeding programmes. This will need a reversal of agronomy research approaches and of priorities in food policy.

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The role of Internet and social media in the diffusion of knowledge and innovation among farmers

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Abstract: The impact of the use of information technology (IT) has been gaining relevance recently in the way it can facilitate communication in the agricultural sector. Farmers can share innovations and knowledge alongside solving problems through social media, or other uses of the internet. Farmer-to-farmer knowledge sharing is an important source of information, but potential obstacles to effective communication can include distance and the amount of time farmers can invest in knowledge sharing activities. The Internet has therefore become an effective way to overcome those obstacles. The internet allows farmers to share their experiences (which traditionally would have been done over a farm gate), via YouTube, web forums and online groups. There are Twitter feeds that farmers can access to ask questions or to share experiences. Whilst some conventional farmers are also using these tools, they have become a lifeline for farmers hoping to or currently farming more sustainably. These farmers are likely to be disparate throughout the UK and may no longer share with their neighbours, but instead rely on social media for advice and mentoring. Key annual farming events are broadcast live via Twitter. Farmers and other participants are encouraged to share highlights of the conference sessions, their comments on the speakers and the event itself, allowing others unable to attend to receive information from the event. Internet and social media have a growing role in the diffusion of knowledge and innovation within the agricultural sector, allowing a greater number of farmers, researchers and practitioners to share information and experiment so as to facilitate innovative farming practices.

Keywords: Social media, farmer innovation, agroecology, internet.

Introduction

When evaluating farmers' knowledge in relation to various agroecological farm management practices, it is important to consider that even though some farmers acquire information from family-led or traditional practices, Ingram (2008) pointed out that farmers tend to lack in-depth knowledge of specific scientific phenomena e.g. in relation to chemical or physical processes in soil management. In fact, farmers are more likely to rely on experience limited to their farm or that of someone close to them such as a family member or relative (Ingram et al., 2010). However, peers-exchange remains an important source of knowledge for farmers, in particular regarding current hot topics such as greenhouse gas emissions or more broadly, the sustainability and environmental issues related to the agricultural sector (Klerkx & Jansen, 2010). As a result, networks of influence represent a valuable source of information for farmers as well as providing advice and support (Klerkx et al., 2012). Examples of such networks in the UK include groups with a differing focus: they can be specific interest groups (e.g. Pasture-Fed Livestock Association), have a geographic focus (e.g. Tamar Valley Organic Group), or a political focus (e.g. Conservative Rural Affairs Group), and they can span local, regional or national levels.

Rural communities in the UK have struggled for many years with slow internet connection, limiting farmers' opportunities to access internet communication outlets or platforms to engage with the wider community and globally (Helsper, 2011; Ofcom, 2013). As a result the internet has been slow to become part of everyday life in many farmers' lives in the UK. However, the development and introduction of smartphones, broadband and 3G mobile networks have provided opportunities for farmers to connect with their peers in spite of the distances separating them. Farmers can use internet tools such as web forums (for discussion and debate), carry out internet searches, access the digital versions of farming magazines (Farmers Weekly, 2016a) to acquire new knowledge, query problems and access information on their phones, even in the middle of a field. Moreover, social media, such as Twitter, Facebook or a Google group, enables them to instantly communicate (over an electronic hedge), with online peers who they may never meet face-to-face, but who they can advise, sympathise with and relate to (e.g. a farmer in a tractor in the Scottish Highlands can easily reach a farmer in Cornwall). Finally, several studies suggest that farmers tend to prefer kinaesthetic ('learning by doing) or audio/visual learning to other learning styles (Franz et al., 2010; McLeod, 2006). The use of IT allows farmers to view or record videos, listen to recordings and watch live web-streaming of conferences, with the subsequent benefit of enabling them to develop their knowledge and learning without having to leave their farms.

The need for more interaction and collaboration between farmers and researchers in order to promote innovation and knowledge exchange is highlighted by the surge in initiatives such as the Soil Association Field Labs (Soil Association, 2016). Open to all farmers, regardless of their farming system (i.e. conventional or organic), the labs are aimed at encouraging farmers to voice the issues and problems they would like to see researched, and then promoting the sharing of information on innovative technologies, practices and collaborative research programmes that can foster greater environmental sustainability between the farmer and researcher.

In a recent study on farmers' attitudes to climate change, a series of interviews were carried out by researchers, followed by a focus group meeting to engage with all the participants and develop future action in a collaborative environment with the researchers (Burbi et al, 2016). The focus group was organised over a day, allowing for sufficient time to travel. However, several farmers could not attend the meeting because they had limited or no staff to replace them at the farm when away. In order not to lose the opportunity to engage in the discussions, some farmers who could not attend called the researchers prior to the meeting, voicing the topics they were more concerned about and would have liked to discuss during the focus group. Other farmers acted as rapporteurs, collecting information from those who could not attend and reporting on the results of the meeting. Alternatives were found, but it has to be considered that family-run farms or small-scale farms often rely on a limited labour force who cannot stay away from the farm for extended periods of time, sometimes even for just one day. Distance and time may therefore hinder the opportunity to engage with other farmers and researchers in person, making the internet medium a more attractive option for them.

This paper describes the authors' research on the use of IT learning. An initial review of the literature helped to identify issues, which were then examined in farmer interviews and focus groups across England.

Methodology

The authors interviewed a total of thirty farmers, farming mixed arable and livestock systems, with a combination of conventional and agroecological techniques. The interviewees were spread across England. The interviews were aimed at acquiring information on how the farmers accessed and implemented learning. The interviews were followed by two focus groups, which encouraged peer learning and further consolidated the data gathered through the interviews.

Issues facing diffusion of knowledge and innovation

Farmer knowledge exchange

Contacts and interactions with other farmers, especially if they are happening regularly, can influence greatly a farmer's attitudes and perception of innovation (Rydberg et al., 2008). Influences external to the farmer's immediate community can come from the media and extension officers, as well as consumer groups. Swanson and Rajalahti (2010) suggest that one of the greatest challenges facing the agricultural sector in the UK, as well as in other European countries, is that over the past 30 years governments have gradually reduced the funding for extension and advisory work. This has resulted in extension services having varying degrees of efficiency and impact, because they now rely mostly on private companies providing agricultural consultancy services in a rather fragmented manner (Oreszczyn et al., 2010). In England, it has been observed that some farmers who rely on networks of influence (i.e. a farmer's own family and peer-to-peer exchange group) to acquire and exchange knowledge among peers tend to resort to agricultural consultants only when these networks of influence do not succeed in providing the farmers with the advice needed (Klerkx & Proctor, 2013). Such premises foster even more fragmented and inconsistent external advice. Moreover, according to Buhler (2002), since more than a decade ago, funding for agricultural research in the UK has been shifted from collaborative projects involving both farmers and researchers to a system that relies on private funding, therefore reducing government expenses on extension services. Buhler further comments that this seems to be influencing the reluctance that some farmers show in adopting new technologies or innovative practices (2002). More recently, Islam et al. (2013) has observed several case studies in the developing world and concluded that the combination of formal and non-formal education (i.e. inside and outside the classroom) has a positive impact on farmers' uptake of innovation, as opposed to approaches that focus just on technical advice, without taking into account the social implications that such innovations could have on farmers' livelihoods. The combination of formal and non-formal education and interaction with researchers has multiple advantages. It can be considered a step forwards in trying to compensate for the reduction in government funding by generating knowledge transfer activities and promoting advances and innovation in the agricultural sector, fostering knowledge sharing and ensuring transparency. This is vital because it also helps to ensure that the advice provided takes into account not only the technical aspects of an innovative practice, but the social and economic implications of it as well, giving the farmers the opportunity to choose the best option based on the farming system adopted (Islam et al., 2013; McKenzie, 2011). Therefore, two-way communication represents a broader approach to extension; it enables farmers and researchers to share and co-generate knowledge whilst enabling researchers and policy makers to gain a deeper knowledge of the underlying factors that can influence the decision-making process in the case of farmers and the means that the sector uses to exchange and generate knowledge on innovation (Kings & Ilbery, 2010). As a result, such collaborative action can be considered beneficial in that it focuses on information directly of interest to the farmers in a practical way, and it attempts to avoid neglecting the environmental, social and economic implications that could also interest policy makers as well as researchers. The clear benefit from such knowledge exchange and interaction is the opportunity to facilitate the implementation of future policies, such as the ones focusing on promoting good agricultural practices and, more broadly, the sustainable management of natural resources by the farming community (Islam et al., 2013; Röckmann et al., 2012).

It can be suggested therefore that in order to promote effective innovation in the agricultural sector it is highly important that farmers, researchers and policy makers engage in successful communication. As an example, Burbi et al. (2016) have addressed the issue of climate change; highly debated in recent years and having to face obstacles, related both to scepticism from some farmers and financial limitations, to the adoption of innovative technologies that could reduce the impact of livestock farming in terms of greenhouse gas emissions from manure storage and treatment. The authors found that farmers tend to state that they would like to have access to unbiased scientific knowledge on climate change. This was likely to be related to the sense of confusion experienced by some farmers, combined with a lack of trust over government action. As a result, farmers expressed a preference for direct interaction with researchers and scientists and preferred collaborative work focused on finding practical solutions for the implementation of innovation (much like the Farm Labs project mentioned above). In such a context, it can also be considered that scepticism and confusion could result in opposite reactions from farmers: some could be discouraged from taking action and engaging with a wider community of farmers and researchers; whilst others could be motivated to look for knowledge originating from other resources, especially if such alternatives are considered more valuable by the farmers themselves.

Access to IT

As mentioned in the introduction, rural areas of the UK still lack access to broadband and experience slow connectivity (Ofcom, 2013), which can limit farmers' online access to knowledge and innovative techniques. Furthermore, slow connectivity can result in access to social media taking significantly longer than a farmer has time to spare. In addition, lack of experience of using social media can slow down a farmer's access and use of sites such as Twitter and Facebook (Hartless Rose, 2016). Another issue the farmers interviewed have experienced is the risk of missing useful information due to the speed of its flow online, or the difficulty in finding specific, relevant, reliable and applicable information amongst the mass of online sources of knowledge (Hartless Rose, 2015a).

Ultimately the internet represents an accessible means to obtain knowledge and to promote the interactions between farmers and researchers across the country that may otherwise have little chance to engage in face-to-face interaction.

Possible solutions based on IT technology

Internet

Most farming magazines and newspapers in the UK (such as Farmers Weekly and the Farmers Guardian (2016)), now have digital editions while more localised farming regions also now release digital editions of their news (Three Counties Farmer, 2016). Farmers can access news, listings and other information relevant to their activities. They can also share links to specific information or news with their peers, or leave comments directly on websites.

Although it is important to acknowledge that there are still rural areas in the UK where broadband and 3/4G mobile internet connections are weak, it has become common to use the phrase 'Google it' to find out information about specific topics of interest. Moreover, with the introduction of smartphones and tablets, answers to questions can be found instantaneously, even outside of the farmhouse. Search engines can be used to identify the best value suppliers for specific products, to look up products before ordering goods, to learn a new technique or simply to book a ticket for an agricultural show (RWAS, 2016).

Alternatively, web forums such as The Farming Forum (TFF) have become popular places for discussions amongst the farming community in the UK. It allows farmers from every spectrum to debate, discuss, advertise and share knowledge on a variety of topics. As with every online community where participants come from a wide range of differing backgrounds, discussions may occasionally turn into heated exchanges of opinions between participants passionately sharing their own views on specific topics, but overall discussion topics are useful for those who use the forum to gain knowledge or find innovative ways of improving their farming (TFF, 2014).

Massive open online courses such as the Farmers Weekly Academy, allow farmers to keep up with their Continuing Professional Development (CPD) by signing up to online courses and expanding their knowledge (Farmers Weekly, 2016b). As another example, Lancaster University offers a free online course on soils of 4 weeks duration, with the possibility of watching classes online in basic or high definition (depending on the student's internet access speed) as well as downloading transcripts of each class for reference. At the end of the course, which is expected take approximately 3 hours per week of study, students will be issued with a certificate of attendance (Future Learn, 2016). The flexibility of such courses can be seen as an advantage in the case of farmers who spend most of their time running their farms. They may have limited time to spend online or it may be difficult for them to keep to a regular schedule to attend classes, even in the case of online classes at fixed times during the week.

Interest groups also provide specific courses that can interest farmers, in particular those adopting agroecological practices. For instance, RegenAG UK (2016a) has been organising courses for a number of years, led by practitioners from various backgrounds and aimed at farmers, as well as researchers and the general public. Even though these courses are not online and require farmers to leave the farm for at least 1 day, the internet medium represents a source of knowledge that is easy to access and allows farmers to explore a variety of options in terms of courses, one-day events or workshops on the topics that most interest them at a specific moment in time. The courses are also followed up with resources sent to the attendees via email. Training is also offered by organisations like Holistic Management International (HMI, 2016b), the Biodynamic Association UK (2016) and the Permaculture Association UK (2016b). These institutions provide free access to a range of information and knowledge bases that could interest farmers. They also list courses available throughout the year, some of which, such as the Permaculture Design Course, are available as online learning (Permaculture Association UK, 2016c). An interesting example of how farmers organise themselves and share knowledge among their peers and the general public is the website of the Pasture-Fed Livestock Association, where one can find a section titled "Learn More" and one titled "Research News" (PFLA, 2016b). These sections feature news of direct interest to members of the association (mostly farmers) and the general public, with links to events and other sources of information of easy access. The PFLA itself was founded by farmers and therefore represents an example of self-organisation within the farming community, with the aim of sharing knowledge and innovation adopting IT technologies and social media.

Audio/visual media

Audio or visual media can provide a valuable source of information for farmers. YouTube has enabled farmers, both in the UK and around the globe, to record new techniques that they are using on their farms and share the videos online for others to watch, learn from and use. As an example, through farmer interviews it was revealed that one farmer in Northumberland (in the North of England) was feeling isolated as neighbouring farms were not implementing the same farming techniques. He had however found videos filmed by a farmer in another area of the country, showing successful and less successful implementations of a specific grassland management option (Havard, 2015) and he stated that he considered the videos to be as helpful as the more traditional farm walks (Hartless Rose, 2015b). Although this is just an example and it obviously cannot be generalised, it has to be noted that in recent years it has become more common practice at conferences to have sessions and keynote speakers broadcast live via YouTube or other similar online video channels (IPCUK, 2015; ORFC, 2016). Videos can also be broadcast using software such as Skype (Kasesalu & Tallin, 2003), allowing farmers to follow what interests them the most in spite of the distance. Farmers who could not attend an event such as the Oxford Real Farming Conference (ORFC, 2016), either due to financial reasons, distance or limited time available can then retrieve videos and transcripts of each session online. The farmers interviewed also followed live updates from the events via Twitter or Facebook (Hartless Rose, 2015b).

Social media

Twitter has become a way for some distantly diverse farmers to chat as well as debate and exchange information. Some farmers belonging to groups such as #ClubHectare (Twitter, 2012) or the account @AgriChatUK (Twitter, 2011a) often greet each other at dawn, or whilst eating their lunch, sharing knowledge of how their day has gone. Following its establishment in the US, AgriChatUK debates topical farming issues every Thursday between 8-10pm. Whilst some farmers feel that AgriChatUK has peaked and has become less relevant (Hartless Rose, 2015c) there are still very lively discussions each Thursday amongst regular Twitter users. Among the latest topics addressed during the Thursday online meetings was "How to use IT effectively to make better business decisions" (17/03/2016), which further highlights the importance that IT tools are gaining in the agricultural sector. Furthermore, farming conferences such as the Oxford Real Farming Conference use their Twitter account (2011b) to broadcast to those who cannot attend the event, and ask for questions during the plenary debates from Twitter and Facebook users.

Facebook pages and groups are an increasingly popular platform for farmers, in particular those farmers adopting management systems such as holistic management (HMI, 2016a), permaculture (Permaculture Association UK, 2016a) and, more globally, about sustainable farming across the globe (Farmers for a Sustainable Future, 2016). Some farmers also use Facebook to connect with their peers in the same area. This is the case with the Warwickshire Rural Hub (2016), which organises regular meetings and farm visits for their members, free of charge, and share practical, up-to-date information regarding National Farmers' Union (NFU) membership and activities, rural payments or other legislative requirements farmers need to be aware of, whether they farm conventionally, organically or follow other guidelines. RegenAG UK is particularly active on Facebook, sharing information on courses aimed at farmers and the general public, including researchers (RegenAG UK, 2016b). It even has a space dedicated to biofertilisers, which is a topic of great interest among small-scale farmers choosing not to apply industrial fertilisers (RegenAG UK, 2016c). Farmers are also using

Facebook to become more political about issues that they feel strongly about, for example in the under-30s branch of the Farmers Club (2016). The use of social media isn't limited to farmers outside the mainstream agricultural sector, i.e. conventional or organic, but has become a widespread communication tool even for Farmers' Weekly and Farmers' Guardian, who feature links to their social media accounts on their website.

Google groups are another example of a means for farmers to share experiences and interact, overcoming the issues of distance and financial limitations to attending events, conferences or even farm walks organised by farmers' groups. The Pasture-Fed Livestock Association (PFLA, 2016a) are frequently asking questions or sharing experimentations with each other via their Google group, with advice offered alongside. Access to the group is open to all PFLA members and supporters. Researchers can also be given access, in order to communicate with members of the association, seek knowledge exchange or conduct surveys on a number of topics of interest to farmers such as climate change, soil health, farm management or grassland productivity.

Conclusion

Farmers across the UK face a number of challenges with regards to attending activities and events that promote knowledge exchange among their peers, as well as engaging in co-learning programmes with other researchers. Issues such as the cost of attending conferences and courses, or the distance and the time farmers have to take off from their businesses in order to attend, can reduce the motivation to engage in knowledge exchanges, potentially slowing down the uptake of innovative practices on-farm. Limitations in the use of IT and social media still include access to fast and reliable interconnections and the availability of spare time to browse through the mass of Twitter feeds, Facebook updates and forum feeds. However, the internet and social media are becoming increasingly useful in enabling farmers from across the whole country (if not the globe) to share views and experiences, successes and failures, creating online communities that contribute to the diffusion of knowledge and innovation across the agricultural sector. Moreover, a number of initiatives provide free online courses for farmers, whilst social media platforms such as Twitter, Facebook, Google groups or YouTube have the multiple benefits of promoting farmer-to-farmer exchanges, as well as the broadcasting live of national and international events and conferences. Such growing interest in the internet and social media is likely to help avoid the feeling of isolation that some farmers may experience, especially those farming in remote areas of the country, or who have smallholdings or are implementing agroecological practices and may be reluctant to follow advice provided explicitly for conventional or organic farms. This leads to the possibility of research institutions further adopting social media as a means to communicate with farmers, collect data and information for research and create continuing interaction, albeit online, between farmers and researchers in the UK as well as globally.

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An agronomical framework for analysing 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 depends to a large extent on each specific farming situation, farmers cannot just 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 concerning the dynamics of the systems or the 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 in 3 phases: (i) design (objectives, experimental design planned, modalities compared, location); (ii) management (indicators to monitor the systems, ways to collect them, reaction to unexpected events); and (iii) conclusion (interpretation of data to assess the systems tested and build new knowledge). Results are two-fold: the framework enables us to describe the diversity in farmers' experiments as described in the literature, even if few articles are precise enough to fully complete the framework; 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

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 depends to a large extent on each specific farming situation, farmers cannot just 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 concerning the dynamics of the systems (e.g. biological regulations) or the long-term effects of a practice (e.g. weeds population with no-tillage practices). Hence, the issue of farmers' experiments 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 a new way of farming on their farm, implement it, take 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 and 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 for 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 majorly redesigning 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 encompasses a large range of definitions and, consequently, perspectives on 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 of 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, characterisation 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 programmes such as Farmers Field Schools (FFS) or Participatory Rural Appraisal (Angstreich & Zinnah, 2007; De Souza et al., 2012; Defoer, 2002) who were more interested in 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 exists (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 analyse 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 organised as follows: we first outline the two main approaches in agronomic experimentation and present the conceptual framework; we then illustrate it with farmers' experiments coming from literature; and finally we use it to fully describe three experimenting situations in our case study, implemented by some French farmers on arable and vegetable crops (Catalogna, PhD in progress).

Methods

Two approaches to 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-fertiliser applied), it has been enriched by numerous forms of experimentation with 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 – both of which we consider to be of use to understanding 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 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 analysing 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 assess only the few systems in which the combinations of techniques seem relevant to reach the given objectives and fit local conditions. This enables the drastic reduction of the number of combinations to set up, and the taking into account of 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 well as the effects of the systems themselves (Debaeke et al., 2009). System experimentation thus partly questions the previous 3-step model of design/management/analyse. 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 the organisation of 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 wonders if they are closer to the farmers' way of experimenting.

Building a conceptual framework to analyse farmers' experiments

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

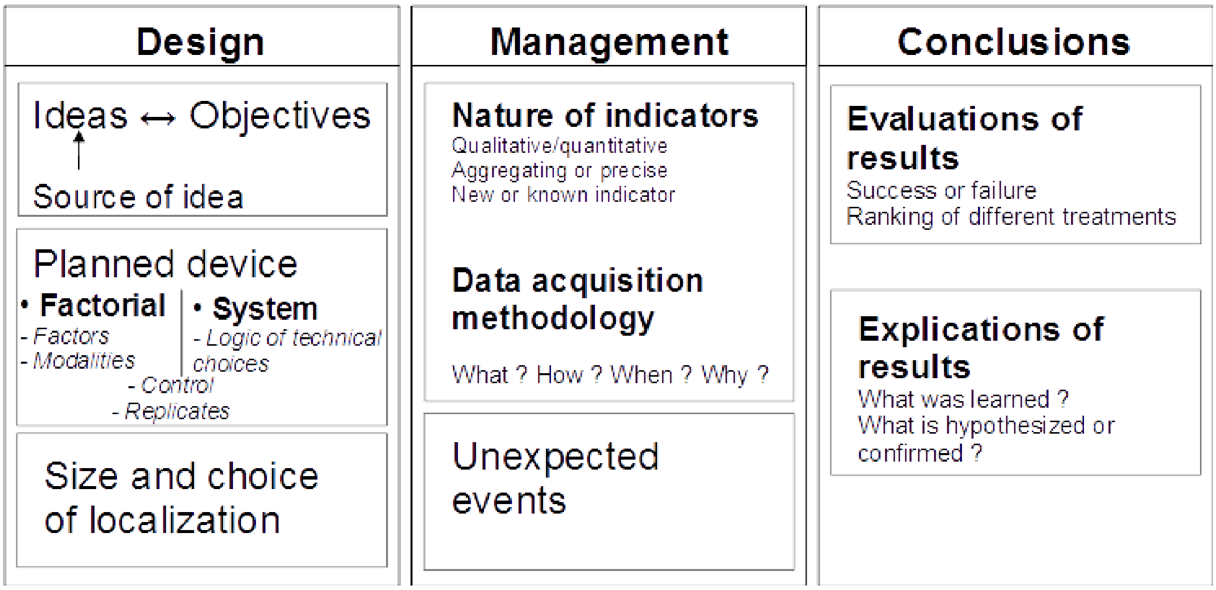

Figure 1. A framework to describe farmers' experiments

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 analyse 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 experiments 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 memorise. Casagrande et al. (2012) showed for example that organic farmers elaborated information on weeds very differently from each other. Agronomists do not manage unexpected events in the same way in factorial or system experiments (see below). Moreover, Stolzenbach (1994) used Schön's theory about practitioners' experiment to describe farmers' experiments 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 being split into 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 for the ending of their experiments to assess the results. 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.

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 with commercialisation, food processing or social organisations. At the end, we analysed 47 articles or book chapters.

Case study

The case study consists of experiments realised 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 analysing farmers’ experiments in a perspective of agroecological transition. At the moment, 19 farmers have been surveyed, who have experimented with 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. Farmer 1 is cultivating vegetables under greenhouses. Farmer 2 is cultivating arable and vegetables crops, and Farmer 3 cultivates only vegetables. Farmer 2 and 3 are organic farmers.

Literature analysis

Design phase

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 with 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, 6% had negative ones and 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 neighbour – e.g. seeds (Bhuktan et al., 1999), as part of a development programme - e.g. modern rice variety extension in Cambodia (Mak, 2001), or from local observations and personal skills - e.g. in Nepal, a 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 the farmer's livelihood. When problems are clearly identified, some authors classify the 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.

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 with chemical fertilisers mixed with traditional organic ones in order to find effective low-cost fertilisers (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 realise 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 form part of a participatory research project 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), animal breeding (Kummer et al., 2012; Scheuermeier, 1997) or animal and crop synergies (Mouret, 2013). In Sri Lanka, instead of burning straws, a couple of farmers experimented with a new system by bringing back straws in paddy fields and reducing the amount of fertilisers 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 mango trees (Millar, 1994). He also associated it with other crops: cassava, ginger and palm plants. An Austrian farmer experimented with 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).

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. This is often far from reality, as 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 experimented with banana and coconut in poorly drained soils. In an agroforestry development project, Brazilian farmers started to experiment with 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; in the second, the farmers wanted to discover the growth potential of new varieties.

Most of the time, experiments are realised on a 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 of specific interactions within on-farm management such as repeated grazing.

Management phase

Indicators

In the literature analysed, 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 with 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 fertilisers 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 behaviour and counted the average number of pests and predators (Winarto, 1994). A Nepali farmer experimenting with 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 trusted to 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.

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) to 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 fertilised 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 fertilised and earthed up groundnuts to flat culture of unfertilised 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.

Conclusion phase

Evaluation 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 those of other farmers. When trying different modalities (for example varieties), farmers may rank them (Bhuktan et al., 1999). Kummer et al. (2012) reported a farmer who classified plants between supporting and inhibiting wild plant species in a vineyard. Counter intuitive fact can be verified, for example, 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). Finally, farmers may refuse or accept an experiment due to labour or capital intensiveness (Bentley, 2006; Stolzenbach, 1994).

Explication 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 new experimentation. For example, a Punjabi farmer who was experimenting with 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 us to describe the farmers' experiments described in the literature, but few articles were precise enough to allow full completion of the framework. That was the issue assigned to the case study.

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

Farmer 1: seeking for a practical solution
Farmer 1 experimented with a new biological control strategy against thrips, whiteflies and aphids under greenhouses in a mono-factorial trial. He chose to experiment with it in 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 to see if aphids were multiplying, they were looking to see 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 with 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 need to prove initial statements; an unexpected event (in this case the presence of other natural predators) is welcome if it creates a new and reproducible situation that solves the problem, even in a factorial experiment.

Farmer 2: incomplete bi-factorial experiment which opens up new questions
Farmer 2 experimented in a bi-factorial way with 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. He concluded that

white-purple clover was better than crimson clover on acid soils, whereas from 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 allowing for wheat competition with clover* [year1] *with the following crop* [year2]."

Farmer 3: results spread over time

Facing a huge problem with time spent ploughing, Farmer 3 experimented with 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 ploughing) was immediately achieved and could explain why he chose 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 mine"*. Farmer 3 therefore reported 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 suggested to Farmer 1 a generalist predator (*Macrolophus pygmeus*) that could control both aphids, thrips and whiteflies. He tested if M*acrolophus* 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 variable. He tested more simple seed mixes to look for the best clover.	Already convinced by no tillage practices, Farmer 3 visited a French farm with a no-ploughing cropping method where crops were grown on permanent garden beds. He tested if permanent garden beds would allow both having more time and improving soil life 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 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 ploughing. Replication : NA
Size and choice of localisation	All greenhouses : half of greenhouse 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 collection 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, colour and biomass (he estimated dried organic matter produced by clover of 1,5-2T/ha). Only sowing rates were written down.	Observed earthworms abundance (worms, castings) Soil colour, stickiness (under shoes after a rain) and smoothness Time spent How felt during action : tools ease of use Heard 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 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 ploughed quickly (August) and sowed rape. But the other crimson clover fields that were reaped were ploughed 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	In the short term, there were fewer aphids under chemical greenhouses. In the 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 at controlling both aphids, thrips and whiteflies in the 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 the time compared with ploughing 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 in the long term by M*acrolophus* 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 stimulates soil life. Ridges increase surface so increase oxygen exchange and so enhance soil life. Moreover, a 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

Discussion and conclusion

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

First, in both cases it was possible to classify a specific farmer's experiment to the factorial or system approach but farmers' experiments do not necessarily belong exclusively to one approach. For example, the Malian farmer who tested groundnut with and without fertiliser 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. In the same way, system experiments on individual farms can sometimes be analysed as a multifactorial experiment from a collective perspective, in which each farmer's 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 identify 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 in 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 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 can 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 belongs to phenomenology, i.e. is grounded in direct experience.

Finally, the literature analysed is mostly implicit on what was learned during the experimentation process. Learning is rather studied from 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 studies is that new knowledge resulted not only from the planned experimenting process, but also from unexpected events that were a source of serendipity. For example, Farmer 1 finally concluded that a combination of two predator species could control the main pests whereas he had just wanted to test if one of these species could do so. Farmer 2 discovered an unexpected behaviour 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 characterisation, 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 alongside 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' groups as a participatory tool to exchange information 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.

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Better than best practice: using farmer field trials to identify adaptive management options within complex agricultural systems

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Abstract: Agricultural systems are widely recognised as being complex, dynamic, and diverse, and consisting of many uncertain or unknown components and interactions. However, management recommendations are often derived from highly controlled experiments that reduce the complex working of the system to artificially simple relationships that are typically investigated in isolation under the assumption of "all else being equal." Such reductionist experiments are appropriate for investigating certain aspects of agricultural systems, but do not estimate the reliability or robustness of the effect of specific manipulations, which is what is implied by "best management practice" recommendations. These limitations are illustrated here through the preliminary results of an ongoing project in Senegal and The Gambia, where a network of farmer field trials tests, and largely rejects, current recommendations for rain-fed crop production, while suggesting potentially more reliable alternatives. These results also demonstrate the research value of experiments that are embedded within a complex system, both as a stand-alone method and as a part of a more integrated approach to the study of complex agricultural systems. While this approach may lead to general recommendations, it can also identify a range of potentially adaptive practices, thereby encouraging multiple adaptive pathways, a result that makes this approach particularly valuable in diverse and understudied systems.

Keywords: Complex systems, soil fertility, farmer field trials, best management practices, Senegal, The Gambia

Introduction

The concept of "best management practices" in agriculture refers to attempts by researchers to develop and prescribe broadly appropriate and reliable management recommendations to farmers. This approach is a deliberately integrated alternative to one-dimensional interpretations, and might balance productivity with input efficiency, cost-benefit analysis and environmental externalities (Ryan et al., 2012). However, the specifics and appropriateness of these recommendations are strongly dependent on the breadth, quality and relative inclusion of the researchers' knowledge, as well as their personal bias towards certain issues, such as production over externalities or vice versa (Roberts, 2007). More critically, the output of this approach is often a specific plan that is assumed to be broadly suitable for adoption, such as an integrated fertiliser use protocol. While there might be a "right source, right place, right timing and right application method" to achieve maximum effect size or input efficiency under certain conditions, it cannot always (or even often) be assumed that there is also a single management plan that is "right" or "best" for a broad group of farmers (Giller et al., 2011; Ryan et al., 2012). The wide variation found in agricultural systems results in such diverse conditions and constraints that adopting a specific "best management practice" might be adaptive for one farmer but maladaptive for a neighbour (Giller et al., 2009). While these integrated interpretations of agricultural systems may be improvements over one-dimensional analyses, the underlying prescriptive approach remains problematic.

The more that is known about an agricultural system, the better that recommendations can be tailored to the known system diversity and behaviour, thereby reducing the possibility of “best” recommendations being unreliably adaptive or, worse, reliably maladaptive (Giller et al., 2011). However, the less that is known, the greater the risk of inappropriate interpretations, making these recommendations potentially dangerous in relatively understudied or particularly diverse or complex systems. In some cases, the best available information may simply not be good enough to justify “best” recommendations, particularly if there is no measure of the reliability of a practice across the relevant diversity of the target system. Despite this risk, it is still common to develop and prescribe recommendations that are based on simplistic assumptions rather than sufficient knowledge of relevant system behaviour (Vanlauwe & Giller, 2006).

An alternative approach in understudied situations is to embed agricultural research within working agricultural systems to implicitly capture the relevant complexity, uncertainty, and variability of the target system (Shennan, 2008). This approach considers farmers and researchers as complimentary specialists, and is in direct contrast to the more conventional top-down model of research and extension, where farmers are not explicitly included in the former and are passive recipients of the latter. While farmer-researcher consultation is a critical component of any agricultural research, the use of farmer field trials is emerging as a rigorous experimental method and legitimate tool for investigating complex systems, rather than simply an extension strategy to demonstrate recommended practices (Snapp, 2002).

This embedded strategy is currently being applied on a large scale in Senegal and The Gambia through coordination of an American university, a UK-based international non-government organisation, regional cooperative farmer organisations and hundreds of individual farmers (Table 1). This paper is a preliminary report on this project and is divided into two parts. The first is a discussion of the theoretical issues underlying this approach, with a focus on the concept of a “(complex) system perspective” as a deliberate epistemological position with implications for research design. The second part describes the project, the methods and some of the initial results. While preliminary and incomplete, these early results show the benefits of this strategy for testing prescriptive hypotheses, and reveal some trends that suggest relevant interactions and alternative options that are not well researched or recognised in the literature.

Complex systems theory and experimental methods

A system is a set of independent components that interact to produce some shared emergent properties. A complex system is one where the processes within the system and the patterns that emerge are not linear, straightforward, or otherwise easily predictable (Zeigler et al., 2000). Used in this sense, a complex system is distinct from a complicated system, which might simply have a large number of moving parts. A complex system might be ontologically complex, due to having some probabilistic or stochastic interactions, or it might be epistemologically complex, due to incomplete knowledge of the components, interactions and emergent processes of the system. Any system that requires investigation falls into the latter category and should accordingly be described and investigated as a complex system.

The concept of a "system perspective" can be found in many of the disciplines that are highly relevant to agricultural sciences. For example, ecology is explicitly focused on the interactions among organisms rather than isolated observations, and the associated concept of an ecosystem is now used throughout the biological sciences (Odum, 1977). "Agro-ecosystem" has been used for decades to describe ecosystems that are managed to produce food and fibre, and current system perspectives on agriculture often draw from the literature on "socio-economic" and "socio-ecological" systems. (Conway, 1987; Young et al., 2006; Giller, 2013). This emerging perspective is a point of coalescence of multiple paradigms, including those that make explicit mention of systems (such as farming systems research) as well as those that do not (such as agroecology and sustainable rural livelihoods) (Chambers & Conway, 1992; Wezel et al., 2011). However, this approach has a much longer history and the term "farming system," for example, was used in the early 1800's to argue that the interaction of topography, climate, infrastructure and labour force made Scotland's Orkney Islands more suited for smallholder production than large-scale industrialised agriculture (Shireff, 1814).

The adoption of a system perspective is often closely associated with an attempt to rigourously describe the system of interest, which can be referred to more specifically as *system analysis*. This analysis might focus on the *system structure*, the equivalent of a schematic diagram identifying components and potential or common interactive pathways, or the *system behavior*, which would be a more pragmatic description of how the system responds to various stimuli without necessarily describing the internal mechanisms (Zeigler et al., 2000; Giller, 2013). This system analysis is primarily a descriptive activity, but the resulting explicit understanding can be used to design experiments to further investigate that system.

A common approach to experimental design is to conduct manipulative studies that investigate a small number of interactions under highly controlled conditions and the assumption of "all else being equal." This method is to deny complexity as such, as from a system perspective this "all else" can never be assumed *a priori* to be irrelevant to the interactions of interest. This approach is therefore *reductionistic* as it presumes to reduce complexity to a series of simple interactions that can be investigated in piecemeal fashion, as if a single complex three-way interaction was analogous to three simple two-way interactions.

An alternative is to design *composite* investigations that manipulate or measure many of the diverse components and complex interactions that have been recognised as potentially relevant to the processes of interest. These composite experiments, also known as "integrated system experiments," are growing in popularity and improve on some of the shortcomings of the reductionist approach, but are not without their own serious drawbacks (Shennan, 2008). Being more complicated by design, these experiments are also more complicated to implement and interpret, and often require significantly higher research investment in terms of time, funding and expertise. In addition only recognised complexity can be incorporated into a composite experiment, making them, like reductionist investigations, susceptible to being undermined by unforeseen or unappreciated components and interactions. Therefore, while composite investigations are an example of applying a system perspective to experimental design, it is still accurate to describe them as an "outside looking in" perspective on complex systems.

An alternative means of applying a system perspective to agricultural experiments is through an “inside-out” or “in-situ” approach where the experiment is embedded within the known and unknown complexity of the system of interest. Unlike composite studies, these *embedded investigations* might focus on manipulating and/or measuring a single variable rather than multiple related variables but, unlike reductionist methods, such experiments are perturbations of a relatively intact complex system rather than manipulations of an artificially simple one. This experimental approach to complex systems is widely used in ecology to study ecosystem responses to changes in specific variables, such as with enclosure or exclusion field trials and large-scale free-air CO2 enrichment experiments (Tilman, 1989; Ainsworth & Long, 2005).

These three experimental approaches to complex systems - reductionist, composite, and embedded - are not in direct competition but rather are each well suited to different questions or interests. Reductionist investigations are appropriate for identifying if a specific interaction or effect is possible or estimating what the effect size might be under certain highly specific conditions. However, unless the system is known to be relatively simple, constant, homogeneous and well-understood, this approach cannot be trusted to estimate the overall robustness of a specific interaction or the reliability of a specific effect size across diverse conditions. The ability to more effectively do so is one of the strengths of embedded investigations, which in turn are not appropriate for estimating a maximum effect size of a specific process and not well suited for investigating potential mechanisms. Of the three, composite investigations are most apt for clarifying complex interactions and identifying the specific circumstances under which the benefits of a practice might outweigh the costs and risks associated with adoption, but they require extensive and accurate knowledge of the system to do so. These respective strengths and weaknesses are recognised by research programs that apply multiple approaches to a targeted system or specific studies that augment a reductionist or composite experiment with an embedded component, an approach that is sometimes referred to as a “mother-baby” design (Snapp, 2002). Even when this integration is not possible within a single study, embedded experiments alone can be used to test specific hypotheses such as “best management practices” and can identify robust ways to manage system behaviour even when the mechanisms of the complexity are not well understood.

Rainfed farming systems in West Africa

Rainfed agriculture is the primary means of both subsistence food production and income generation in rural parts of Senegal and The Gambia, with most of it occurring on sandy and semi-arid upland soils with low soil organic matter. Uncultivated fields are routinely found to have less than 1% soil organic carbon (SOC), even within only the top 5cm, while the percentage in cultivated fields is much less and can be as low as 0.15% (Tiessen et a.,l 1998; Peters, 2000; Elberling et al., 2003). As 0.5% SOC is globally used as a rough threshold to identify severely degraded soils that are not well suited for agriculture, it is likely that soil fertility is a common constraint in this region. In addition, there has been limited development and distribution of newly developed crop varieties, and most farmers do not have access to seed stores that might offer high quality seed stock. While traditional methods of seed preservation and exchange are still common in many areas, it is likely that some proportion of farmers in this region, perhaps especially the poorest ones, are working with low quality seed stocks or poorly adapted varieties.

The use of organic amendments, inorganic fertilisers, and high quality and locally-adapted seed stocks are therefore likely variables that can be manipulated to increase crop production, and through that, the production-dependent aspects of food security in rural Senegal and The Gambia (Vanlauwe & Giller, 2006). While these three variables are often key components of agricultural recommendations, the interaction is not necessarily part of standard "best practice recommendations." For example, while all three might be considered "good," this doesn't address how adopting a new crop variety might compare with increasing the fertilisation of the current variety. In addition, of course, the effect of any specific practice can be highly variable due to local variation in availability, soil conditions, application logistics and other characteristics of diverse agricultural systems that influence farmer practices, treatment effects and cost-benefit interpretations (Vanlauwe & Giller, 2006; Smith et al., 2011).

The current official recommendations for fertility management of upland crops in Senegal and The Gambia range from 150-200 kg NPK per hectare annually with the same rate of urea application for non-legume crops (Posner & Crawford, 1992; ISRA 2005). Specialised NPK mixes such as 6-20-10 or 8-18-27 are recommended but widely unavailable, and so often replaced by the more ubiquitous 15-15-15. These general recommendations come with no further clarification given for the relative influence of other variables that are known to be relevant to production, such as field history, socioeconomic conditions, or variation in rainfall and associated ecological characteristics. The recommendation of inorganic fertiliser is not, for example, described in association with the use of local organic amendments, despite the common cultural use of these inputs and the increasing scientific evidence of effective integration of the two (Place et al., 2003). In addition, it is not stated whether the recommended rates reflect the productive ceiling, which is the common target of agronomists, or some unstated cost/benefit calculation, such as any farmer must make.

New crop varieties are a major part of many agricultural recommendations in sub-Saharan Africa, and are often presumed to be well adapted, to the extent that they are often referred to as "improved" rather than "new" varieties. This presumption, however, is based primarily on highly controlled reductionistic studies and is rarely tested across the spatial or social variation that occurs within the scale at which they are recommended. The Gambia has limited capacity to develop or test new varieties, and while Senegal does, the rainfed crop trials occur primarily at research stations in the central Thies region (ISRA 2005, Figure 1). The local development and testing of new varieties often selectively excludes many of the stresses that are expected in farmers' fields, such as weed pressure, intermittent drought and low soil nutrient levels, as well as relevant social and economic constraints such as labour and adoption cost.

Farmer field trials in Senegal and The Gambia

This ongoing project is a large-scale embedded investigation of alternative management practices for rain-fed crop production in Senegal and The Gambia, with a focus on: i) locally available organic amendments; ii) widely available inorganic fertilizers; and iii) nationally-certified seeds, which may or may not be distinct varieties from what farmers are currently planting. Instead of attempting to control for all of the known, unknown and unappreciated complexity found in this region, this two-year project establishes trials of fixed design in hundreds of independent farmer fields across the region, which are then managed by participating farmers under the supervision of project staff. These farmer-led trials are not controlled and replicated in the traditional sense that reduces and thereby denies complexity. Instead, the complexity of the system is constrained by the standardised design, training and supervision of the participants, and the trials are repeated broadly across the diversity of conditions found within the system to document the robustness of any effects.

Over 400 farmer-led trials were established in 2015 within six focal regions in Senegal and one in The Gambia (Figure 1). Four community clusters were selected within each region, with each cluster representing up to three immediately adjacent communities and the clusters spaced no less than 15 kilometers from each other and all within 50 kilometers of the primary regional population centre. The primary emphasis during 2015 was on millet, groundnut and cowpea, with secondary emphasis on upland rice, sorghum and maize.

Two trial designs were used in this project, both using a non-replicated split-plot factorial design. “Step 1” trials tested a single “new” certified variety of each crop alongside the participating farmer’s “local” seed stock and across a combination of two organic and two inorganic fertility treatments, resulting in 18 treatment plots per trial. Each treatment was 5m x 10m, for a total of 30m x 30m for each Step 1 trial. The organic treatments were millet husks, the waste of the threshing process and locally gathered cattle manure, which is often applied to fields through annual or seasonal livestock rotations. Both organic amendments were applied at 3000 kg/ha (1.34 US tons/acre), which was agreed upon by participating farmers as a rate that might reasonably be locally collected and applied by most farmers. Inorganic fertiliser was applied at the recommended level of 150 kg/ha (“high”) and 50 kg/ha (“low”) 15-15-15 NPK, with the same level of urea also added for non-legumes. These Step 1 trials were designed to target farmers who were producing primarily for personal consumption and had limited experience investing in their production. These are more likely to be relatively resource-poor households, who might be limited by insecure or insufficient access to land, labour and financial investments. Those farmers who might already be producing on a commercial level and experienced with investing in their production were targeted by “Step 2” trials, which compared the farmer-standard seed stock against four certified varieties that are currently available for purchase in Senegal. These trials ranged from 0.25 to 1 hectare in size depending on the crop, and both groundnut and millet were 1 hectare in total with each varietal plot 0.2 ha in size. All trial areas were demarcated by project field officers working alongside the participating farmers. The farmers were given the appropriate seeds for each trial and trained in the design and constraints of the trial, particularly the importance of managing each trial as a unit so that, for example, all plots are planted and weeded at the same time. The timing of the planting was determined by the farmer, but usually after the second or third significant rain in the region. Animal traction was used for all plantings, and hired locally as necessary. The organic amendments for Step 1 trials were collected by each participating farmer and applied under supervision just after the first rain. Inorganic fertiliser was applied by project field officers soon after emergence for the NPK and a few weeks later during rapid vegetative growth for the urea. Harvest was again supervised by field officers using local labour and consisted of all Step 1 treatment plots (5m X 10m each) and a representative 5m X 10m plot within each Step 2 varietal planting. Field measurements consisted of: i) number of productive plants or tillers; ii) fresh weight of harvest; and iii) dry plucked or threshed weight, all measured per plot.

Results are reported for millet and groundnut trials and presented here in three ways: i) as dry harvest per hectare; ii) as # productive plants/tillers per hectare; and iii) as dry harvest per plant. In the few cases where the fresh weight was available but the final dry weight was not, the latter was estimated using the mean percent weight loss with drying across all trials for that crop. The results are shown here primarily as the median percent change from the control plot, which is the “local/no organic/no inorganic” plot for Step 1 and “local” for Step 2. The Step 2 trials (varietal) are of a simpler design and the results thereby presented before the Step 1 trial (variety X organic X inorganic) results and also include the median, maximum and minimum of the harvest measurements.

Preliminary Results

Only a subset of the farmer field trials that were established were successfully measured during harvest (Table 2). When averaged across all Step 2 trials, the new groundnut varieties resulted in an increased yield per hectare and productivity per plant, while the new millet varieties showed the former for three out of the four varieties (Table 3). However, all three yield measurements varied by orders of magnitude for both crops. The only strong trend of the median effect size, calculated as the percent difference from the control within each trial, was an increase in yield per hectare of new groundnut varieties, and again there was dramatic variation among the trials for all measures (Table 4). The same analysis of the Step 1 trials appears to show all three management practices influencing yield in an additive fashion, such that the greatest median effect sizes come with the combination of all three (Table 5 and Table 6). This same trend is also apparent in the number of millet plants per plot, which is an indication of germination or maturation success, but is not clear in the other analyses. With only one exception (low inorganic, no inorganic, local groundnut), all treatments in the Step 1 trials on average resulted in a positive increase over the control, although without disaggregation and some assessment of variability, these trends are only suggestive.

Discussion

The official "best management practices" that are currently being recommended in Senegal and The Gambia regarding the use of inorganic fertilisers and certified seeds do not appear to be widely appropriate for farmers in this region. The common prescription that farmers should adopt certified "improved" seeds to increase their yield is particularly inappropriate, as the pairwise comparisons of the Step 2 trials found that new varieties of millet had, on the whole, a negligible influence on yield, while the new groundnut varieties were overall an improvement, but perhaps not at the dramatic level that is often stated or implied by the recommendation or worth the additional investment. This average effect is also no measure of reliability, and in both cases the new seeds were also sometime dramatically outperformed by the local variety.

The Step 1 trials that tested this adoption effect against alternative management options suggest that the effect of this single practice alone, which comes at a high cost for the certified seed, may often be outweighed by the potentially cheaper use of local organic amendments and locally available inorganic fertilisers. Similarly, the Step 1 trials found that while the recommended high inorganic fertility amendment on average drastically improved yield, the effect size was in fact far less than when integrated with local crop residue or animal manure. While many recommendations focus on new seed stocks and inorganic fertilisers, others focus exclusively on organic amendments, which where found in the Step 1 trials to be potentially valuable but not highly effective on their own, at least not at the rate that farmers identified as being pragmatically reasonable. Higher application rates of organic amendments are likely to have a greater effect, but would come with increased labour cost and may simply be unobtainable in some spatial and social circumstances.

This is not to say that using new seed stocks, inorganic fertilisers, and organic amendments are not potentially useful management practices, but rather that specific recommendations are not guaranteed and perhaps not even reliable. The original reductionist experiments that led to these recommendations and the observed maximum effect sizes in these farmer field trials indicate that these alternative practices have the potential to dramatically increase yield. However, it is no more appropriate to assume from these maximums that the practices are broadly adapted and robustly effective than it would be to assume from the minimum effect sizes that they are reliably maladaptive and ineffective. The problem here is that with "best," these alternatives are presented as simple and reliable prescriptions, whereas they are in fact something more like "optimal practices" or "sometimes best practices." The failures of the current official recommendations to reflect the trends observed in these preliminary results should now lead to the question "well then, what IS the best practice?" In this region, as perhaps in most agricultural systems, the diversity of relevant factors might be such that there are simply no simple and broadly "best" recommendations. Strong evidence for this is the wide range of harvest measurements and effect sizes, which indicates that there are many other factors influencing the effectiveness of these practices.

An alternative strategy is to present farmers not with specific "best practices" prescriptions, but rather with alternative options, so that they can identify for themselves what might be most appropriate for their own circumstances. Such options are "adaptive" rather than assumed to be "adapted" or "best," for this model encourages farmers to continue to adapt, alter and combine the identified practices rather than strive to adopt specific practices. For example, the recognition of the importance of high quality seed stocks can lead to multiple adaptive responses, such as stronger selection of personal seed stock, local sourcing of higher quality seed of existing varieties, or purchasing of nationally certified seed or new varieties. Similarly, the observed effectiveness of reasonable levels of locally available organic amendments and of lower than recommended levels of inorganic fertiliser suggests that these inputs have incremental value rather than a threshold for effectiveness, as might be assumed from the current recommendations.

The active role of farmers in the agricultural research can also help to identify alternative interpretations to what a scientist might conclude from the statistical results alone. For example, the failure of the millet trials in the Ziguinchor region was largely the result of birds destroying the early maturing varieties, leading the farmers to abandon the trials. However, follow up surveys found that these farmers were not overly concerned by this and were instead planning on delaying planting of early maturing varieties and/or planting larger fields where scaring tactics would be more efficient. Similarly, the higher rainfall and longer rainy season in this region has led agronomists to assume that short season crops are not needed or even not appropriate, yet many of the participating farmers recognised the potential of the new varieties to meet marketing niches, such as fresh early groundnut, and to allow for successive or relay cropping. While maximising yield or input efficiency are common targets of agronomic studies, they are only two of the many characteristics that a farmer must consider when adopting and adapting alternative management practices.

Embedded investigations are an effective stand-alone research method and particularly valuable in understudied systems, but they can also be integrated with other experimental and observational approaches. The rapid recent development of remote sensing data and spatial analysis offers powerful new observational tools, and to combine these with embedded experiments is to investigate complex agricultural systems from both within and from literally thousands of miles away. This potential integration can test the reliability of alternative practices while also identifying the variables that might be relevant, thereby providing a more complete alternative to piecemeal and reductionistic interpretations of complexity. Soil conditions and precipitation patterns are two factors that are critical to production in the rainfed agricultural system of Senegal and The Gambia, but both are often treated in spatially simplistic ways. This region is mostly flat and formed primarily from weathered sandstone, resulting in uplands soils that are sandy and of low-organic matter by global standards and as a result considered relatively homogeneous. The latitudinal precipitation gradient is often assessed by annual mean only and classified as semi-arid or as a dichotomy between a drier Sahel ecotype in the north and a wetter Sudan-Savannah in the south. However, remote sensing data and spatially explicit estimates offer much higher resolution information of soil and precipitation, including soil characteristics at 250m resolution and decades of daily rainfall estimates at 10km (Love et al., 2004; Novella & Thiaw, 2013; Hengl et al., 2015). The resulting maps clearly show that simple spatiotemporal estimates of soil and precipitation are both inappropriate and unnecessary (Figures 1-3).

Conclusion

These preliminary results illustrate the risks associated with making general agricultural recommendations based largely on reductionistic studies of complex systems. The method presented here of using farmer field trials as a form of embedded investigation to assess alternative practices is particularly appropriate for diverse or understudied complex agricultural systems. This approach can be used to both estimate the robustness of a practice and test assumptions of how the system works. It is not, however, a replacement for other experimental and observational methods, but rather a practical compliment that can offer novel insights into complex interactions.

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Table 1. Organisations participating in the on-going project in Senegal and The Gambia. **(***The names of the Senegalese organisations are translated from French***)**.

Organisation	**Description**
Concern Universal (Senegal/The Gambia/Guinea Bissau office)	Non-government organisation (International, UK-based)
Senegalese Network of Farmer and Breeder Organisations (RESOPP).	Farmer cooperative and nationally certified seed producer (Senegal, multi-region)
The Rural Cooperative of Pambal	Farmer cooperative (Senegal, Thies region)
The Agricultural Cooperative of Malicounda	Farmer cooperative (Senegal, Thies region)
The Agricultural Cooperative of Késlle Guèye	Farmer cooperative (Senegal, Louga region)
The Rural Cooperative for the Inclusive Development of Missirah	Farmer cooperative (Senegal, Tambacounda region)
The Cooperative for Sibassor Local Development	Farmer cooperative (Senegal, Kaolack region)
Constructing the Peace	Non-government organisation (Senegal, Ziguinchor region)
Njawara Agricultural Training Center	Non-government organization (The Gambia, North Bank region)
Africa Geodata	Gambia-based spatial analysis consultancy
University of California, Santa Cruz	American University

Table 2. Number of trials included in the statistical analysis as per crop, region, and trial type, out of a maximum of eight trials per Location X Crop X Step. (*Some farmer field trials were unsuccessful due to a combination of factors including insufficient training and support for some farmers, the complexity of the harvest protocol and local disturbances. All locations were grouped together for analysis but disaggregated by crop and step).*

Location	**Millet**		**Groundnut**	
	Step 1	**Step 2**	**Step 1**	**Step 2**
Louga	5	8	7	7
Matam	0	3	0	3
Thies	5	5	2	6
Kaolack	5	7	0	2
The Gambia	5	5	7	8
Ziguinchor	0	0	5	8
Tambacounda	2	3	2	6
Total	**23**	**39**	**21**	**40**

Table 3. Median, maximum and minimum plot-level harvest measurements for millet and groundnut Step 2 trials.

Variety	Threshed kg / ha			# Plants or tillers / plot			Dry kg / 100 plants or tillers		
	Median	*Max*	*Min*	**Median**	*Max*	*Min*	**Median**	*Max*	*Min*
Millet									
Local	**676**	*1690*	*281*	**233**	*523*	*45*	**1.76**	*6.44*	*0.39*
Souna 3	**754**	*1674*	*120*	**220**	*789*	*43*	**1.95**	*6.46*	*0.66*
Sosat	**640**	*2002*	*223*	**216**	*537*	*38*	**1.53**	*6.58*	*0.39*
Gawane	**736**	*1458*	*76*	**205**	*674*	*31*	**1.63**	*6.97*	*0.54*
Thialack	**816**	*1994*	*124*	**231**	*755*	*63*	**1.93**	*4.76*	*0.57*
Combined new	**740**			**214**			**1.77**		
Groundnut									
Local	**1109**	*2292*	*42*	**322**	*1101*	*91*	**1.75**	*6.72*	*0.06*
Fleur 11	**1300**	*2630*	*150*	**293**	*1492*	*130*	**2.06**	*6.4*	*0.38*
7333	**1538**	*2493*	*152*	**293**	*880*	*141*	**2.16**	*5.44*	*0.14*
55-437	**1611**	*2840*	*200*	**420**	*910*	*166*	**2.29**	*3.85*	*0.31*
GH 119/20	**1392**	*2800*	*24*	**306**	*815*	*108*	**2.30**	*4.33*	*0.11*
Combined new	**1418**			**320**			**2.16**		

Table 4. Median, maximum and minimum treatment effect across all Step 2 trails, calculated as the % different of treatment plots from the adjacent control plot within each trial.

Variety	Threshed kg / ha			# Plants or tillers / plot			Dry kg / 100 plants or tillers		
	Median	*Max*	*Min*	**Median**	*Max*	*Min*	**Median**	*Max*	*Min*
Millet									
Souna 3	**+ 2%**	*+ 300%*	*- 59%*	**+ 3%**	*+ 140%*	*- 62%*	**+ 1%**	*+ 69%*	*-70%*
Sosat	**- 14%**	*+ 99%*	*- 75%*	**- 10%**	*+ 88%*	*- 44%*	**- 3%**	*+ 147%*	*- 63%*
Gawane	**- 12%**	*+ 150%*	*- 71%*	**- 8%**	*+ 95%*	*- 60%*	**0**	*+ 527%*	*- 74%*
Thialack	**+ 2%**	*+ 200%*	*- 59%*	**+ 9%**	*+ 207%*	*- 53%*	**+ 1%**	*+ 254%*	*- 60%*
Combined new	**- 3%**			**- 3%**			**0**		
Groundnut									
Fleur 11	**+ 18%**	*+ 338%*	*- 59%*	**+ 2%**	*+ 97%*	*- 37%*	**+ 4%**	*+ 539%*	*- 59%*
7333	**+ 29%**	*+ 262%*	*- 65%*	**0**	*+ 169%*	*- 52%*	**+ 1%**	*+ 521%*	*- 55%*
55-437	**+ 27%**	*+ 638%*	*- 44%*	**+ 17%**	*+ 201%*	*- 30%*	**+ 7%**	*+ 692%*	*- 57%*
GH 119/20	**+ 14%**	*+ 171%*	*- 80%*	**+ 3%**	*+ 168%*	*- 67%*	**- 1%**	*+ 160%*	*- 67%*
Combined new	**+ 22%**			**+ 5%**			**+ 3%**		

Table 5. Median treatment effect across all Step 1 millet trials, calculated as the % different of treatment plots from the adjacent control plot within each trial.

Millet						
Threshed kg						
	No Organic		**Millet Husk**		**Animal Manure**	
High Inorganic	101%	105%	179%	192%	221%	182%
Low Inorganic	53%	82%	103%	100%	124%	157%
No Inorganic		33%	28%	22%	54%	91%
	Local	**Souna 3**	**Local**	**Souna 3**	**Local**	**Souna 3**
# Plants						
	No Organic		**Millet Husk**		**Animal Manure**	
High Inorganic	58%	43%	83%	95%	77%	102%
Low Inorganic	21%	29%	50%	55%	73%	73%
No Inorganic		8%	18%	23%	38%	45%
	Local	**Souna 3**	**Local**	**Souna 3**	**Local**	**Souna 3**
Threshed kg / plant						
	No Organic		**Millet Husk**		**Animal Manure**	
High Inorganic	13%	25%	30%	45%	35%	33%
Low Inorganic	14%	29%	23%	16%	17%	33%
No Inorganic		7%	1%	0	1%	5%
	Local	**Souna 3**	**Local**	**Souna 3**	**Local**	**Souna 3**

Table 6. Median treatment effect across all step 1 groundnut trials, calculated as the % difference of treatment plots from the adjacent control plot within each trial.

Groundnut						
Dry plucked kg						
	No Organic		**Millet Husk**		**Animal Manure**	
High Inorganic	51%	108%	79%	135%	97%	143%
Low Inorganic	17%	49%	65%	90%	69%	115%
No Inorganic		29%	28%	52%	45%	90%
	Local	**Fleur 11**	**Local**	**Fleur 11**	**Local**	**Fleur 11**
# Plants						
	No Organic		**Millet Husk**		**Animal Manure**	
High Inorganic	9%	11%	12%	11%	12%	16%
Low Inorganic	9%	9%	14%	14%	11%	14%
No Inorganic		8%	7%	8%	6%	12%
	Local	**Fleur 11**	**Local**	**Fleur 11**	**Local**	**Fleur 11**
Dry plucked kg / plant						
	No Organic		**Millet Husk**		**Animal Manure**	
High Inorganic	39%	61%	51%	71%	27%	50%
Low Inorganic	- 4%	34%	30%	40%	33%	62%
No Inorganic		21%	15%	30%	32%	30%
	Local	**Fleur 11**	**Local**	**Fleur 11**	**Local**	**Fleur 11**

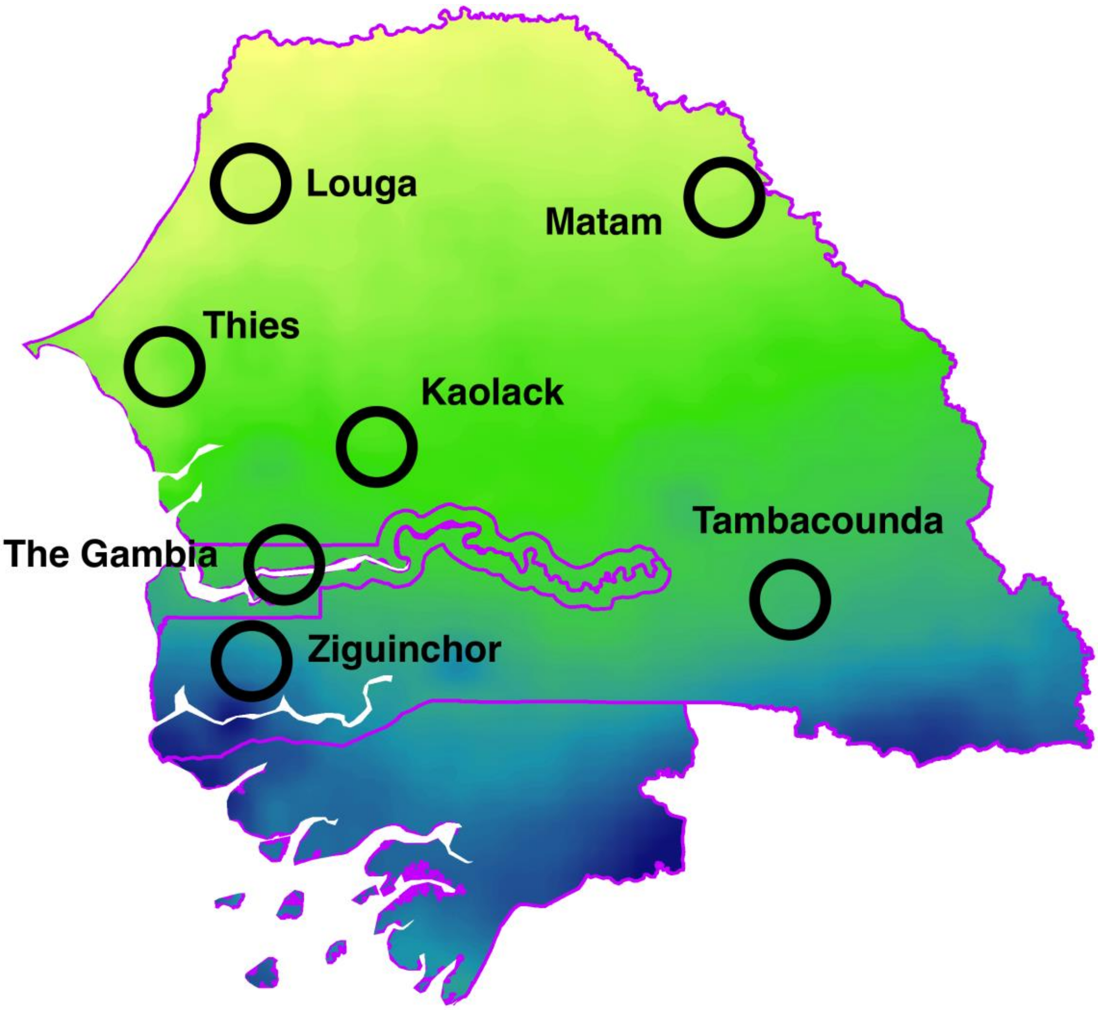

Figure 1) Administrative boundaries of Senegal, The Gambia, and Guinea-Bissau and general trial locations, with each circle containing 60 farmer field trials in 2015. (*The background image is the mean annual rainfall from 2001-2015 as calculated at 10km resolution from the daily estimates of the Rainfall Estimator Version 2 (RFE2), then smoothed at a higher resolution for presentation).*

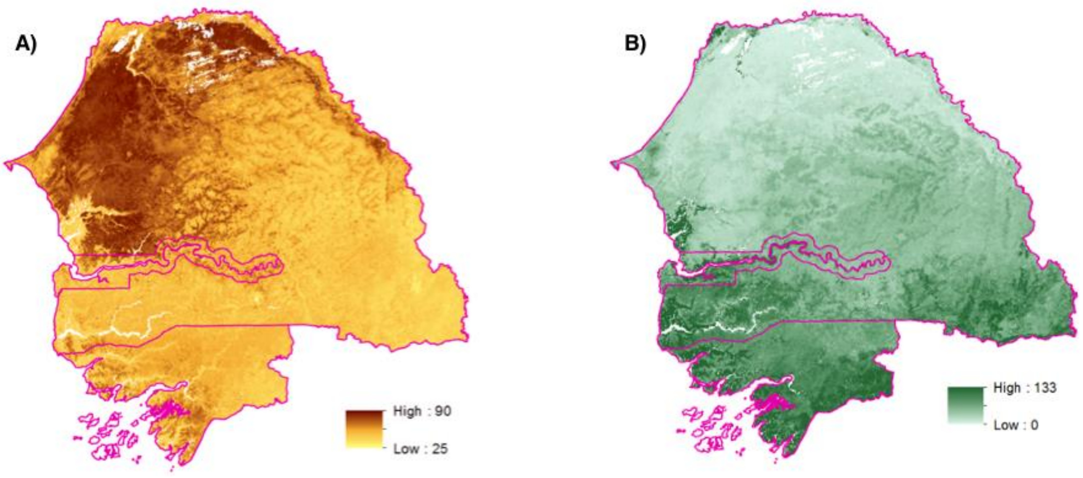

Figure 2. Spatial patterns of A) % sand and B) SOC organic carbon (g/kg soil) in the top 15 cm of the soil *(as estimated by the Africa Soil Information Service (Hengl et al., 2015)).*

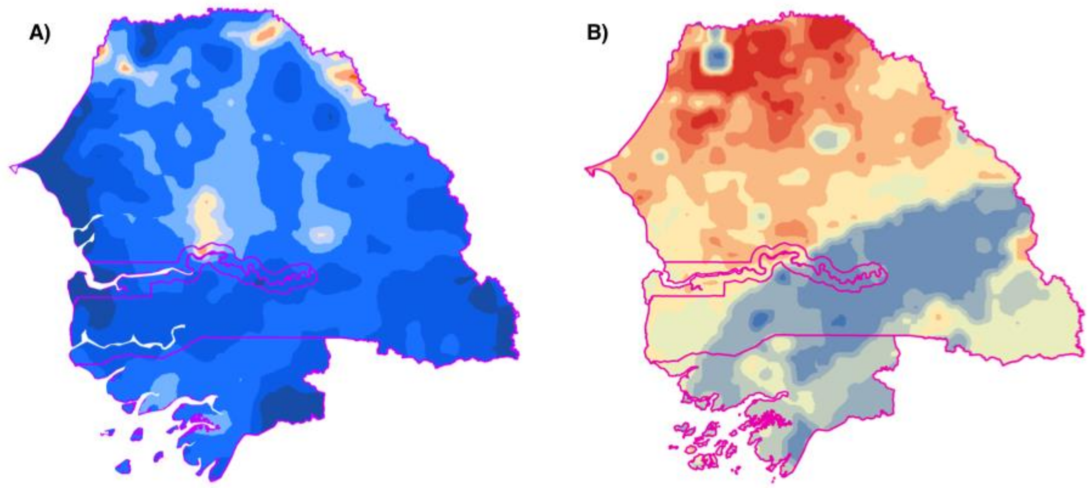

Figure 3. Spatial comparison of the 2015 rainy season and the mean of 1983 to 2015 presented as: A) % difference in total precipitation and B) % difference in length of season, calculated as the number of days between the first and last day with greater than 10 mm of precipitation and correcting for outlier events. (*The values are calculated at 10 km resolution using the Africa Rainfall Climatology v.2.0 (ARC2) dataset, then transformed to a higher resolution and smoothed for presentation (Novella & Thiaw, 2013). This dataset is less accurate than the RFE2, but with a longer timescale is more suitable for temporal comparisons).*

Farmer experiments, agro-environmental policies and practice change

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Abstract: More sustainable farming practices need to be developed and adopted. Current agro-environmental policies struggle in efficiently promoting sustainable agriculture. On the other hand, many farmers experiment constantly in order to improve their practices, but the created knowledge is rarely acknowledged by formal agricultural research or extension, nor is it systematically collected to provide general lessons. Farmer experiments can be seen as a part of the creation of farmers' local knowledge as opposed to more scientific and bureaucratic knowledge that forms the basis of policy formulation. This paper explores the role of farmer experiments in the building of their expertise and the relationships between experiments, agro-environmental policies and changing farming practices. Findings from thematic interviews with 31 Finnish farmers are provided. Farmer experiments were identified as important in translating innovative technologies and practices promoted by policies to the local circumstances. To encourage experimentation, policies need to leave sufficient room for local adaptation while encouraging practice change. If collected in a systematic manner, farmer experiments could be an important source for improving the policies as well as facilitating the spreading of environmentally friendly practices.

Keywords: Experimentation, farmer innovations, local knowledge, knowledge systems, agro-environmental policies, cultivation practices

Introduction

Farming is always site specific. It is performed at a unique setting regarding fields, crops, weather and farmer's purposes. Generic rules or technologies developed in agricultural science are rarely directly applicable in the local context without being translated to the particular circumstances. Without translation and modification, they can easily be rejected as unfit for the current practices and purposes of the farming system (e.g. Noe et al., 2015). Similarly, the making of environmental policies and regulations often ignores the local specificities. This can result in failures in agro-environmental policies (e.g. Morris, 2006; Riley, 2008; Bartel, 2014).

Farmers have valuable knowledge built experientially over the years and previous generations (Millar & Curtis, 1999; Baars, 2011), but their knowledge is informal in comparison to more explicit scientific or bureaucratic knowledge. This local knowledge goes under many slightly differing terms such as tacit, implicit, vernacular, indigenous or traditional knowledge (Raymond et al., 2010; Bartel, 2014). The divisions between different knowledge types are somewhat arbitrary, since a person's knowledge is always hybrid, combining different ways of knowing. The cross distinction between scientific knowledge constructed using scientific methods, bureaucratic knowledge constructed in policy making and implementation processes, and local knowledge production types is however useful in pointing out the varying ways of knowledge production and legitimisation (Morris, 2006; Raymond, et al., 2010). Scientific knowledge is based on scientific rules and processes, farmers' knowledge is constructed via their own knowledge systems and policies are based on the bureaucratic knowledge system (Morris, 2006). These discrepancies in the knowledge systems make policies seem distant and unreliable from the farmers' perspective (and sometimes from the scientists' perspective as well). Riley (2008) has suggested that understanding farmers' ways of knowing and how these affect farmers' perceptions of practices promoted by agro-environmental policies can facilitate policy design and implementation. One way of increasing this understanding is to focus on the experimental nature of farming.

A farmer's experience with his/her fields is a result of ongoing experimenting and following learning in order to improve livelihood. Especially in the developing country context, it has been noted that many farmers experiment constantly to improve their farming practices (e.g. Bentley, 2006). Following Sumberg and Okali (1997), I argue that experimenting is a central process for the creation of local knowledge among farmers. By focusing on their experimentation process, it is possible to scrutinize knowledge creation and assess the knowledge discrepancies causing policy failures. The role of experiments in creating local knowledge and mediating policies has not been explored previously. Analysing Finnish farmers' arable farming practices, the following research questions are asked: how do farmers build new knowledge via experimenting?; what is the role of policies in the experimentation processes?; and could building on farmer experiments be a way to improve the policies?

In line with Kummer et al. (2012) I define farmer experiments loosely as a process where something totally or partially new is introduced at the farm and the feasibility of this introduction is evaluated. In the analysis, experimentation refers to both planned and non-planned situations, where lessons are learned from observing the initial situation, making treatments and observing and monitoring the results (Hoffmann et al., 2007; Kummer et al., 2012).

Farmer experiments mediating knowledge asymmetries

Farmer experiments as livelihood experiments

Farmer experiments differ from more formal scientific or more applied innovation experiments which are focused on developing pre-determined solutions in an organised manner (Huttunen & Zavestoski, 2016). These so-called local livelihood experiments or folk experiments (Bentley, 2006), i.e. experiments that are performed in everyday life to improve one's livelihood are (re)gaining attention in farming systems' studies (Maat, 2011). Farmer experiments have been approached via the call for participatory research, acknowledgement of farmers' local knowledge and the need to co-create innovations rather than disseminate information from science to farmers (e.g. Hoffman et al., 2007; Baars, 2011). Especially in the developing country context, farmer experiments have gained interest as a method of developing and spreading agricultural innovations (e.g. Bentley, 2006). In a more developed country context, farmer experiments are related to the development of unorthodox methods, which have initially not been promoted by the extension services. Typically, these include organic farming and no-till, which were developed via farmer experiments and exchange of knowledge via farmer networks, as no information was available apart from other practising farmers (Ingram, 2010; Goulet, 2013). In fact, all agricultural research has its roots in farmer experiments; only the increasing complexity and methodological organisation of agricultural science have distanced research from farmers working on their fields (Maat, 2010).

Farmers have different styles for experimenting and the degree of experimentation varies among them (e.g. Lyon, 1996; Bentley, 2006; Vogl et al., 2015). Livelihood improving experiments need not be encouraged by advisors or scientists, but many farmers conduct them as a part of normal farming activities (Bentley, 2006; Munya and Stillwell, 2013). The experiments can be accurate, resembling scientific style in their design and management or they can be accidental implying that the experimenting farmer was not initially aware of conducting an experiment (Kummer et al., 2012). The experiments can be directed to solving a single, even incremental problem or towards wider transformative development of the farming system (Bentley, 2006). In the latter case, several consecutive experiments are conducted over a longer time-period to reach the development target via trial-and-error adjustment (Ingram, 2010).

Farmers evaluate the results of their experiments taking into account diverse observed factors and drawing from their local knowledge developed over the years of farming experience encompassing previous generations and neighbouring farmers (Lyon, 1996; Vogl et al., 2015; Baars, 2011). The results are discussed in farmer networks, leading to co-creation of new (local) knowledge (Goulet, 2013; Dolinska & d'Aquino, 2016) facilitated by farmers' readiness to trust information obtained from other farmers (Hoffmann et al., 2007). The holistic evaluation style and implicit sharing of results suggest two major advantages in farmer experiments compared to top-down policy steering and extension: the knowledge created experimentally is adapted to the local circumstances; and it easily spreads in existing farmer networks facilitating its adoption.

Experimentation and environmental policy

Farmers perceive agro-environmental policies from the perspective of their local, practical knowledge (Riley, 2008). As new policy measures are introduced, farmers need to decide whether and how to implement them. The policies can appear far-fetched from the farmers' perspective if the policies rely strongly on other knowledge systems. Famers can find their knowledge superior to that of the government because it is more practical, evidence-based and effective (Bartel, 2014). They possess their own systems for the legitimation and production of knowledge (Morris, 2006; Goulet, 2013). In comparison, the knowledge systems used in making policies or science are unfamiliar to farmers making the knowledge produced seem non-transparent and invalid in the local context. This can lead to direct rejection of introduced policy measures and farming practices they promote.

The discrepancies between the different knowledge systems have been approached by bringing the scientific knowledge production closer to the production of local knowledge. Participatory and transdisciplinary research projects have managed to combine the different knowledge making processes and create new hybridised knowledge (e.g. Misiko, 2009; Nguyen, et al., 2014) and the ideas of co-creating knowledge and increasing dialogue and knowledge brokerage have been adopted in extension and innovation (e.g. Millar & Curtis, 1999; Klerkx & Leeuwis, 2008). From the policy perspective, the discrepancy has been approached by pleas to better incorporate farmers' perspectives in the policy-making processes and to make the policies more fitting to farmers' practices and purposes (Riley, 2008; Burton & Schwarz, 2013). In addition, attention has been paid to facilitate the internalisation of the policies by farmers via enhanced education and co-learning processes (Lobley et al., 2013; Stobbelaar et al., 2009), which connects the issue back to increasing participation in agricultural science (Nguyen et al., 2014). Experimentation provides a new angle to the debate by providing a broad arena in which the social learning can occur (c.f. Nguyen et al., 2014). Farmers mix the knowledge systems via experimentation drawing ideas and discussing results in their networks (Munya & Stillwell, 2013).

Thus, if the agro-environmental policies are mandatory or despite the far-fetchedness seem lucrative, due to monetary compensations for example, a process of implementation starts. This can be seen as an experimentation process. When farmers start experimentally implementing the policies by adopting the promoted farming practices, they incorporate the knowledge the policies provide to the creation of their own locally based knowledge. In this way experimentation functions as a process of knowledge integration, where farmers incorporate the knowledge implied in the agro-environmental measures into their own knowledge system finally resulting in modified or newly performed farming practices (Fig. 1).

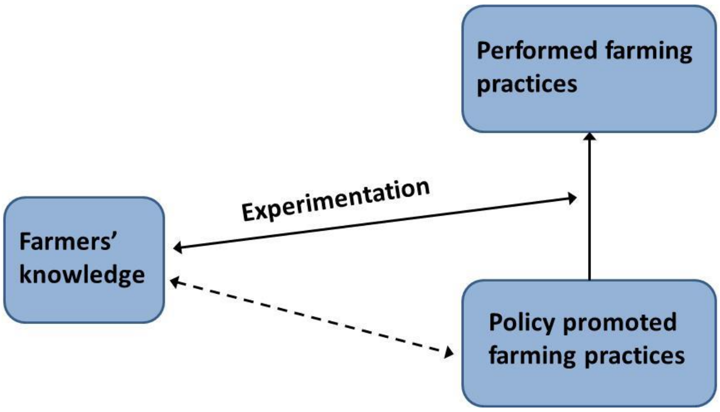

Figure 1. Framework for analysing the role of experimentation in the adoption of policies at the local level.

I use this framework to analyse the role of experimentation in Finnish farmers' farming practices and implementation of both voluntary and non-voluntary agro-environmental measures applied in the country via rural development programmes between 1995 and 2014.

Data and analysis

The analysis is based on 31 qualitative interviews of Finnish farmers, representing different locations, farm sizes and production lines. A detailed description of the data is available in the article by Huttunen and Oosterveer (2016), see also Table 1. The interviews were conducted during fall 2014 and they lasted from one to three hours. The thematic interviews focused on farmers' arable farming practices, their changes during the past 20 years and the role of agro-environmental policies in these changes. Experimentation and learning emerged as an important category discussed with the farmers and the analysis derives mainly from this part of the interviews. In the analysis, the issues the farmers themselves identified as experiments were considered as experiments.

The analysis followed content analytical methodology (Mayring, 2004). The interviews were analysed qualitatively in two phases with a small quantitative element to describe the different experiments (Table 1). In the first phase, the transcribed interviews were read through while searching for specific experiments. These experiments were then scrutinized to identify their motivation, source of idea, design, innovativeness and results. These were classified under categories developed based on the identified issues and existing literature on farmer experiments (e.g. Vogl et al., 2015) (Table 2). In the second phase, the focus was reverted to the whole interviews to enable a deeper understanding of the farmer's learning and relationship between policies and experimentation. The following questions were posed at the interviews: how does the farmer build his or her knowledge?; and what is the relationship between experimenting, learning, practice change and policies? (Figure 1). The analysis was made with the help of an Excel spreadsheet, facilitating the collection of the relevant information from each of the interviews into shorter descriptions and enabling categorisation and comparison.

Farmer experiments in Finland

Experimenting was quite common: in total 18 out of the 31 interviewed farmers told about having experimented and 43 experiments were described at varying levels (Tables 1 and 2). The majority of the farmers told about one or two experiments, but up to six experiments were touched upon in an interview. The number of experiments discussed does not provide accurate number of the experiments actually performed at the farms as it was unlikely that the farmers remembered or found it necessary to describe all their experiments.

Table 1. Experiments at different farms and (socio-economic) characteristics of the farms studied.

		Experimenting farmers (18)	Total farmers (31)
Number of experiments in a farm	*Minimum*	1	0
	Median	2	1
	Maximum	6	6
Farms by area	*Uusimaa*	5	11
	Southwest Finland	5	11
	Ostrobothnia	7	9
Farms by production line	*Cereal, ley or vegetable*	7	16
	Dairy	7	8
	Other animal husbandry	4	7
Farms by field area (ha)	*Minimum*	13	12
	Median	70	70
	Maximum	161	214
Farmer's age (years)	*Minimum*	29	29
	Median	47	49
	Maximum	66	66
Gender of the interviewee	*Male*	11	21
	Female	2	2
	Farmer couple	5	8

In general, the identified experiments were about improving the farming system by either searching for solutions to particular problems, or finding new ways to make agricultural production more efficient. This reflected in the motivations behind the experiments, which usually related to a desire to improve the economic result of the farm (Table 2). However, not all experiments aimed simply at economic benefit. Curiosity towards new issues was an important motivator, often connected to other motivations. In particular the farmers who experimented often regarded it as important to always try out new things and apply them at the farm level to see if they really work in practice. Other motivations also involved a desire to improve the environment, the soil or to help other farmers. Policy-measures had directly motivated the experimenting in five cases, but they had indirect effects on many other experiments (see below).

Table 2. Diversity of the 43 identified experiments summarised.

What was the experiment about?	New crop/ crop mix	30% (13)
	Fertilisation	21% (9)
	No-till/ reduced tilling	12% (5)
	Green manure	9% (4)
	Adding organic/inorganic matter to the soil	7% (3)
	Plant protection	5% (2)
	Other (e.g. separating manure, calculating nutrient balance, microbial additive to seeds)	16% (7)
Motivation (multiple reasons apply)	Directly improving the economic result:	
	Saving capital	37% (16)
	Improving yield	26% (11)
	Curiosity	33% (14)
	Improve fields/ soil	21% (9)
	Saving labour	16% (7)
	Available subsidy	12% (5)
	Other (environmental change, improve the environment/reduce emissions, help someone else)	7% (3)
Where did the idea come from? (multiple sources apply, in some cases no source was identified)	Promoted/suggested by another farmer (incl. contractors)	23% (10)
	Agricultural advisor, or project	19% (8)
	Read about it from a magazine	16% (7)
	Own idea	12% (5)
	Policy recommendation/ option	12% (5)
	Commercial agent	12% (5)
	Agricultural Education	5% (2)
	Other (visit abroad, previous work experience, suitable machinery)	7% (3)
Design	Direct application to a small area	49% (21)
	Direct application to a large area	16% (7)
	Serial experiments with modification	21% (9)
	Comparison on parallel fields	7% (3)
	Accidental	5% (2)

Innovative scale of experiment	Adopting new technology/crop/practice at the farm	56% (24)
	Adopting new rare technology/crop/practice at their farm	37% (16)
	Creating a completely new or significantly modifying a technology/crop/practice	7% (3)
Result	New technology/changed way of doing	49% (21)
	No clear result/ more experimenting required	33% (14)
	Failure	19% (8)

The experiments mainly involved adoption of existing technologies, crops or practices not previously used at the farm. The experimented issue could be quite common among other farmers, or it could be rare, such as applying a recently developed product or no- and reduced tillage in their early development phases. In these cases, the experimenting involved finding out whether the issue fits the conditions at the farm and making the required modifications to improve the compatibility. In three cases, farmers developed a new issue or made a new kind of application for an old method. These were about fertilisation and preventing water pollution.

Farmers designed their experiments to varying levels. The most common method was simply to try something out on a small parcel of land or in such a way that the potential failure would not mean significant financial loss or other problems severely hampering the functioning of the farm. In some cases, farmers directly employed a larger land area, but then they were quite certain of the success of the experiment beforehand based on the experiences of other farmers. Farmers could also design the experiments to resemble formal trials comparing parallel fields for example. If the first experiment provided successful results, the farmers often expanded the experiment and developed it further, potentially leading to full adoption of the new practice. In two cases the experiment was initiated by accident and resulted in a discovery of a suitable practice.

Farmers evaluated their experiments based on their own observations on the growth of the fields, soil structure, the level of yield and the amount of weeds, depending on the subject of the experiment. Many discussed and exchanged results with neighbouring farmers and recommended good practices to others. Hence, farmers did not experiment in isolation, but they benefitted from the knowledge of neighbouring farmers or other farmer-friends. Farmers also discussed the results with agricultural advisors and retailers, but their knowledge was perceived in relation to their practical experience as farmers (c.f. Hoffman et al., 2007). Experimentation was a co-learning process, where new knowledge was produced discursively comparing experiences and practices between different farms. It has been suggested that the discussions with other farmers create a space for the generation of new knowledge via the generation and reinforcement of new discourses (Dolinska & d'Aquino, 2016).

The described characteristics of the experiments are well in line with farmer experiments described elsewhere, including those in both developed and developing countries (e.g. Vogl et al., 2015). The particular role of policies as motivation and a source of ideas, however, is rarely scrutinized in previous literature.

How experiments translate policies into practices?

The interviewed farmers emphasised learning by doing. Knowledge was built over the years by observing fields under different weather conditions, while cultivating different plants and using different farming techniques. This also made the created knowledge manifestly local and applicable only at the particular farm or in its proximity. The creation of experiential knowledge was slow and the farmers emphasised that one never stops learning. As described by Hoffman et al. (2007), farming is a life-long case study or a continuous experimenting process, where results are composed holistically in relation to time and space. Many farmers did not connect their experimenting directly to policies, but were highly motivated to develop their farming and saw policies more as hampering their endeavours than facilitating or promoting them. However, policies clearly had induced experimenting; they were translated into local practices and knowledge via experimentation in the various settings.

Policies inducing experiments

The interviewed farmers considered new issues in relation to their local knowledge. Introduced policy measures did not easily shift the understanding of proper and functioning ways of farming, hence there was reluctance and a feeling of misfit regarding the policy measures as reported in previous studies (Morris, 2006; Riley, 2008; Bartel, 2014). However, policies provided a motivation via subsidies and requirements, and induced experimentation to test the possible ways to implement the policy demands. The interviewed farmers described many areas where experimentation with new practices related to changes in policies. Common examples are no-till related to the requirement to increase plant cover during winter and reducing fertilisation. A young farmer explains how the plant cover demand induced them to experiment with winter crops:

> "*We started cultivating winter grain due to the environmental support, one reason was the high price of rye and the other was the requirement for plant cover in winter. And we wanted to experiment with them, because we had never tried them before, to see how they succeed".* (B1)

Usually the policy induced experimentation resulted in the adoption of the promoted farming practices, but also more ambitious development of new farming systems, like no-till. Not all the experiments were successful and some farmers rejected the new methods as unadoptable at their farms.

The policies could also support experimentation and development work in subjects not directly related to the particular policy measure. For example, one farmer was continuously experimenting related to different means to improve the structure of soil on his fields. He benefited from the subsidies to establish a wetland and utilised the topsoil removed during the establishment of the wetland to improve his clay fields. In similar vein, farmers selected optional policy measures based on their predicted fit to their existing farming system. This limited the potential scope of policies to induce experimentation on new issues. As was evident from the evaluation of experiments, farmers consider their farm holistically, and the changes need to work well in relation to multiple interconnected farming practices. An older vegetable farmer describes his decision-making related to optional environmental measures:

> *"Largely we have taken the actions, which won't require any radical modifications to our practices. That they wouldn't make it impossible to do some important cultivation measure. This means that we have looked at what we can do and then tried to improve it and fit it to the environmental measures".* (A2)

The knowledge building initialised by policies can also be hampered, if the regulations are too tight and leave no room for experimentation, or if new technologies cannot be adopted in the first place because of the regulations.

> *"There were these requirements related to how deep you can till, it was something like 13 centimeters, nobody can measure it, and there is no machine that can do it precisely the way the requirements demanded. These kinds of ridiculous requirements should not exist".* (B2)

The fear of new restrictions and the resulting change can also keep farmers from committing to the means, but they may still experiment on related issues.

Policies mediating knowledge

Experimentation provided the means to slowly build new knowledge via combining local and scientific knowledge. A farmer growing vegetables describes the development of his fertilisation activities with respect to the policy demands to reduce fertilisation:

> *"I have continuously questioned it (fertilisation reductions demanded by agro-environmental policy), that does it really work. We developed the system via fertilising the crops several times, which helps in getting the right nutrient to the right place at the right time. In this way the reduction of fertilisation begun. Then we used soil fertility analysis to monitor the remaining amount of phosphorous. The figures were wild; in principle we should not have needed to utilise phosphorous at all. Then we tried it on a couple of small fields, where we did not use phosphorous at all. But we had to revert to giving part of the plant's phosphorous need at each fertilisation time to make the plant feel well, so that it could utilise the phosphorous in the soil".* (A2)

The farmer had high motivation for reducing the environmental impacts of his farming practices. He had internalised the need to reduce fertilisers, prevent pollution and connected these to his motivation to reduce cultivation costs. He tested the knowledge on the functioning of reduced fertilisation promoted by policy. In doing this, he used scientific knowledge provided by the soil fertility measurements and his own observations on plant growth and modified his practices accordingly. This resulted in a new fertilisation system, which demonstrated increased knowledge of the nutrient needs of the plant.

The farmer evaluated the fertilisation system mainly to produce healthy plants. Also, the success of the experimenting with different new systems (such as green manure, reduced tilling or manure injection) were evaluated and modified based on the improvement of the farm economics and overall improvement of the farming system, not in relation to the environmental benefits. Hence, successful experiments performed in order to accommodate policies do not necessarily mediate scientific knowledge related to the environmental impacts of farming, but they can simply translate the policy measures into local knowledge (c.f. Nguyen et al., 2014). This is the case especially if the reasons or scientific understanding behind the promoted measures are not made explicit to the farmers or if the farmers do not understand them. The search for (economic) farming system benefits resulted in some disappointments related to the policy measures and the questioning of their appropriateness. A cattle farmer explains his selection of the measure on specifying nitrogen fertilisation:

> *"Farmer: we have selected the measure on precise nitrogen fertilisation.*

Interviewer: Do you remember why you selected it?

Farmer: the idea was to select everything, which even in theory can reduce fertilisation costs, but as we have the tools for the measurements and we have made the analyses, it feels a bit frustrating. We have not found any high values indicating that we should drop the fertilisation level". (C3)

The farmer felt the measurement was useless, a waste of time, because it induced no further development with potential savings in fertilisation costs. The knowledge itself was not important to him.

Higher education helped some farmers to understand what lies behind the policies instead of mere mechanical implementation. Higher education provided farmers with tools to develop their farming: enhanced experimentation style; measurements to support their observations; and increased openness and boldness in testing and searching for new ideas. A cattle farmer with considerable crop production also emphasised that education was important in helping him to understand policy requirements:

"I think the university education has affected me in such a way that I don't have any threshold to trying anything, not as high a threshold as my parents had. It has somehow widened my world view, given me the ability to experiment and ensured that the initial reaction is not rejection… It has probably given the so-called scientific world view, so that I believe research results and let them influence what I do. It also means that when there are all these instructions and regulations in the environmental support system, I have a better chance of understanding the background and reasons for their existence". (B8)

The relationship between understanding and embracing the purposes of the policy measures and the experimental farming style appears crucial in improving environmental policies (see also Stobbelaar et al., 2009). Currently, the policies do not promote experimentation and innovation to better reach the policy aims, but merely to fit the policies to the farming systems. The potential learning effects to merge scientific knowledge with local knowledge via policy-induced experiments do occur, but policies could benefit much more widely from farmers' experiential learning and innovation potential.

Policies to enable experimentation

The results suggest two improvements for the policies: i) focus on facilitating the understanding of the policy aims and their internalization; and ii) enable experimentation to reach the policy aims. A farmer couple discussed the role of motivation and understanding in implementing agro-environmental policies:

"Farmer 1: I believe that a better way is that the person who actually is taking the actions, that he has a motivation and a personal goal. And that it can be influenced. For example, if you think about the environmental issues, that we would want to care for the environment. It does not happen by handing out 10 orders saying that you need to do this and this and this. That only results in opposition, especially here in Finland.

Interviewer: You mean that you would need to understand why you are doing the things, and that there is a concrete purpose?

Farmer 1: Yes, exactly

Farmer 2: That would work better here, I'm sure of it.

Farmer 1: These are related to the fact that currently the understanding is not facilitated, orders are just delivered: draw a line to the wall at this date.

Farmer 2: You don't need to know anything, just do these things. This is the attitude related to subsidies. It is none of your business, just carry out the actions. The spreading of information is second-rate". (A4)

The importance of farmers' understanding on why certain environmental measures are required and motivating farmers to take environmental actions are widely acknowledged (e.g. Stobbelaar et al., 2009; Burton & Schwarz, 2013; Nguyen et al., 2014). Farmers' experimental development of their farming systems brings about a new dimension for its importance. Experimentation is mainly done in order to improve the farming system, hence the motivation and understanding is crucial. Selecting the policy measures which were the most natural from the point of view of the farm, which would be done anyway, or which would imply the least harm, have not necessarily encouraged innovation or thoughtful implementation. However, the cases where the aims of the environmental support system were internalised demonstrated how new innovative systems can be developed going beyond the mere adoption of a required action.

The understanding and adoption of the policy aims is not sufficient, if the policy measures enable implementation only in a strictly defined manner. A cattle farmer explains:

"I think that we should create opportunities for action, so that the system would steer the opportunities in such a way that it would pay off to do certain things… so that a farmer could make supported choices to develop his farm holistically". (C3)

There should be an incentive in the subsidies to actively develop farming instead of merely restrictions and punishments. The experiments related to policies were not very innovative, but often related to application of quite common methods. This is partially due to the small room for development available in the fixed policy measures.

To go beyond mere adaptation of the suggested technologies, the key issue is either the internalisation of the aims promoted by the policies or the openness of the policies themselves to allow for the development of the systems. Recent studies have pointed out how agro-environmental schemes can eventually lead to internalising at least some of the environmentally beneficial aims (e.g. Huttunen & Peltomaa, 2016). The development of the so-called result-oriented agro-environmental measures can provide a means for further opening space for experimentation within the policy measures. These measures subsidise farmers for the measured amount of environmental benefits they produce, not merely for performing a certain pre-defined action (Burton & Schwarz, 2013). Hence, they leave room for farmers to invent ways to produce the benefits, while also contributing to the internalisation of the understanding and motivations related to the environmental benefits. For experimentation to occur, an emphasis on enabling resources rather than strict guidelines is important.

Conclusions

Farmers learn by accumulating experience, and experimentation is a central process used for this learning. The interviewed Finnish farmers experimented in different ways and to a varying extent. Experimentation provides a means to accommodate new knowledge and practices promoted by policies and policies provide inspiration for experimentation. This efficiently domesticates new practices and can result in the creation of new innovative practices. Experimentation provides a means to distribute innovations at the ground level and develop them further to meet the requirements of different kinds of farms. Thus, building on farmer experiments provides an interesting way to improve agri-environmental policies.

The results highlight the importance of farmers' motivation to achieve the environmental improvements and understanding of the reasons and scientific mechanisms behind the policies, resulting in experimenting incorporating scientific knowledge and a better functioning of the policies. Without proper attention on the creation of understanding of the environmental aims and mechanisms behind the policies, the experimental implementation by farmers risks losing its potential to create new environmentally beneficial practices. Rather, the experimentation merely accommodates the policy measures (not the aims) to the local knowledge.

Experiments can also lead to new innovations which should be taken into account in policy-making. It is important to collect experiences from farmer experiments and applications of existing technologies at different kinds of farms. This could be combined with advisory services and development projects aiming at advising and changing farmers' practices. The collection of experiments would be valuable especially as the resources for agricultural research are diminishing, but also because the translated knowledge can be more useful for farmers than results from scientific research. In the future agro-environmental policies would benefit from promoting experimentation for the implementation of policy aims and taking into account experimental innovations in policy design.

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Sparking small scale dairy farmers' enthusiasm within a transdisciplinary project in Kenya

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Abstract: Small-scale dairy farming systems in Kenya are low-external input systems and therefore show a high context dependency. As most small-scale farmers have low capital endowment and have poor access to new information, they often do not see chances to improve their situation on their own. Fostering change in such systems requires methodologies that give farmers voice in the research process and that integrate and expand farmers' knowledge and capacities, leading to improved action. As part of a transdisciplinary research project, two small-scale dairy farmer groups in Nakuru-County Kenya engaged in a collaborative learning process. This article seeks to analyse the processes that contribute to successful facilitation of farmers' experimentation and innovation. We want to understand how enthusiasm was triggered, maintained, or suppressed. Enthusiasm is defined as a desire to engage with practices that draw on the energy, imagination and ideas of an individual or group (Russell & Ison, 2000). We found that enthusiasm played a role throughout the four collaborative learning phases, i.e. establishing the collaboration, dialogue, discovery and application. Democratised research relationships sparked enthusiasm during the steps of establishing the cooperation and dialogue, while a sense of progress and success maintained it during the steps of discovery and application of new knowledge. The article concludes by stressing the importance of new forms of research, such as transdisciplinary research, that include local actors, i.e. those that can change the system by changing their actions as partners in a knowledge creating dialogue.

Key words: Transdisciplinary research, enthusiasm, farmer-led experimentation, innovation system, Nakuru County, Kenya.

Introduction

Smallholder farmers in Kenya have limited physical and financial capital to improve production conditions. For this reason, smallholder farming systems are also referred to as *low external input systems*. Such highly context dependent systems are characterised by multiple human-environment interactions over space and time. Agriculture itself represents a co-evolution between society and environment (Bacon et al., 2012). Thus, any attempt to bring about sustainable change in agricultural systems requires a *social-ecological analysis,* i.e. an analysis that considers how agriculture produces landscapes that are social, cultural and ecological (Cronon, 1996). In agricultural systems, social-ecological analysis focuses on how farmers deal with variability and change and how this change occurs at the individual and the collective level (Coughenour, 1984). Hence, when analysing such coupled systems there is an emphasis on understanding agriculture as a *human activity system*, i.e. a system established and managed by farmers with their actions and knowledge (e.g. Bawden et al., 1984; Woodhill & Röling, 1998; Dillon, 1992; Valentine, 2005; Caporali, 2007; Halliday & Glaser, 2011; Kaufmann, 2011; Bacon et al., 2012; Blythe, 2012; Lescourret et al., 2015; Kaufmann & Hülsebusch, 2016; Moraine et al., 2016; Restrepo et al., 2016).

As most small-scale farmers generally have low capital endowment and are often isolated from networks of regional and global communities, i.e. have poor access to outside information, they often do not see chances to improve their situation on their own. Fostering change in such systems requires methodologies that integrate and expand farmers' knowledge and capacities, leading to improved action. The contextuality of smallholder farmers' systems calls for transdisciplinary research, i.e. open to *real world actors*. In transdisciplinary research approaches diverse knowledge systems bring multiple perspectives (from academic, practitioner and other societal actors) and enable a better understanding for finding applicable solutions to *real world problems* (Stokols, 2006; Lang et al., 2012). Consequently, contemporary approaches to generate practically relevant knowledge take into account the local context and address real world actors' perspectives (including researchers) of the problematic situation through dialogue.

As part of a transdisciplinary research project, two small-scale dairy groups in Nakuru County, Kenya engaged in a collaborative learning process. Groups were invited to apply for farmer-managed innovation funds. The funds were directed at learning about, and experimenting on, key constraints in the farmers' agricultural system, i.e. to stimulate farmer-led experimentation without individual farmers bearing the financial risk of experimentation. Hoffman et al. (2007) acknowledge the power of informal modes of farmers' experimentation, while Wettasinha et al. (2014) stress the importance of experimentation that uses only local resources in innovation development with marginalised smallholder farmers. Farmer-led experimentation is defined as the process by which farmers conduct informal trials or tests that can result in new knowledge (Rajasekaram, 1999 cited in Leitgeb et al., 2014). We chose to work with a transdisciplinary approach in this research with farmers because: (i) one-size fits all solutions are not useful in context dependent systems; (ii) we acknowledge the importance of arriving at a common understanding of the problematic situation with all involved actors; and (iii) solutions identified and implemented with real world actors are more sustainable. This article seeks to analyse the processes that contribute to successfully facilitating farmers' experimentation and innovation. Within a collaborative learning process, we want to understand how enthusiasm is triggered, maintained, or deterred in a collaborative learning process that promotes farmer-led experimentation. We pursued this line of inquiry with two dairy farmers' groups in Nakuru County, Kenya. Enthusiasm is defined as a desire to engage with practices that draw on the energy, imagination and ideas of an individual or group (Russell & Ison, 2000).

Materials and methods

Study site

The study area is located in Nakuru County in the Rift Valley of Kenya. Nakuru County is classified as having a humid to sub-humid climate (Muriuki, 2011), and it is favourable for dairy and crop production (van de Steeg et al., 2010). Two areas were selected, Mukinduri (0°58´S, 35°98´E; 2687 masl) and Lare (0°44´S, 36°00´E; 2160 masl). The first study site is adjacent to the Mau Forest Complex, while the second is adjacent to Nakuru National Park. Mean annual precipitation in Mukinduri is 1400 mm, while in Lare it varies between 600 - 1000 mm (Figure 1).

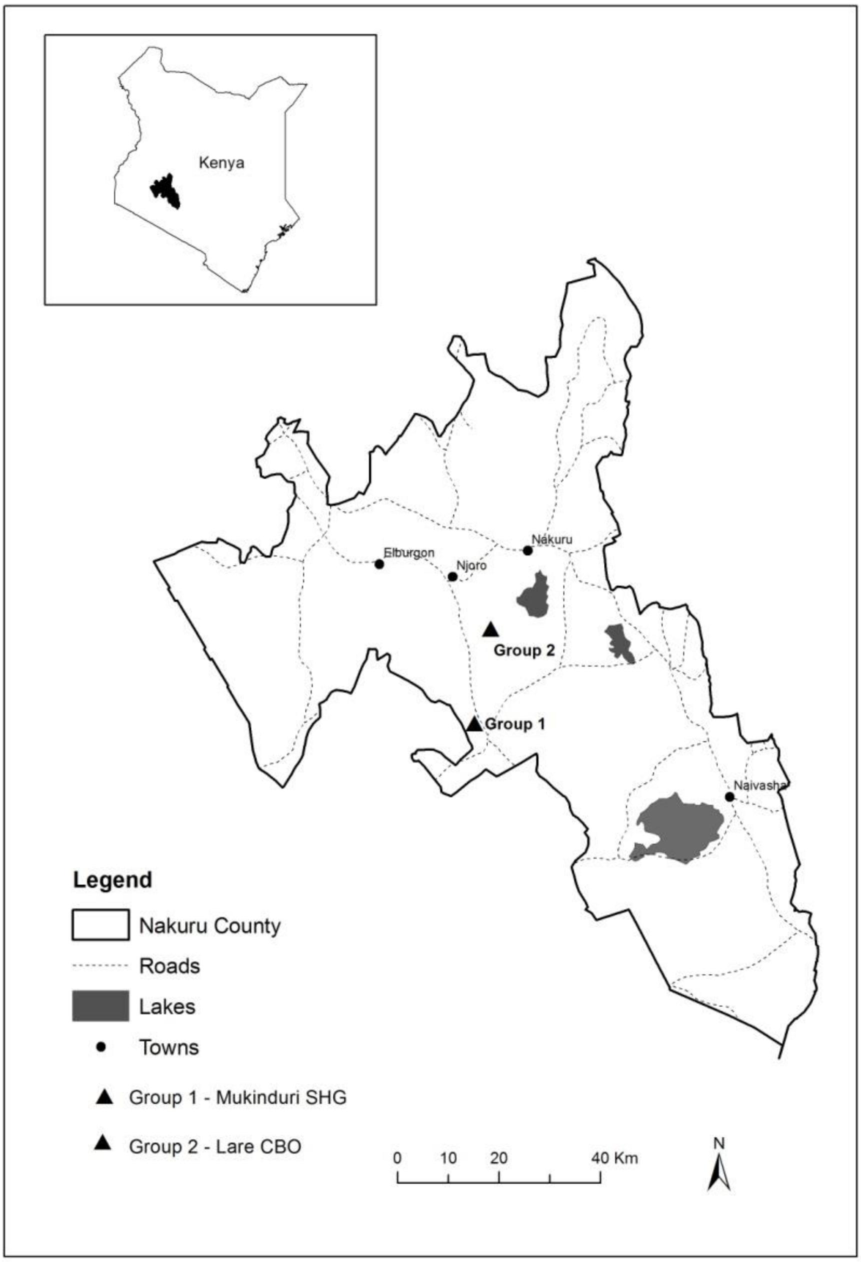

Figure 1. Map of Nakuru County, Kenya depicting site 1 (Mukinduri SHG) and site 2 (Lare Livelihoods CBO)

Smallholder dairy farmers in the study area usually keep one crossbred cow, with a maximum of three. Cows are commonly fed with Napier grass, crop residues from the farm (i.e. maize stalks, bean and pea stubbles, as well as residues from carrots, cabbage and potatoes) and weeds. Lactation periods vary between 7 and 24 months, as cows may continue to be milked even when they did not conceive in time. The majority of the daily milk is marketed and milk is also used for family food needs.

Data collection and analysis

A collaborative learning process was established with the Mukinduri group in August 2013 and with the Lare group in June 2014. Farmers' perspectives on the experimentation process were systematically documented from February to November 2015 using a combination of oral and visual methods. We conducted a series of complementary inquiry methods to assess what farmers have learned and how they evaluate the collaborative learning process. These included: 12 semi-structured interviews (SSI) including critical incident questions related to their own motivation and satisfaction (Brookfield, 1995); participatory scoring of benefits from the experimentation process with all group members (n=40) (Holland, 2013); 5 narrative interviews (NI) exploring farmers' experiences during the collaborative learning process (Jovchelovitch & Bauer, 2000); and group sessions to share the stories of change from 33 farmers (October 2015) using the Most Significant Change technique (MSC). MSC is a form of participatory monitoring and evaluation that provides data on impact and outcomes from actors' own perspectives (Davies & Dart, 2005).

The duration of the semi-structured (SSI) and narrative (NI) interviews was between 45 and 90 min. The stories of change (MSC) sessions lasted ca. 120 min. With farmers' permission, each individual interview and group session was audio recorded and transcribed. For the semi-structured interviews guiding questions were used to maintain focus; however, the interviews did not follow a formal structure but were rather conversational for reciprocity of dialogue. This approach allowed interviewees to feel comfortable and to focus primarily on the topics that they were most familiar with.

A content analysis was conducted with the qualitative information obtained. It included inductive and deductive coding of the data to identify similarities and patterns. Codes used were related to learning topics, benefits from the collaborative learning approach and relational aspects of learning. Tables and diagrams were constructed based on this information.

Context: steps of a collaborative learning process with two farmers' groups

Two small-scale dairy groups in Nakuru County, Kenya, engaged in a collaborative learning process as part of a transdisciplinary research project for reducing food losses and adding value. This project was conceptualised as four interconnected phases (for further information see Restrepo et al., 2014): (A) establish the collaboration; (B) process of dialogue; (C) process of discovery; and (D) applying the new knowledge (

Figure 2).

During the process of *establishing the collaboration* a partnership was institutionalised between the two small-holder dairy farmer initiatives and the researchers. Farmers had the status of co-researchers, i.e. they had voice in the process of defining, designing, testing and implementing sustainable solutions for a jointly defined real-world problem.

The process of *dialogue* enabled: (i) development of a shared understanding of the complex problematic situation, i.e. problems related with milk quantity (seasonality and work load), quality (cleanliness and milk composition) and market (rejection and seasonality); and (ii) realisation of a joint strategy for achieving goals, that included different types of fodder and silage to improve milk quantity, and both on-farm milk quality testing and construction of a zero-grazing unit to improve milk hygiene.

Through the process of *discovery* farmers were able to fill knowledge gaps and to develop innovations for problematic activities. The process consisted of (i) farmer-to-farmer exchange sessions with peers having silage, different types of fodder or a zero-grazing unit; (ii) farmer-led experimentation in order to gain experience; (iii) collecting information using different instruments, e.g. keeping records of milk production and testing milk density and mastitis incidence; (iv) analysing new information and reflecting on what worked and what didn't during group meetings; and (v) evaluating the results and drawing conclusions regarding what might need to be done differently.

After testing the different options, *applying the new knowledge* is the basis leading to the consolidation of a new activity into a more broadly recognised social practice. This phase is on-going.

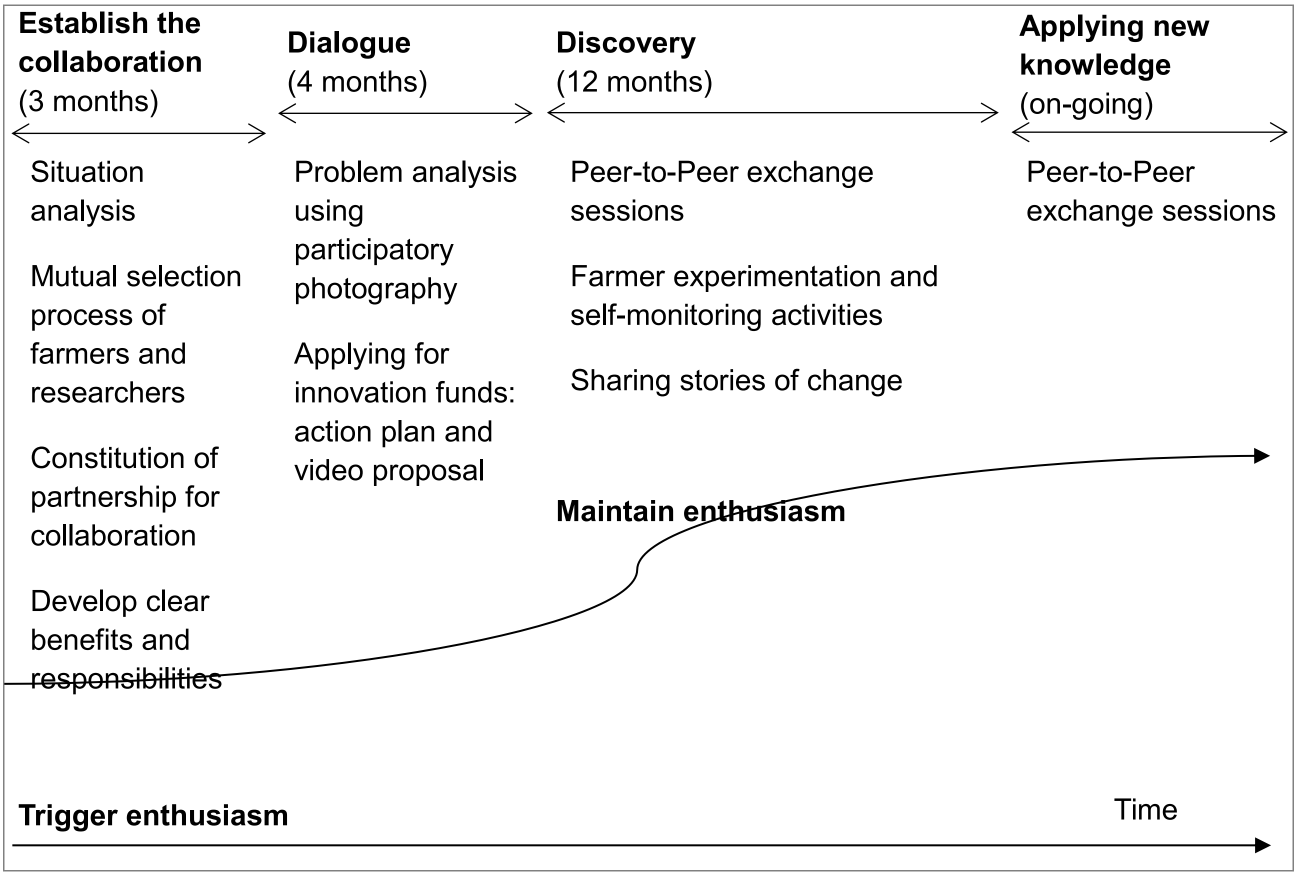

Figure 2. Methodological sequence in a collaborative learning process with two farmer groups in Nakuru County, Kenya

Enthusiasm

We found that enthusiasm played a role throughout the four collaborative learning phases, i.e. establishing the collaboration, dialogue, discovery and application (Figure 2 and Table 1). In the next section we will present different factors that triggered and maintained enthusiasm, both from farmers and researchers, during the different collaborative learning phases. Finally we discuss tensions that suppressed enthusiasm, for both farmers and researchers. Through this section, we illustrate our findings with representative examples using farmers' own words.

Table 1. **Factors affecting enthusiasm during the collaborative learning process** (***Theoretical items from the researcher's perspective)***

Collaborative learning phase	Methodological sequence	Enthusiasm is: Triggered	Maintained	Suppressed
(A) Establish the collaboration: Mutual selection	Situation analysis			Long and extractive process
	Mutual selection process of farmers and researcher	Valuing all actors - respect		
	Constitution of partnership for collaboration	Feeling of actual potential to make changes Forming hope		*Power imbalances (researcher-farmers)**
	Develop clear benefits, roles and responsibilities	Balancing power relations Mutual trust building		Hidden agendas
(B) D*ialogue:* Integrating knowledge	Problem analysis using participatory photography	A meaningful and rich way to share farmers' perception of the problematic situation Relevance Skills and equipment		Long process with no actions for farmers and results for researchers Time constraints Power imbalances (between peers) Imposed solution Inconsistent participation Position(s) of self-gain Not keeping session on time Ineffective communication among actors Monopolizing equipment
	Applying for innovation funds: action plan and video proposal	Open story for farmers to re-write (Dolinska & d'Aquino, 2016) Sense of ownership and commitment Agency Skills and equipment		
(C) D*iscovery:* Constructing knowledge	Peer-to-peer exchange sessions	Agency -Sense of "we can do it"	Re-defining roles among local partners	Not keeping session on time Ineffective communication
	Farmer experimentation		Farmers see themselves in the position to try new things based on their own priorities and	*Imposed experimentation parameters** *Technologies not accessible**

			conditions (low cost and based on local conditions) Ownership of experiments and results	Unsuccessful past experiences Perceived risk Long process without actions/results
	Self-monitoring activities		Short term results - feeling of progress Monitoring effects of own ideas for improvement: - Milk quantity with records - Milk quality with lactometer Learning from each other Friendship and trust	Monopolizing observation tools *Imposed monitoring strategy**
	Sharing stories of change		Sharing perceived benefits - feeling of progress Friendship and trust Sense of pride	Not keeping session on time Ineffective communication among actors
(D) Applying new knowledge	Peer-to-peer exchange sessions		Sharing results with other farmers Increased self-esteem	

Establish the collaboration: mutual selection process

In establishing the collaboration, a mutual selection process between farmers and researchers was a first step in fostering enthusiasm as it fomented hope, as stated by one of the farmers during the Most Significant Change session "*I had one cow and ... I was contemplating selling it. But when we came together, I decided to keep it, because I saw some light*" (female farmer, MSC) (see also social capital in Figure 4). In the selection process, researchers, guided by explicit and implicit selection criteria, chose two smallholder farmer initiatives to establish a partnership; Lare Livelihoods Improvement CBO and Mukinduri Dairy Self-Help Group. Importantly, the two farmer initiatives also chose the researchers to facilitate the process by proactively engaging with the researchers and expressing their desire for a collaboration contract. Both groups represent bottom-up initiatives, and are an example of farmers coming together because of their willingness to change, as can be seen with the following quote: "*Let's say the issue of joining the group was not in me. But the chairman told me ... that they are very much interested in learning more about dairy farming … in this area there has never been a group like this one*" (male farmer, NI).

Once the collaboration was institutionalised, we worked on balancing power relations so that everyone's knowledge and experience was recognised as important: "*we are all learning and no one is ahead of others*" (male farmer, NI). After clarifying roles and responsibilities, the size of the group in Mukinduri became smaller "*when we formed the group we were 47 members, and that group just reduced in size because some had different aims where some had thought that the researcher had come with money*" (male farmer, NI). Farmers with unrealistic expectations left, leaving only those willing to take the risk of embarking on a learning process into uncharted territory. As a young farmer stated, "*we did not know that there is a way you can learn, even if the person (researcher) does not give you anything, she can teach you and you get that knowledge*" (male farmer, SSI). This is an expression of the trust that was built during the first steps, but also of the desire to engage and change.

Dialogue: integrating knowledge

Using participatory photography, researchers facilitated the problem analysis from the farmers' perspective, something that was later much appreciated by the farmers themselves. As one of the farmers in Mukinduri remarked, "*it was good that we were capable of talking about our problems .... even if our government listened to our problems and we were assisted, it could be of great help. Perhaps this could be done using a video just like we did*" (male farmer, SSI). Possible solutions emerged, after which the development of an action plan was facilitated. Farmers applied for an experimentation grant using a video proposal which served to jointly re-conceptualise their experimentation plan. The grant was intended to stimulate experimentation without farmers bearing the financial risk. In the *dialogue* phase, coming to a common understanding of the problematic situation triggered enthusiasm by promoting relevance, ownership and commitment (see social capital in Figure 4) as stated by one young farmer in Lare "*everyone participated in planning even if they did not appear in the shoot (video proposal)... we were happy because we knew we are part and parcel of that. The video brought us all together because we had to discuss and agree upon what to do. It helped in decision making*" (male farmer, SSI).

Discovery: constructing knowledge

In the discovery phase, farmer-to-farmer exchange sessions grounded farmers' experiments and enhanced a collective sense of `we can do it´. As stated by one of the farmers, "*When we* visited his (peer's) place I was able to learn a lot about making silage practically. I saw that I can also make mine because he has already done his. So I was able to follow from step one to the last steps*" (male farmer, SSI). Exchange sessions permitted farmers to see how peers are addressing the same problematic situation by making silage and planting different types of fodder for cows. It further increased farmers' agency, as farmers had the space to test and evaluate how silage and different types of fodder could work and to remove doubts. Exchange sessions were also important in re-defining roles as *teachers*, as stated by one of the farmers that facilitated the exchange session, "*when I was going to teach them I was happy that I was chosen ... although initially people were fearful to try silage, now they are doing it"* (male farmer, SSI).

Subsequently, farmers developed their own trials to test sustainable practices to improve milk quality and to buffer seasonality based on different feeding strategies. Figure 3a) shows farmers' participation in the farmer-led experimentation aiming to improve milk quantity and quality and to buffer seasonality. Farmers had in their hands the decision of what to test according to their current situation. For example, weather condition, land availability and labour; the experimental year was a dry year in Lare, and in Mukinduri farmers had already allocated most of the land for other crops. Enthusiasm was maintained during the experimentation process as can be seen by the high level of satisfaction (Figure 3b).

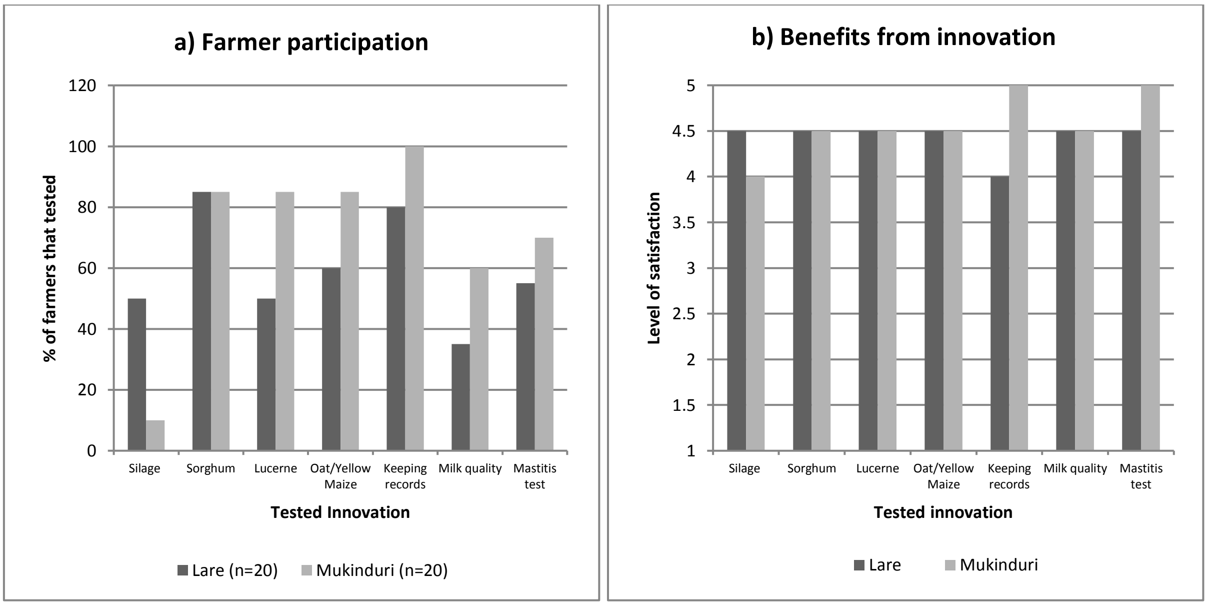

Figure 3. Farmer a) participation in, and b) perceived benefits (5 Excellent – 1 Bad) from farmer-led experimentation in a collaborative learning process in Nakuru County, Kenya (*n=40; benefits only from those farmers that tested the innovation*)

Farmers also tried different observation tools: keeping records, testing milk quality and early detection of mastitis using the California Mastitis Test (CMT). Using these tools, farmers implemented self-monitoring activities which maintained enthusiasm by highlighting the progress achieved. For example, as seen by a young farmer's comments, "*since we started recording the amount of kilos (of milk) the cow produces, someone can say from here to here, that my cow has made a difference*" (male farmer, SSI). Farmers also used observation tools to further test the impact of the different feeding strategies, "*I have used the lactometer. I wanted to know whether the density improved; it went from 26 to 29 and even 31. This was after feeding the cow with the new fodder*" (female farmer, SSI). Self-monitoring activities helped in maintaining enthusiasm. A young farmer stated that other areas of production activity were positively affected, "*if your cow produces low-density milk, the milk density rises when you add Lucerne (alfalfa). When you deliver your milk, it will never be rejected and they (milk traders) gain trust in you…"* (male farmer, SSI).

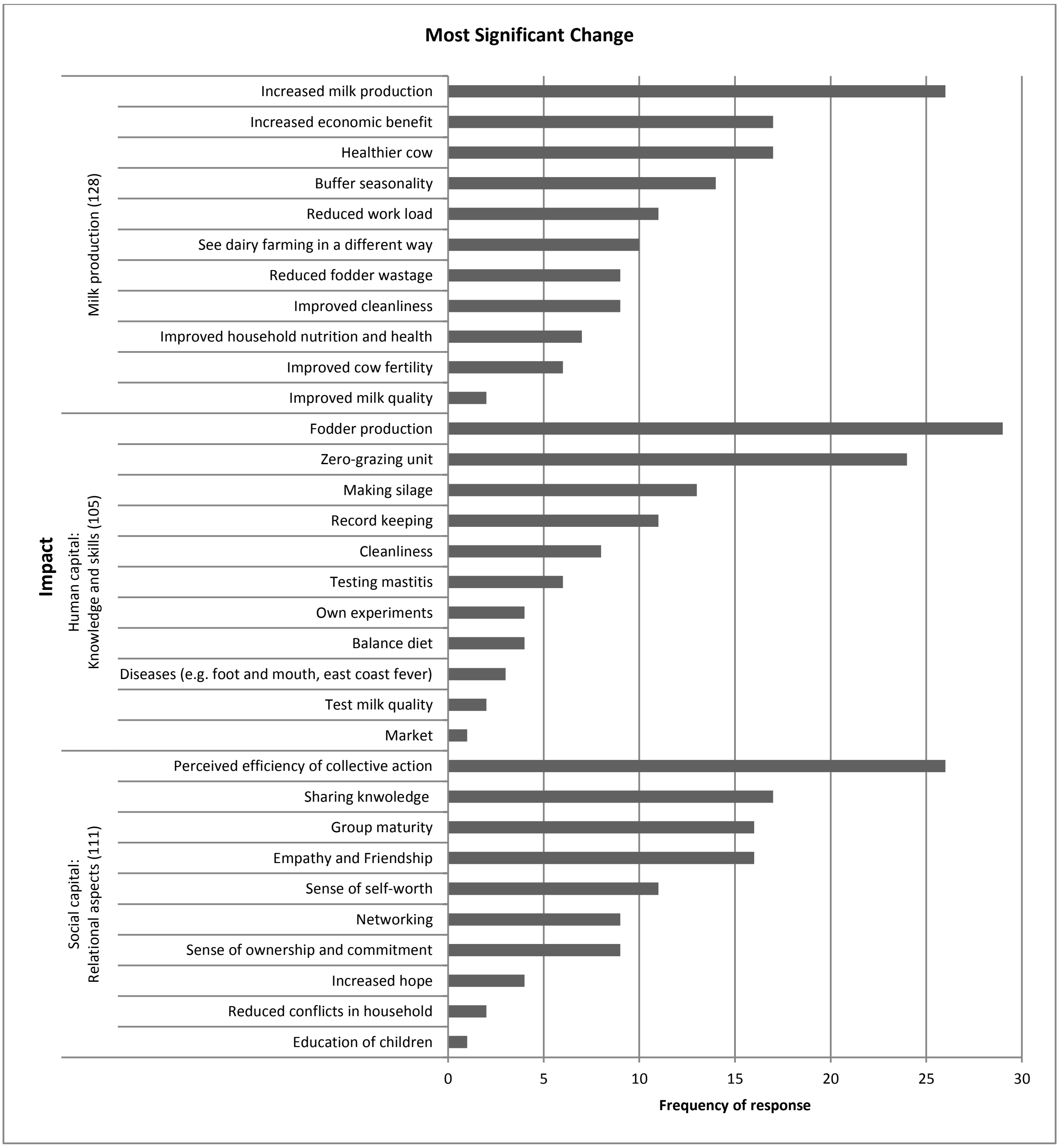

Figure 4. Perceived impact after sharing stories of change in a collaborative learning process in Nakuru County, Kenya (*n=33; frequency of response; multiple answers per respondent*)

Farmers emphasised the value of farmer-led experimentation, as can be seen by the following comments, "*it's a lot of power to learn and to practice*" (male farmer, NI) and "*we were discussing according to how we have learned, the knowledge is more than money. Because if it was money we would have shared amongst us, spent and forgot*" (male farmer, SSI). Experimentation was important for maintaining enthusiasm, as it provided short-term results, "*I planted the seeds that we received for investigation… it was excellent, because the cow produced enough milk for my family and I, and we were even able to sell*" (female farmer, SSI).

The results from the individual experimentation were shared informally during casual meetings: "*through the group I have many friends, so in case I have any problem when we meet, I share the problems and exchange ideas. That has helped me a lot*" (Lare, MSC). Results were also shared formally during group meetings and through the Most Significant Change session. Here farmers commented on what had changed during the collaborative learning project. Results from sharing the stories were grouped into those related to a) milk production; b) Human capital: acquired knowledge and skills; and c) Social capital: relational aspects of learning (Figure 4). Sharing results maintains enthusiasm as farmers' develop a sense of progress. Most importantly, farmers value the benefits from experimenting: "*I have seen the benefits of trying new things. I will continue experimenting*" (male farmer, SSI) and "*the most important thing I have learnt is the passion for testing new things*" (male farmer, SSI).

Applying new knowledge

In the application phase, group members implemented various innovations on a wider scale, which also expanded outside the groups. As an example, one young farmer in Lare has implemented silage and fodder on a larger scale, "*I have done so much silage that during this dry period I was able to share with my father, as he did not have enough fodder to feed his cows*" (male farmer, SSI). With the objective of selling the milk as a group, in Mukinduri, a small group of seven farmers pilot tested a local quality guarantee system, "*we (with six other farmers) implemented a system for testing milk quality every 2nd week to avoid rejection*" (male farmer, SSI). Finally, as stated by a farmer in Lare, "*the group is gaining recognition, and we are spreading our roots …*" (male farmer, SSI).

Tensions: factors that reduce or suppress enthusiasm

In our concrete experiences, *time* is an important factor that could suppress researchers' and farmers' enthusiasm. When working with farmer-managed innovation funds one needs to bear in mind that there are trade-offs between facilitating the initial phases so that the partnership is solid (i.e. balancing power relations; clarifying benefits, roles and responsibilities; preventing the occurrence of self-serving positions; improving decision-making among group members). All require a lot of time to set up. In such partnerships, researchers need results while farmers want action. Inconsistent participation from farmers during the *dialogue* phase not only reduced enthusiasm, but also increased the time needed to arrive at a joint understanding of the problematic situation and an agreement on strategies to achieve goals. The time use in the sessions (i.e. participatory photography, video proposal, peer-to-peer exchanges or Most Significant Change) also affected enthusiasm when the sessions did not start at the agreed time, or took longer than had been agreed upon by the group. The issue of time was contentious. A participant explained that, "*the challenge… for me is especially concerning transport… the journey is not short, but I sacrifice a lot because it is for my own good and also for the society in my area. So I make sure I arrive at the right time*" (Lare, MSC)

A situation analysis at the beginning of the project is seen as offering important initial information for the researchers, but farmers did not see the need for it. Moreover, they felt it was extractive and resulted from a hidden agenda. Both farmers and researchers also discovered that some members of one of the farmer groups had a hidden agenda related to local politics, which created confusion and slightly reduced commitment among other members.

During the *discovery* phase, unsuccessful past experience explained why the percentage of farmers that tested Lucerne (alfalfa) in Lare was low, as the dry season was strong and farmers knew the crop was not easy to establish. The percentage of farmers that tested silage in Mukinduri was low due to the perceived risks of failure (the innovation funds covered all materials except the crops from each individual farmer), and greater in Lare due to the imminent drought. Monopolisation of tools to test for milk quality and mastitis not only reduced the number of farmers that tested them, but also had an impact on enthusiasm.

Finally, when working in a situation were not all actors (particularly the researcher) speak the same language, there is a need for an interpreter. Communication dynamics can reduce enthusiasm when: (a) the researcher and/or interpreter use overly technical or paternalistic language, in some cases pejorative terms; and (b) the message does not reach all members of the partnership in a timely manner (not all farmers obtained accurate information about dates, objectives and duration of sessions).

Discussion

This paper presents different factors that triggered, maintained and suppressed enthusiasm during a collaborative learning process that promoted farmer-led experimentation in Nakuru County, Kenya. The reported findings demonstrate that it is possible to actively trigger and maintain enthusiasm through inclusive methods: participatory photography and video; farmer-led experimentation; self-monitoring activities; and sharing results. By analysing farmers' perspectives on the experimentation process, we highlight the importance of: (i) democratised research relations that included farmer-managed innovation funds to co-construct knowledge; (ii) building trusting relations; (iii) peer-to-peer exchange sessions; and (iv) sharing short-term results to accentuate a sense of progress.

For sparking farmers' own enthusiasm in a collaborative learning process that included farmer-led experimentation, one important issue is to give farmers an active voice in the research process, i.e. they can decide what they want to experiment on, how and why. Building the foundations of the research with the farmers implies having an open-story for farmers to re-write (Dolinska & d'Aquino, 2016). Hence, the emphasis is on shifting the project towards co-construction rather than transfer of knowledge or, as Sewell et al. (2014) expressed it, "sharing power with farmers". This also means that farmers have the freedom to decide how they prefer to implement their experiments and what they prefer to observe according to their interest, curiosity or knowledge needs. Facilitating the use of different tools to observe and monitor (e.g. keeping records, on-farm testing for mastitis and milk quality), was also perceived by farmers as motivating. These observation tools were further used according to different needs and interests to self-monitor the outcomes from experiments. As Saad (2002) and Bentley (2006) argue, it is not necessary that farmers employ scientific methods (e.g. formal treatments, random trials or control groups) to experiment and learn.

Because of smallholder farmers' low financial capital endowment, working with farmer-led innovation funds is a good idea as farmers can experiment without bearing the financial risk. As stated by Ton et al. (2015), grants targeting smallholder farmers are a promising agricultural policy instrument. Farmer-governed funds have been widely implemented by PROLINNOVA (Wongtschowski et al., 2010). For these funds to succeed, it is important to work with group dynamics to facilitate a partnership in a collaborative process. Faure et al. (2011) describe such partnerships in action research as the commitment of different actors who maintain their autonomy and bring together different human and material resources to achieve a shared objective. As stated by Rist et al. (2006), the willingness to collaborate in a partnership comes along with trust building, and the development of trustful relationships is related to less hierarchical patterns of communication.

The peer-to-peer exchange sessions helped farmers on one side to change their perception towards a determined technology and on the other side to become more aware of their own knowledge. For example, silage was perceived as something that only rich farmers can do, but after meeting peers that have adapted and adopted silage successfully, their own agency increased. Besides, peers who were visited became aware of their own knowledge when performing their new roles as *teachers*, also reported as a key factor in a social learning process by Rist et al. (2006). Finally, when farmers are experimenting individually or collectively they are also observing the results from their experiments. When they meet and share these observations, enthusiasm grows as they can see the progress.

Conclusion

The article concludes by stressing that democratised research relationships spark enthusiasm during the steps of establishing the cooperation and dialogue, while a sense of progress and success maintained it during the steps of discovery and application of new knowledge. The collaborative learning process supported farmers in: (i) constructing knowledge that answered contextual problems, therefore improving the management systems; and (ii) strengthening their own agency. This example from two groups in Nakuru County, Kenya can serve to provide guidance on how to initiate, maintain and support enthusiasm through different stages of participatory research that hinges on empowered farmer-led actions.

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Integration of knowledge for sustainable agriculture: why local farmer knowledge matters

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Abstract: Previous research has revealed that transition to sustainable agriculture requires a new knowledge base - new content and forms of knowledge and learning. In this paper, we explore farmers' knowledge and learning practices with a focus on the role of informal knowledge and learning in strengthening agricultural sustainability and resilience. It is based on 11 case studies from the international RETHINK research programme, which discover diverse pathways of farm modernisation and related knowledge and learning processes. We outline the diversity of knowledge sources and learning forms that farmers use and the particular role of local farmer knowledge. We argue that the potential of farmer knowledge is not being optimally used, and we identify several ways in which different kinds of knowledge can be integrated: by the individual farmer by synthesising knowledge from different sources; through farmer networking – whether or not facilitated by formal agricultural knowledge institutions; through collaboration between farmers and researchers as knowledge co-generator; and through multi-actor knowledge networks that bring together participants from various fields. We conclude that the dynamic contexts, complexity and the local specificity of the current challenges facing agriculture and the many roles it is being asked to fulfil require more inclusive, flexible modes of the generation, integration and sharing of knowledge. All stakeholders and all kinds of knowledge need be brought together on an equal basis in innovation processes. For these purposes, policy frameworks and initiatives that promote an interactive multi-actor approach to agricultural development can play a considerable role.

Keywords: Farmer knowledge, learning, sustainable agriculture, knowledge networks, knowledge integration

Introduction

During agricultural industrialisation the role of farmer knowledge has been largely deteriorating; a lot of this knowledge has even been lost all together with the spread of productivist logic and standardised solutions, and declining farmers' community (Fonte, 2008). However, in the face of the many contemporary challenges - climate change, food security, resource depletion, to name a few - a growing number of development specialists admit that farmer and local knowledge is a valuable resource to reorient modern agriculture towards more sustainable and resilient paths of development.

In this paper, we explore farmers' knowledge and learning practices with a particular focus on the role of informal knowledge and learning in constructing sustainable and resilient agriculture. We use the distinction between formal and informal knowledge to better illuminate the diverse forms of knowledge which exist outside the formal agricultural knowledge system and are generated by practitioners from their experience, without externally imposed criteria and agenda (Livingston, 1999).

It is recognised that sustainable agriculture, due to its holistic, diverse and distinctive nature - explicitly interlinking environmental, social and economic dimensions - requires new content and forms of knowledge and learning (Curry & Kirwan, 2014; Kloppenburg, 1991). As formal agricultural knowledge and innovation system (AKIS) is still strongly focused on the production-oriented model of agriculture, farmers who choose more sustainable paths rely often on alternative learning networks and knowledge sources. Therefore better recognition of local farmer knowledge, and the combination of local and scientific knowledge are needed in order to meet sustainability goals in agriculture (IAASTD, 2009; Pretty, 2008). In recent years agricultural sustainability is linked with the concept of resilience, which evokes the capacities of an agricultural system to adapt and transform in order to persist over the long term. Learning to live with change and uncertainty, and combining different types of knowledge, including farmer, appear as critical for building resilience (Folke et al., 2003; Darnhofer et al., 2016).

This paper advances the stream of research that points to the potential of informal knowledge, and local farmer knowledge more specifically, in strengthening agricultural sustainability and resilience. The rest of the paper is organised as follows. The next section details the concept of informal knowledge, and learning networking for sustainable and resilient agriculture. The subsequent chapter presents our multi-case methodological approach. Next, we analyse farmers' knowledge sources and learning practices and how these are related in various networks. We explain why informal knowledge and learning matter for sustainable and resilient agriculture. Finally, we identify several action points to enhance (informal) learning.

Theoretical framework: knowledge and learning networks for sustainable and resilient agriculture

Research literature brings up several overlapping concepts to delineate informal knowledge (local, practice-based, traditional, lay, farmer, tacit, endogenous, indigenous etc.) and informal learning modes (self-education, learning by doing, experimenting, observing, from own or other's experiences, in social interactions etc.) in agriculture. We focus on two core interrelated kinds of informal knowledge - local and farmer. Local knowledge involves dynamic and complex bodies of know-how, practices and skills, developed and sustained over time on the basis of local people's experiences in their environmental and socio-economic realities (Beckford & Barker, 2007). Farmer knowledge is a subset of local knowledge, enabling farming in specific local conditions. As agriculture is highly dependent on the local environment, local farmer knowledge is of particular importance as it contains an intimate understanding of the particular set of local cultural and natural resources.

The holistic and adaptive character of local knowledge - considering local systems as a whole, integrating their social, environmental and economic aspects, empirical and spiritual dimensions (ICSU, 2002) - makes it especially relevant to agricultural sustainability and resilience. This is illustrated by the development of agriculture within its environmental and social settings through accumulation and application of local knowledge in many regions of the world, over generations (IAASTD, 2009). For example, traditional farmers integrate their farming methods with natural ecological processes and reproduce biodiversity (Altieri, 1999); local farming practices address local community needs - food security, social activities related to food, local economic conditions and sustainable soil management (Briggs & Moyo, 2012). This points to the links between local farmer knowledge and specific ethical, environmental and social values. This issue is of particular pertinence when discussing sustainable agriculture which is driven by different values to conventional agriculture and new ways of thinking.

Informal knowledge is often regarded in relation to formal knowledge (Table 1) and perceived as being pushed into a subordinate position. The science driven conventional agriculture with its technological and organisational changes has resulted in farmers being increasingly dependent on external inputs, and loose tacit knowledge due to alienation from production processes, and reduction and standardisation of skills (Timmermann & Felix, 2015).

Table 1. Differences and commonalities between informal and formal knowledge (*Source: Authors' compilation***)**

	Informal knowledge	**Formal knowledge**	
		Academia	Industry
Source	Own experimentations and practical experience	Research stations	Research stations
Ownership and certification	Practitioners, farmers, local community	Scientists	Specialists, scientists
Approach	Holistic	Complexity	Fragmentation, specialisation
Transferability	Locally specific solutions	Standardised and locally specific solutions	Standardised decontextualised solutions
Transmission and access	Exchange with peers, passed through generations	Peer-reviewed articles, conferences	Education in schools, courses, training groups, literature

A juxtaposition of informal and formal knowledge is helpful to illuminate their different characteristics. However, it does not reflect well the farming reality where farmers integrate and use all kinds of relevant knowledge they have access to (Figure 1). Moreover, the domination of formal knowledge is not straightforward; farmers do not accept it uncritically, rather they negotiate various expert and local information against their own experience-based knowledge (Kaup, 2008). They even tend to value more practice-based knowledge (Wood, et al., 2014; Fonte, 2008) and are able to mobilise their local knowledge to resist the scientific one (Wynne, 1998).

Still, beyond the farm gates, scientific knowledge is more prominent. Together with increasing standardisation and certification of knowledge, farmers' knowledge and skills are devalued and their application is restricted by legal means via laws and regulations. In other cases farmer knowledge is appropriated and codified by scientists and industry, excluding producers and local communities from the benefits of the valorisation of the product (Fonte, 2008). Poor links and interchanges between scientific and practitioners' life-worlds and knowledge, their asymmetrical powers and interests, complicate the applicability and implementation of scientific knowledge in practice and integration of farmer's perspectives into scientific research (Noe et al., 2015).

However, there is an increasing body of research showing the complementarity of informal and formal knowledge, and expansion of multi-stakeholder and participatory approaches where joint trans-disciplinary knowledge production is enabled (Scoones & Thompson, 2009). This research confirms that contemporary sustainable agriculture is advanced by multi-actor knowledge networks where various kinds of knowledge are exchanged, and new meanings and practices of farming are negotiated and institutionalised (Moschitz et al., 2015; Tisenkopfs, et al., 2015; Wood, et al., 2014; Knickel et al., 2009). It is also noted that knowledge creation and dissemination for sustainable agriculture often happen through informal mechanisms (like networks, personal and local daily relational structures, co-learning, mutual support) rather than formal ones (Curry & Kirwan, 2014; Wood, et al., 2014).

As multi-actor knowledge networks bring together different stakeholders, negotiation of the meanings and practices of sustainable agriculture is a part of their interactions and contestations. Such a "social" process brings more sustainable outcomes than purely rational top-down planning, especially in situations when decisions have to be taken on complex issues (Bodin & Crona 2009). In order to reach different stakeholders' mutual understanding and enhance transition towards sustainable agriculture, knowledge mediators or brokers play a key role through facilitation of interactions, joint reflection and integration of various knowledge cultures (Moschitz et al., 2015; Tisenkopfs et al., 2015).

Methodology and case studies

We base our paper on 11 case studies carried out in the international RETHINK research programme. The cases were selected to illustrate diverse pathways of farm modernisation, their connections to rural development and resilience, and the role of knowledge and learning (Table 2). The case studies utilised common conceptual and analytical frameworks and methodology (Darnhofer, et al., 2013; Darnhofer, et al., 2014). Information was gathered through a range of methods involving semi-structured interviews and group discussions with farmers and other key stakeholders from market, public, administrative and civil society sectors. Also relevant secondary data from surveys, statistics and previous research were integrated into the original research. Empirical material was gathered, analysed and structured according to several predefined themes: farmers' needs for knowledge; how they source it; learning modes; networks and outcomes. These themes were also used as the basis for comparative analysis.

Table 2. Overview of the case studies and key knowledge and learning issues

Case	Key knowledge and learning issues
Organic farming and resilience, Austria	The case demonstrates the role of farmer-led networks, informal knowledge building and knowledge transfer and the way they are supported (or not) by formal institutions such as vocational agricultural schools or institutions of life-long learning.
Landscape strategy making and agriculture, Denmark	The case presents how farmers gain knowledge on local landscape management in Odderbaek watershead, and depicts learning as both individual and collaborative, a social capital-building process.
Transitions towards ecological production, France	The case focuses on the types of technical knowledge built during the transition towards ecological production in the French Drôme department fruit and vegetable sector, and the role of on-farm experimentation in the learning processes.
Opportunities for creating an eco-economy: lessons learned from the Regional Action and Bio-energy Regions schemes, Germany	The case explores links and interactions between key stakeholders who build competence for the bio-energy regions and their cross-sectoral and multidisciplinary exchange of information in a transition towards a low-carbon resource-efficient economy.
Farmer adoption of a new nutrient management technology, Ireland	The case highlights farmer learning and the adoption of a new nutrient management method and decision support tool in study groups across the Teagasc Agricultural Catchments Programme. It characterises the role of farmers as intermediaries in innovation dissemination in livestock manure application.
Rural innovation in global fluctuation: the Arava region case study, Israel	The case explores the variety of learning tools available to a farmers' cooperative in the Arava desert area, and their gaps regarding the need for new skills and knowledge, such as marketing, self-organisation and product development.
Extensive pig production systems, Italy	The case reveals the role of collaboration / competition and knowledge exchanges between the food-chain actors, research organisations and regional development agencies in the development of a PDO certified supply chain.
Smallholder farm development strategies, Latvia	The case explores small-holder farmers' knowledge and learning practices and networks and highlights the importance of informal knowledge and learning in this farming segment.

Resilient farming systems and market differentiation: challenges and opportunities in farmers' markets, Lithuania	The case study focuses on the role of the agricultural knowledge system in Lithuania, particularly formal education and advisory, in stimulating farm innovations at local level both in traditional and alternative food chains.
Innovation and social learning in organic vegetable production in the Region of Murcia, Camposeven, Spain	The case study explores how the cooperative's internal governance structure and relational networks promote integration of experiential and expert knowledge, and connecting knowledge and learning to action.
Sub-urban food production systems in a Swiss agglomeration: the example of the milk supply chain in Bern, Switzerland	The case explores knowledge and learning processes across five milk delivery channels with a focus on the role of formal knowledge institutions and informal networks. It points to farmers' strong respect for local farmer knowledge, as well as illuminating learning from consumers in direct sales and CSA systems.

Analysis: learning for sustainable and resilient agriculture

Farmers' knowledge needs and motivations to learn

We discovered a complex of personal and societal drivers behind farmers' learning decisions and activities. The evolving character of agriculture and new societal demands towards it require new knowledge and skills from farmers. Also farmers' motivations and values guide them in selecting knowledge subjects, sources and learning forms. We group these motivations around two axes: business; and ethical and social.

"Business" is of central importance when farmers learn to improve their market performance, increase income, and gain economic stability and growth. In all cases one of the key knowledge needs is marketing, in particular for small-scale farmers and those building new marketing channels (e.g. direct selling, processing or a PDO market chain). Another is technical knowledge that manifested the most in the cases which depended on advanced technologies, like bioenergy production or farming in severe conditions in the desert. Competition, quality demands and opportunities created by scientific advancements push towards constant updating of technical knowledge. To carry out the "business" side successfully, farmers also need bureaucratic, administrative and legal knowledge. The motivation to do better business also involves building certain social and personal skills, like networking, conflict management, creativity and time management.

While a strict division cannot be made between business and non-business, we examine "ethical and social" motivations and corresponding knowledge needs separately. "*I love what I'm doing*" was a common phrase that farmers used when describing their work. This passion is also urging them to discover, learn and experiment in fields of interest to them. Pride in and responsibility for working on the farm that has belonged to the family for generations was another common learning framework, prioritising some solutions over others. This can establish a certain path-dependency, an unwillingness to break with family traditions. But the long-term involvement fosters creativity as farmers learn and develop solutions to stay on their farm even in high-pressure situations. Responsibility for the farm also involves caring for its natural environments – soil, landscape, old trees, wildlife etc. Farmers tend to preserve these resources and learn ways to do so, sometimes even at the expense of production efficiency. Another "ethical and social" motivation is consideration for the interests and resources of the community: neighbouring farmers; a cooperative; a local village; or a broader region. Finally, striving for certain autonomy was guiding knowledge acquisition as farmers are seeking to maintain some independence from market, financial and public forces, and wishing to keep control over their farming decisions and operation.

Knowledge sources

The cases demonstrate that farmers use and integrate knowledge from various sources in order to meet their diverse knowledge needs. In many cases farmer knowledge was the most prominent and trusted knowledge basis due to its local relevance and meaningfulness. In their daily operations farmers rely primarily on their own knowledge accumulated over extended periods of time from practical experience by doing, experimenting and observing.

Traditionally, farm families have been a core platform for learning and knowledge decisions, and in countries like Latvia and Lithuania this is still very common. Another cornerstone source of knowledge featured in the cases is other farmers. Farmers consider their successful colleagues as reputable experts and particularly trustworthy due to their practical experience in similar conditions. Traditional farmer knowledge serves as a solid production resource and a source of inspiration. For example, production of the reputable ancient Cinta Senese pig meat in the Italian case (De Roest & Ferrari, 2015) or retro-innovation projects combining traditional knowledge, handcraft and regional resources with new technologies and creative marketing ideas in Austria (Darnhofer & Strauss, 2015).

In all the cases farmers use also knowledge from formal agricultural institutions (provided in the form of training courses, advice, field days, etc.), but not on a daily basis. The involvement of formal AKIS institutions in local knowledge and learning processes varies and is higher in the cases of advanced technologies. Sometimes farmers choose formal courses over informal learning due to the high profile of the AKIS, its clear production-oriented knowledge content, higher public appreciation and approved certificates (Darnhofer & Strauss, 2015).

Public administrative and controlling institutions are critical knowledge sources for farmers to receive public support. As food production and distribution are strictly regulated and the agricultural regulative framework and support measures are regularly changing, farmers need to frequently update their knowledge. Farmers often perceived this as a burden that demands financial investment, practical adaptations on the farm and considerable bureaucratic work.

Market actors, in particular consumers, are another important source of knowledge and innovation for farmers. In the Austrian and Swiss cases, the direct link to consumers stimulates farmers to rethink their habits of working, and to design new products and services (Darnhofer & Strauss, 2015; Bourdin et al., 2015). For part-time farmers, their off-farm jobs and exposure to other sectors provide additional soft skills, new ideas and experience to integrate into their farms.

The variety of knowledge sources brings us back to the issue of integration, which happens (or fails) in interactions in networks.

Relations between formal and informal knowledge bases

Mediating and transmitting knowledge in networks

In line with previous research, our study demonstrates that farmers operate in multi-actor knowledge networks consisting of overlapping formal and informal sub-networks.

Formal knowledge networks contain various formal institutions: research institutes; advisory services; farmers' organisations; etc. They have a strong historical and institutional 'back-up', have a more structured agenda, operate at a larger scale and receive some public funding. Formal knowledge is often inscribed in printed and digital artefacts circulating in these networks and connecting actors.

Conversely, informal knowledge and learning operate in fuzzier networks, relying on farmers' private interests, community ties, family and personal relations, neighbourhood associations, peer groups, territorial communication structures and tradition. They are often a part of farmers' daily routines and the first channels for exchanging and disseminating ideas and practices. These networks are more local, but not exclusively so, as thanks to mobility and modern ICT tools the connections may be to more distant partners (Šūmane, et al., 2015).

In several cases a central node in farmers' learning networks are farmers' organisations. As Austrian organic farmers and Latvian niche farmers show, farmer groups are particularly important in the pioneer phase of new agricultural approaches when formal knowledge, advice or manuals are limited and farmers look for both knowledge and moral support. Farmer organisations retain an essential role also in well-established sectors and businesses as sites for sharing information, knowledge and experiences, and assisting farmers to manage both farming and non-farming related issues. Farmer organisations also connect farmers to other knowledge sources assuming mediation with wider AKIS.

Complementarity and creative synergy

Informal and formal knowledge are often complementary. We identify several ways of integrating different kinds of knowledge.

At an individual level, farmers use and integrate the many knowledge sources that are available to them, from scientific to their own experiential knowledge. The Irish case demonstrates how a scientifically based support tool (hydrometer) aids farmers' decision making on nutrient management. Its application ameliorated farmers' awareness of the nutrient value of organic manures, improved resource use efficiency and planning, led to savings on chemical fertilisers and reassured farmers about their own estimations (Buckley & Shortle, 2015).

Another level of knowledge integration and dissemination occurs through farmers' networking both in their formal organisations and informal structures. Farmers adopt more easily external ideas and practices which are already accepted and successfully applied by other farmers. An example of the key role of informal knowledge networks in supporting scientific knowledge is the eradication of fruit-fly pest in the Arava region, where the informal social networks and parallel interaction on agricultural and social levels contributed to a region-wide, successful eradication that was unsuccessful elsewhere (Hurwitz et al., 2015).

Formal AKIS institutions, particularly advisory services, can provide another way of facilitating knowledge transfer and exchange between farmers. They organise knowledge exchange between farmers through site visits, study trips, farmer discussion and training groups, formal forums and the like. In some countries, like Ireland, farmer discussion groups are facilitated by approved agricultural advisors, and monetary incentives are given to farmers for participating.

A variation on the above is co-creation of knowledge between farmers and researchers as equal partners, with mutual benefits. Teagasc, the Irish research, education and extension institution, maintains information feedback loops between researchers and advisors and the farmers, whose experience and opinions are used to evaluate the new technology and its likely success or failure if introduced to the wider farming population (Buckley & Shortle, 2015).

Finally, mixed actor groups, involving participants from both agricultural and non-agricultural fields, can lead to completely new, unforeseen insights and developments. In the Odderbæk river valley (Denmark), the cooperation between farmers, local administration and academics has raised awareness about the diversity of local environmental and cultural resources and resulted in a shared vision and strategy for landscape management in the watershed of the Odderbæk. The initiative integrates agriculture into a broader rural development context and has launched a more complex approach to local development (Pears et al., 2015).

Each site and level of integration of different knowledge sources has its role in farm development and modernisation. Better outcomes in terms of agricultural sustainability and resilience are achieved when various kinds of knowledge – formal and informal, local and external – are incorporated into networks, and all actors are reflexive and sensitive to potential synergies.

Conflict and contest

Diverse knowledge sources may also provide conflicting knowledge. Such knowledge clashes were clearly identified between farmers' practical knowledge rooted in their experience and the knowledge of agricultural practices presented in regulations of food production and distribution. The increasing standardisation of agricultural knowledge and practice can be restrictive given farmers' diverse knowledge and skills, lack credibility, and demand cognitive, financial and practical efforts to adopt. Latvian small-scale farmers testify that often agricultural knowledge is locked into certified expertise, and they cannot perform some exercises they might otherwise do themselves (e.g.vaccination) because of regulations (Šūmane et al., 2015). Austrian farmers complain that the dates for distributing manure on grassland are fixed by regulations which ignore the regional conditions of weather, soil patterns etc. (Darnhofer & Strauss, 2015). In these cases farmers are not appreciated as experts, and their experience-based knowledge and skills are ignored, hence undermining the sustainability of their agricultural practices.

So, formal and informal knowledge and their respective networks may be competing. Where informal knowledge networks are strong, formal advisory services have a weaker role as the informal networks dispense with their technical advice (Lamine et al., 2015). On the other hand, there is a trend towards formalisation of knowledge structures and the increasing need for formal knowledge, reducing informal networking and learning (Darnhofer & Strauss, 2015; De Roest & Ferrari, 2015).

The existence of conflicting knowledge can close down or open up the space for innovation and novelties; it demands flexibility from farmers to assume and work it out for their use. For instance, the regulation regarding approved slaughterhouses and processing areas demands intensive investment and prohibits farmers from simple on-farm processing. But these restrictions urge them to look for new market and organisational solutions, like expanding processing, cooperation among farmers or creating a joint commercial enterprise. Nevertheless, this creative energy and the efforts of farmers would be more effective if AKIS and other formal agricultural institutions would acknowledge farmers not only as recipients of information, but also as knowledge generators. In the context of modernisation their expertise is often neglected, although it is a considerable resource to increase resilience and sustainability.

Contributions of informal knowledge and learning to sustainable and resilient farming

Our study confirms that informal knowledge generated in local contexts tends to be holistic - it considers the complexity of the reality in which farms operate integrating the many or at least several of the environmental, economic, social, financial, technical and other dimensions into a single whole. The diverse and dynamic Latvian small-holder farms' strategies illustrate how farmers develop and adapt their farms on the basis of their personal interests, family situation, knowledge of the farm's agro-environmental conditions, regional traditions, market opportunities, available technical and financial resources, labour, public support etc. (Tisenkopfs et al., 2015).

Practical, experiential knowledge adds to farmers' confidence, professional satisfaction and autonomy. Farmers admit to the difficulties of their profession, but in general they express pride and pleasure in applying their creativity and knowledge and seeing them bring results both for their family and community. Their knowledge accumulated over a long time through personal experience in local settings forms a reliable basis for farming and improves their adaptive capacity – to select solutions that best fit their unique conditions.

Similarly, farmer confidence and capacity to act is increased through informal knowledge networking with other farmers. Informal learning networks ease innovation diffusion as farmers adopt more easily practices accepted by their peers. Importantly, knowledge obtained from family or neighbouring farmers is often the initial motivator and guide into agriculture for young and new farmers. Local farmer knowledge also continues to serve as a valuable support and source of inspiration and innovation for experienced farmers.

Informal knowledge sources diversify farmers' knowledge and in this way they also strengthen resilience. They compensate for knowledge gaps in the formal knowledge system, in particular with regard to novel, niche, alternative farming practices as well as non-technical knowledge and skills to which formal knowledge institutes pay less attention. Informal knowledge is even more important when you take into account the weak or weakening state and accessibility of public formal agricultural knowledge systems in some regions or countries.

Direct knowledge exchange not only helps to develop and disseminate sustainable practices, but also strengthens the social structures through which these practices are disseminated: ties of friendship or solidarity; community; and identity building. This is even more pertinent when collective benefits result from joint learning e.g. improved local settings, an eradicated pest, a boosted local economy or an empowered farmers' community.

In addition, we also identified environmental benefits linked to informal local knowledge. For instance, many of the small-scale farmers studied practice less intensive farming techniques linked to specific local knowledge, rooted in natural processes and creating less environmental pressures. In the Danish case, the experiential local knowledge has been a key to developing a shared integrated vision and projects of agricultural landscape management. The Israeli Arava farmers' unique local knowledge on farming in extreme climatic conditions is relevant when considering climate-smart agriculture.

Thus informal knowledge and the social mechanisms through which it is acquired and disseminated can compensate for the shortcomings of formal knowledge systems, demonstrating a range of contributions to resilient and sustainable agriculture, including those to farmers' identities, communities and environments.

Conclusion

We have examined the multiplicity of knowledge sources and learning structures in agriculture, the integrative links between informal knowledge and formal knowledge, and demonstrated the prominent role of farmers' informal knowledge for sustainable and resilient agriculture.

Integration of various knowledge sources and learning forms appears as a key aspect in order to survive, adapt and prosper in modern agriculture, in particular if one innovates and wishes to depart from the well-trodden paths. It requires of individuals and systems both sturdiness and flexibility. Personal curiosity and willingness to learn, together with social networking and supportive formal knowledge and governance structures appeared as central elements for successful learning, knowledge integration and innovation. Both formal and informal knowledge sources have their strengths, yet it is networking and knowledge exchange which make knowledge flexible and sustainability-enhancing. The particular role of informal knowledge lies in the fact that adaptation and transfer of knowledge are mediated by farmers' own and local knowledge.

While joint knowledge activities among various stakeholders are expanding, additional targeted consideration still needs to be given to farmer knowledge and innovation, other informal knowledge sources and learning forms, and the ways to better integrate this knowledge. Such recognition and use of farmer knowledge would also support the goals of an inclusive knowledge-based society, which builds on the respect of knowledge diversity, broad knowledge access and everyone's participation with his/her knowledge. The more recent engagement of AKIS in multi-actor knowledge networks and the closer collaboration with farmers point to the development towards more participatory, inclusive and comprehensive knowledge and learning processes.

Our research suggests some areas of engagement for formal knowledge institutes and agricultural policy makers:

- Facilitating connections and knowledge exchange among various stakeholders for joint learning such as: joint events with experts from all the relevant fields; collaboration between farmers and formal research institutes in field tests or when developing new products; and consulting farmers to integrate their knowledge into regulations;
- Supporting local-level initiatives such as networking, cooperation, mentoring, exchange of experiences, young farmers' projects etc. Advisory could become

involved in such knowledge exchanges acting as a professional knowledge mediator and facilitator;

- Training in the social skills of networking, collaboration and joint learning could help to strengthen both networks by avoiding over-reliance on the few skilful leaders and the outcome of learning;
- Financial support for organisational expenditure (e.g. printing materials, postal delivery and travel costs) of the learning networking together with simple and transparent guidelines to apply for such funds would be helpful, in particular to reduce financial and time constraints of dedicated and trusted farmers who are often overburdened.

The changing nature of agriculture, its links to other rural sectors, as well as the current challenges facing agriculture and the many roles it is being asked, require development of mixed knowledge and learning networks with a broader inclusion of both agricultural and non-agricultural stakeholders. All stakeholders, including farmers, need to be recognised as equal co-authors of knowledge, and all kinds of knowledge, both formal and informal, need be enhanced and brought together in innovation processes.

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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. In contrast, several studies recognise 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 it possible to develop action strategies when farmers were facing hindrances to continuing their technical changes. Our findings concern the specific fundamental knowledge actually mobilised, and the processes of its linkage with action through contextualisation. 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 with fundamental scientific knowledge on agroecosystems components to enhance cropping system redesign.

Key Words: Cropping system re-design, agroecology, inductive case study, knowledge.

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 & 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 & Toledo, 2005; 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, emphasising 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 fertilisation 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 and nitrogen) and rarely biotic processes, while these strongly impact low-input systems (e.g. those linked to diseases, pests and soil biological activity). As a result, these integrated models may lack contextualisation 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 mobilise 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 the 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 & Martin, 1988; Ingram et al., 2010). Based on these distinct aims, scientists have developed numerous decision support systems as a 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 of 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' actions. What is 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 generalisable 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 mobilise general scientific knowledge in their particular situation?; how is this knowledge contextualized?; and 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.

Methods

We selected in this paper two examples (out of a larger set) of technical change in *step-by-step* re-design processes, as characterised 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 (Case 2). For each case study Table 1 states the timescales that the data we collected concerned, the location, and the number and professions of actors involved. On the one hand (Case 1), we observed a group of farmers in a one-day design workshop. On the other hand (Case 2), we carried out an individual semi-structured interview with a farmer, focusing on the implementation of one specific technical change, and asked the farmer about the information sources mobilised, the successive actions he implemented and the observations he made.

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 organisation)	One-day meeting (at the start of a 3-year project)
2	A farmer's implementation of stubble ploughing	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 applied or observed to collect data. The column "time scale of the story" refers to the actual temporal spreading of the data collected).

We made an instrumental use of the cases (David, 2003): in each case, we particularly observed the moments when new knowledge was mobilised 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. 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. The main questions we used to obtain this information concerned: how specific knowledge is asserted and discussed; how generic knowledge is used in a specific context or, conversely, how localised experiences are discussed and shared in general terms; and how it allows the farmers to choose new practices or strategies they intend to implement.

Case studies

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 used. The results from different experiments comparing various soil tillage tools quickly prompted discussions about organisational 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 at the end of summer? Are they increasing when the plant grows?). 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. Only then were two practice strategies to test proposed (Table 2, line 5).

Table 2. Case study specificities according to the knowledge and experiences exchanged, the agronomic problems and the technical strategies built.

		Organic farmers' meeting about perennial weeds control	**A farmer's implementation of stubble ploughing, cover crops, in a minimum-tillage system**
1	The initial problem	Controlling perennial weeds without herbicide	Implementing non-ploughing strategies consistently with other practices on the farm: stubble ploughing was introduced to prevent 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 into pieces); the soil factors favouring thistle;	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 described in terms of nutrient uptake and release, growth dynamic and competitive capacities.

		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. Two 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*").	
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 the discussion		The different applications of stubble ploughing 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 ploughing, and a ploughing 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 built his soil tillage strategy under the constraint of a 10cm depth limit. He adapted and reinterpreted the stubble ploughing action from this basis.

A farmer's interview in a minimum-tillage system

This farmer participated in an eight-year project with a R&D organisation 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 on carabids' biology, and in particular 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.

Crosscutting analysis: mobilisation and contextualisation of "fundamental knowledge"

The mobilised knowledge is focused, partial and 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 and groups of species such as carabids in Case 2). 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 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 2 concerning the carabid species' biology (an entomologist specialised in carabid species). These specialists belonged either to research institutes or to national technical institutes, but their legitimacy in the eyes of the farmers lay 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 organised in a synthetic form. We stress the fact that this focus on specific aspects of the knowledge mobilised, which is fragmented and concerns biological objects, highlighted differences compared to what most crop simulation models show. The prevalence of partial knowledge on a limited part of the system components might seem contradictory with the need 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.

Farmers use the knowledge they can link to their own action

The knowledge mobilised 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 2, the farmer built a new complete soil management strategy starting with

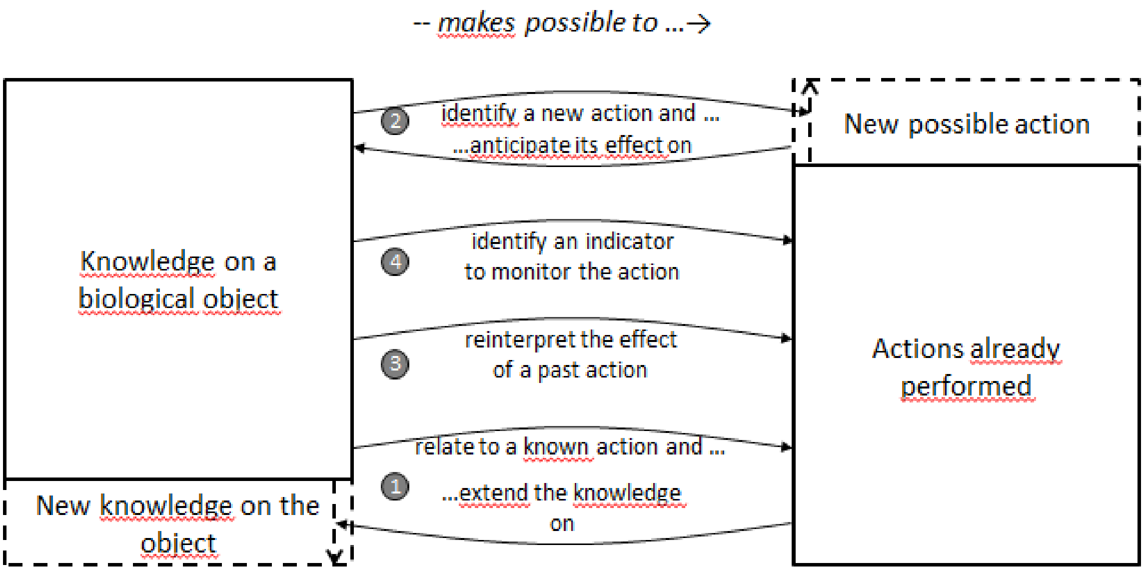

Figure 1. The different ways knowledge was linked to action. (*The numbers in grey circles correspond to the four patterns described in the text).*

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 into short pieces, stimulating re-growth.

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 mobilisation of knowledge to design new actions in a cropping system. They highlight the fact that farmers gradually organise 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 formalise 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 organised 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 why we observed such organisation of knowledge in both directions: new knowledge also led to the organisation 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 the farmer's own action.

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 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 emphasising 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 conceptualised 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".

"Fundamental knowledge" and farmers' own cropping system are linked through three main processes.

We now propose an analysis of the way fundamental knowledge is mobilised 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; and 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 above. 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 is it because we avoid flowering or is this the case even in a wild system?*" This second process also materialised 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 formalise local qualitative knowledge, emphasised 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).

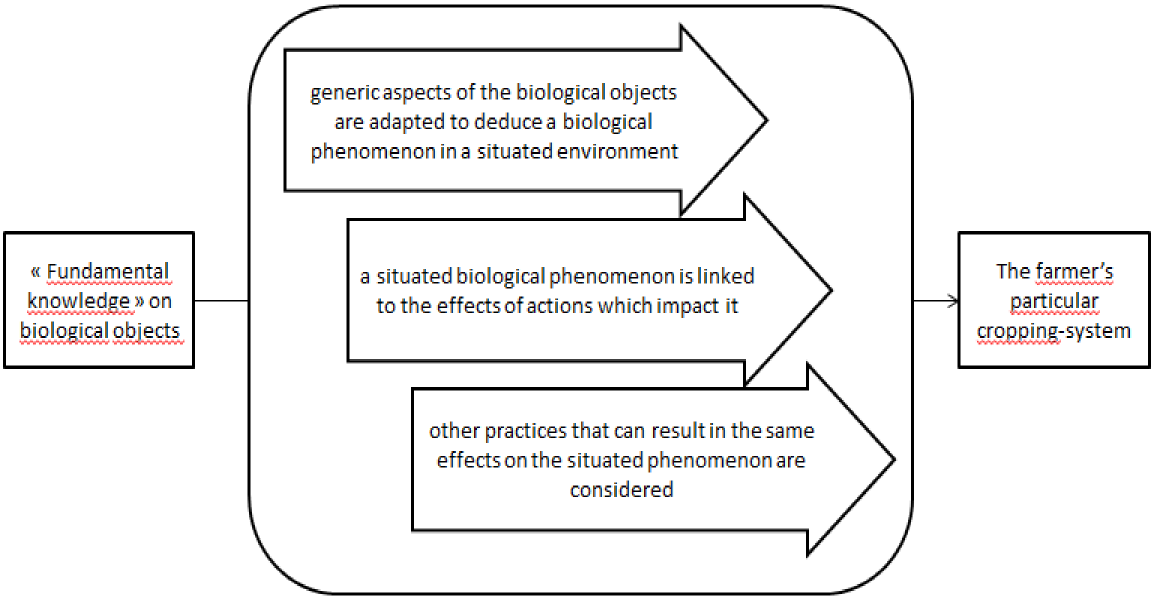

Figure 2. The three processes (large arrows) applied by farmers in order to gradually link fundamental knowledge to their particular cropping system.

We have previously shown how particular and situated experiences were used to bring out decontextualised causal relations within the cropping systems but the description of these three processes addresses the way farmers contextualise generic knowledge on non-situated biological objects. The contextualisation 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).

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 decontextualisation and contextualisation 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 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 understanding of the functioning of a part of the cropping system which includes action. In that sense, the contextualisation 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 mobilisation 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.

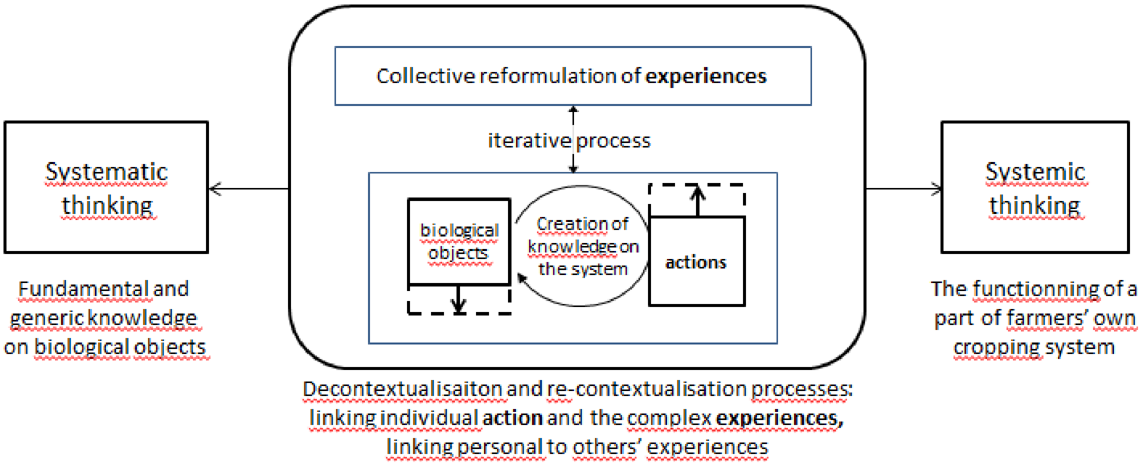

Figure 3. Farmers alternate between systematic and systemic thinking. The two elements in the central box insist on the iterations between a creation of knowledge on the system through the linking of "fundamental knowledge" to isolated actions on one hand, and the collective reformulation of personal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

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 dynamic, 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' actions. It is worth remembering that these findings relate to re-design situations geared towards a greater mobilisation 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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Farmers' experiments and innovations: a debate on the role of creativity for fostering an innovative environment in farming systems

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Abstract: Innovation has become *the* promising concept to overcome problems and enhance agricultural performance in agricultural research and policies. In the past, innovation was mainly seen as being developed by science or enterprises, and only recently the focus has shifted from a linear to a systemic perception, acknowledging that innovation is a dynamic process that implies the participation of a diversity of stakeholders. Consequently the role of multiple stakeholders, including farmers, in the innovation process receives more attention. Farmers' experimentation is the process by which farmers informally conduct trials or tests that can result in innovations suitable for their specific conditions. Although the role of farmers experiments in the innovative process is increasingly acknowledged, literature on the creative process that leads to farmers' experiments and innovations is missing in farming systems research. The aim of our contribution is discussing this missing link, focusing on how motivations, learning processes and specificities of the workplace farm may influence the creativity of farmers.

Keywords: Farmers' experiments, innovation, creativity, agricultural knowledge and innovation systems (AKIS), organic farming

Introduction: farmers' experiments and innovations

The historical development of locally adapted farming systems worldwide can be ascribed to continuous experimentation activities of farmers (Hoffmann et al., 2007). Farmers' experimentation is the process by which farmers informally conduct trials or tests that can result in new knowledge and innovative management systems suitable for their specific agro-ecological, socio-cultural and economic conditions (Rajasekaran, 1999). Experimenting enables farmers to adapt to constantly changing conditions (Bentley, 2006; Darnhofer et al., 2010), is a means to generate local knowledge (Sumberg & Okali, 1997), and builds the base for countless agricultural innovations (Vogl et al., 2015). For a long time the term 'innovating' was mainly associated with science or enterprises and only recently the focus has shifted from a linear to a systemic perception on innovation, acknowledging that innovation is a dynamic social multi-stakeholder process that implies the participation of a diversity of stakeholders and institutions (Klerkx et al., 2012b), including farmers. Consequently the role of farmers as innovators and the value of local knowledge receives more attention (Brunori et al., 2013). Also, with the increasing interest in novel approaches to rural development including the concepts of participation and empowerment in sustainable rural development, the topic of farmers' experiments and innovations began to attract more attention (Bentley et al., 2010).

Innovation research has become a field of science covering a remarkable diversity of topics with a high complexity of theoretical and applied debates. One of the areas of research in innovation studies is agriculture where e.g. agricultural knowledge and innovation systems (Knierim et al., 2015) provide details on the process of innovating in the agriculture sector. In a claim for fundamental reorientation, systems redesign and radical innovations, Klerkx et al. (2012a) show the importance of visions - visual and tangible representations of novel agricultural system concepts in innovation and learning processes. Heterogeneous multi-actor environments with a variety of actors, sources, types and processes of active social learning are state of the art in learning and innovation networks for sustainable agriculture (Tisenkopfs et al., 2015).These environments enable co-learning and link grassroots experimentation of farmers with agricultural research and extension. These environments create a 'dialogue of wisdoms' (Tittonell et al., 2016).

Nevertheless, the creative process that leads to farmers' innovations is rarely studied nor described precisely in agricultural sciences and not yet taken fully into account in organic farming systems research (Vogl et al., 2015). As an example, in the organic farming literature, terms currently used for describing what leads to farmers innovations are e.g. 'problem solving', 'innovating' or 'self help' (TP-Organics, 2014). These terms are however used ambiguously and imprecisely, which might easily lead to ignoring the complexity of the processes involved. Both the organic farming and agroecology movement feature innovations (e.g. Herren et al., 2016) but miss carefully addressing the origins of innovations.

A lack of knowledge of this genuine creative process of 'innovating' might lead to ignoring the intervening factors, misplacing the key incentives and thus not sufficiently taking into account the opportunities for encouraging farmers' experiments and innovations. To our knowledge specific literature on the genuine process of creativity that leads to farmers' experiments and innovations is missing in agricultural sciences and farming systems research. Therefore, the aim of our contribution is discussing the link between creativity related research and farming systems research. We start by summarising and defining relevant selected literature on creativity, motivation, learning and workplace influence, with specific focus on the potential relevance for farming systems research, farmers' experiments and innovations. After outlining and defining these concepts, we discuss options for creativity research in (organic) farming systems, with an additional focus on the specificity of the workplace 'farm'.

Creativity

Creativity is defined as the "development of a novel product, idea, or problem solution that is of value to the individual and/or the larger social group" (Hennessey & Amabile, 2010). Creativity can be found behind all innovations. Creativity is an attitude towards life that responds to problems in a fresh and novel way (Sternberg, 2012).

Creativity is being conceptualised in various models. We choose the Four-C Model, which distinguishes four levels of creative magnitude and development (Kaufman & Beghetto, 2009) in a way that will later allow us to link these levels with examples from farming systems:

- mini-C creativity consisting of the creativity inherent in learning processes;
- little-C creativity consisting of amateur, everyday creative activities;
- pro-C creativity consisting of professional-level creativity;
- big-C creativity consisting of eminent creativity.

The investigation of creativity can be separated into the study of creativity of products and the creativity of persons. When creativity is perceived in terms of products achieved, creativity is understood as largely situation-dependent and spontaneous. Contrary to this, creativity of persons rather perceives creativity as a stable and enduring trait of individuals (Hennessey & Amabile, 2010). Creative people habitually: a) look for ways to see problems that other people don't; b) take risks that other people are afraid to take; c) have courage to defy the crowd and stand up for their novel beliefs; and d) seek to overcome obstacles and challenges (Sternberg, 2012).

Methodologically, the creativity of products can be evaluated by self-assessments (mini-C), consensual assessments from experts in the corresponding field (little-C, Pro-C) or major prizes or honours (Big-C) (Kaufman & Beghetto, 2009). The type of creative products achieved can be conceptualised as “contributions that accept current paradigms, contributions that reject current paradigms, and contributions that attempt to integrate multiple current paradigms” (Sternberg, 2006).

The study of creativity of persons on the other hand relies on experimental, case study or questionnaire-based research designs (Hennessey & Amabile, 2010). Creativity of persons depends on six distinct but interrelated resources: intellectual abilities (including seeing problems in new ways); knowledge (know enough about a field); a thinking style that gives preference to think in new ways; personality (including willingness to take sensible risks and overcome obstacles); environment (supportive and rewarding for creative ideas) and motivation (intrinsic, task-focused) (Sternberg, 2012).

Historically, the term creativity was approached by scholars from a variety of disciplines – including education, arts, economics, neurosciences, anthropology and diverse sub-disciplines of psychology such as cognitive, developmental, social and organisational – all concentrating on very specific aspects of creativity. This resulted in a wide range of knowledge about creativity but also in fragmented and isolated groups of researchers losing sight of each other. Also, across all disciplines, creativity research has long concentrated on the creative individual or products obtained but largely neglected the creative environment in which creativity may or may not flourish (Hennessey & Amabile, 2010). Systems models were created to improve the understanding of creativity, and aimed at connecting (sub-) disciplines and increasing interdisciplinary investigation on creativity and at broadening the level of analysis to include the social and cultural environments in which creativity grows (Csikszentmihalyi, 2014; Hennessey, 2015).

Although systems views of creativity help to generate new insights and research questions, they may not adequately foster the application of these insights in real world settings (Hennessey & Watson, 2016). Since the ultimate goal of creativity research needs to be the promotion of creativity, a further focus of creativity research should lie on the application of findings in real world settings (Hennessey & Watson, 2016), such as schools, organisations, arts and, as our main concern, farming systems. For promoting creativity, e.g. in farming systems, a close look at motivation or motives is essential.

Motivation

Motivation is a frequently researched influential trait for creativity. To be motivated was defined as ‘to be moved to do something’ (Ryan & Deci, 2000). The types of motivation can be distinguished as intrinsic and extrinsic. Intrinsic motivation means behaviour that is inherently interesting and satisfying and thus results in positive feelings. Intrinsic motivation is enhanced by autonomy or self-determination, feelings of competence and a sense of connectedness or relatedness to individuals, groups or societies (Ryan & Deci, 2000). Extrinsic motivation means to be moved to do something because a separable outcome is strived for, whereas the activity itself is not as satisfying (Deci & Ryan, 2008). Examples of extrinsic motivation include reward, expected evaluation, surveillance, competition or restricted choice. Intrinsic motivation was found to enhance creativity (de Jesus et al., 2013; Hennessey & Amabile, 2010), whereas extrinsic motivators can reduce intrinsic motivation and creativity when self-determination is undermined. However, extrinsic motivation was also found to enhance creativity in some cases, such as rewards when people are already intrinsically motivated or when they confirm competence (Hennessey & Amabile, 2010).

Creativity may also, under certain conditions, be enhanced by prosocial motivation (Forgeard & Mecklenburg, 2013). Mood states (Baas et al., 2008) and stressors (Byron et al., 2010) have also been linked with creativity. The links between motivation and creativity are thus pronounced but complex. Autonomy, competence and connectedness are key for enhancing intrinsic motivation, which again is important for enhanced creativity.

Both creativity and motivation are key concepts used in research related to learning environments.

Learning

There are two premises regarding creativity in education: first, creativity can be developed; and second, all individuals have potential to be creative (Lin, 2011). Enhancing creativity has become a global-wide interest reflecting the demand to raise competitiveness, and so there is a trend to reform educational systems to equip young people with innovative and creative capacities. Consequently, creativity is regarded as a life capacity for future success (Lin, 2011). Sternberg (2008) defines success in his "Theory of Successful Intelligence" as "*the use of people's abilities, recognising their strengths and correcting or compensating for their weaknesses, adapting to or shaping environments, and finding a balance in their use of analytical, creative and practical abilities*" (Sternberg, 2008).

Three interrelated elements are distinguished in creative pedagogy: creative teaching (focusing on teacher practices); teaching for creativity (highlighting the learner agency); and creative learning (Lin, 2011). Torrance (1963) contrasted *learning creatively* with *learning by authority*: children learn by authority when they are told what they should learn and accept ideas from authorities (e.g. teachers, books), whereas when learning creatively children learn by means such as questioning, searching, manipulating, experimenting and playing (Torrance, 1963 in Lin 2011).

There exists a synergistic cycle among self-actualisation, learning and creativity, but the fact that in the current educational systems we do not achieve excellence on a broad level indicates that there are significant challenges to entering and sustaining this cycle (Burleson, 2005). A way to enhance learning experiences is to let learners use their imagination and multiple points of view, by asking their own questions and seeking answers in diverse ways, in a process of developing and exchanging perspectives. Several important scientific discoveries were developed by imagination and the use of analogies, such as Einstein's Theory of Relativity or the discovery of the benzene-ring structure (Burleson, 2005).

One important barrier to learning is the fear of failure, although failures are critical to learning, and experts can be regarded as people who have failed many times. To overcome this barrier, the consequences of failure and humiliation should be minimal, motivation should outweigh failure, and learners should strengthen abilities to persevere through failure, such as motivation, will and effort. It can also be helpful when learners can reflect on their failures with experts and learn from the experts' experiences and strategies to deal with failures (Burleson, 2005).

Despite the abundance of research on creativity and learning, little achievements have been made to apply these research findings to the classroom or other real-world settings, except in the area of corporate creativity and innovation, with the aim of helping companies boost profits (Hennessey & Watson, 2015).

There is a multitude of academic references on the importance of learning within agricultural systems and in natural resource management in general, including literature on social-ecological resilience. But when searching for concrete relationships between learning and innovation with creativity, there is not much to be found. Most academic discussions circle around the question of how to facilitate and enhance social learning (e.g. Blackmore, 2007; Hubert et al., 2012), how to enable learning and innovation networks (e.g. Moschitz et al., 2015), and adaptive (farm) management (e.g. Armitage et al., 2008; Darnhofer et al., 2010). Structural conditions hindering or facilitating innovation systems described in literature (Hermans et al., 2015) focus on (knowledge) infrastructure, laws and regulations, norms, values and culture, interactions, market structures, and finally capabilities of the involved actors – a point where creativity could be relevant.

Workplace

Much attention in scientific literature on innovation and creativity is given to topics related to characteristics of workplaces, performance of employees, behaviour of employers, architecture or interior design of office space and office buildings. The interest guiding research and development in these domains is often efficiency and effectiveness of the performance of staff, the enabling environment for innovation but also how certain characteristics support or inhibit the creativity of the working process or products. Constraints and pressure in the work environment are detrimental to creativity. Speaking up about concerns, reporting mistakes, proposing new ideas, autonomy in the workplace, or a degree of empowerment can be important for organisational creativity. Also important are team leader support, the behaviour of managers, time pressure or psychological safety (e.g.Hennessey & Amabile, 2010).

Compared to the vast, diverse and detailed literature on industrial or so called white collar workplaces, or on the workplace 'classroom' at schools or universities, the literature on the workplace 'agriculture' is relatively sparse. Conflicts based upon social processes between generations at farm level (Jaunecker et al., 2011; Larcher & Vogel, 2009), the ergonomics or safety of work in agriculture or forestry (Kogler et al., 2016) are just two examples of topics that are discussed. The debate on creativity in agriculture, forestry, gardening or other related professions that manage natural resources is seemingly non-existent.

Options for creativity research in (organic) farming systems

When we look into farming systems, innovation has become *the* promising concept to overcome problems and enhance agricultural performance. In the European Union Common Agricultural Policy there is a clear shift from innovations originating from state and corporate Research and Development activities towards participatory innovations, which depend on individuals' or rural societies' own creativity. Innovations should consequently be developed in collective and creative learning processes (EU-SCAR, 2012).

Trying, testing or experimenting at farm level is one of the inherent processes of farming that contributes to explaining how the process of innovation is approached by farmers (Vogl et al., 2015), but the research on farmers' experiments has so far not explained sufficiently how and why individuals become experimenters. The scientific debate on creativity may help as it has not yet been extended to farming systems research.

Farmers and gardeners are immersed in a workplace that can be analysed related to creativity of products and/or creativity of processes. Interpreting Kaufman and Beghetto (2009) we see:

- mini-C creativity consisting of the creativity inherent in learning processes at farm level for the farmer and the farming family, e.g. in continuous contacts with consumers, other farmers, as a participant in training courses or when watching TV documentaries on farming practices;
- little-C creativity consisting of everyday creative activities such as finding spontaneous solutions when confronting problems, and simple trial-and-error experiments (repairing, adapting, substituting resources…);
- pro-C creativity (professional level creativity), i.e. the constant adaptation of farming practices to seasonality, trends in the market, available labour at the farm, etc.;
- big-C creativity consisting of eminent creativity, that could be attributed to personalities such as Lady Eve Belfour, Hans Müller, Hans Rusch or Rudolph Steiner, who are seen as key persons to the development of organic farming.

At all these levels of creativity various and differing factors influence creativity, including motivation, learning and the workplace, and thus the innovative capacity of farmers. And for all these influencing factors a range of discussion points and questions emerge about their interaction with creativity. In the case of intrinsic motivation (consisting of autonomy, competence and connectedness) such questions include:

- How do current agricultural politics and market forces influence farmers' autonomy and self-determination?
- How do farmers' basic and advanced education, peer group interactions, product vending, consumer interaction, local community etc. promote or weaken feelings of competence?
- How can farmers' evaluation, such as in environmental or quality control systems, be shaped to confirm competence and increase intrinsic motivation rather than induce a sense of surveillance and thereby contribute to the opposite?
- How do family members, neighbours, peer farmers and the larger society value farmers' innovations and thus create a sense of connectedness?

One possible strategy to promote new, creative ideas and social learning for innovation is to integrate 'outsiders' into the existing agricultural innovation systems (Hermans et al., 2015), but for this to happen it needs brokerage and dialogue between members at the periphery (Ingram et al., 2014). Another entry point to enhance creative learning within agricultural systems is in the agricultural education system, be it at university level (Francis et al., 2012; Salomonsson et al., 2008) or at the level of agricultural schools and extension (Francis &

Carter, 2001). This leads us to the question of how different learning environments and workplaces influence creativity.

If we aim at studying e.g. motivation and its impact on creativity at farm level, the concept of 'the workplace farm' might be too general. Work at farms often includes (as for example at diverse organic family farms):

- a series of different tasks with complex job descriptions, different from one task to another, like managing the farm forest, arable crops, horticulture crops, farm animals for commercial purposes or for subsistence, maintenance and repair of machinery, household, administrative tasks or social networks, etc.;
- a diversity of actors involved, like family members of different age and sex, neighbours and friends that support the farm to a varying degree of intensity with a variety of complementary skills, hired labour, etc.;
- a managed mosaic of buildings, plots, and other units of the farming operation;
- an environment of seasonality, shocks and trends.

The impact of intrinsic or extrinsic motivation on creativity might be easily tested at the agricultural workplace and support a better understanding of the factors that support creativity, experiments and innovations at farm level. But these factors might depend heavily on the various multifaceted sub-workplaces and actors involved. There is not 'a (proto-) typical workplace farm' but e.g. the son's work in the forest or the mother's work in the greenhouse or the father's work on any other task that might have totally different enabling or inhibiting environments for creativity and thus the innovation capacity of the farm.

Farmers and their workplaces are embedded in what e.g. Hennessey (2015) calls the "myriad of environmental factors" or the creative milieu with a strong impact on the intrinsic or extrinsic motivation. "For each of us, when prompted by just the right amount of novelty, feelings of competence, and sense of control, the inner state of intrinsic motivation sets the stage for prolonged periods of concentration, deep learning and the possibility of creative performance" (Hennessey, 2015, p. 196). Contrary to this, a variety of environmental constraints imposed by (or on) work place managers can have especially damaging effects on an individual's intrinsic task motivation and subsequent creativity performance. The environmental constraints may be cultural values, expectations, and associated practices by entire nations, regions or groups, as well as the culture of specific institutions and environments (Hennessey, 2015).

More detailed research is needed on these topics in the context of farming systems. Especially in the context of formal and informal institutions, like for example the tight regulations for organic farming at European level (and in many countries also at national or provincial level), paired with private schemes for organic farming might have an impact on creativity and innovation not yet explored sufficiently. Agricultural policy may have neglected the impact of its instruments, like rules and regulations, on risk taking, experimentation and collaboration, i.e., the motivation and creativity of farmers, and therefore on the capacity of the so much appreciated innovation partnerships.

The evaluation of work, including how this evaluation is delivered, has a strong impact on creativity (Hennessey & Amabile, 2010). This evaluation of the farmers' work expressed in e.g.

inspections or controls of a variety of institutions is a frequent phenomenon at farms (Vogl & Axmann, 2016). As one example (organic farming inspection) we conclude that the social and technical skills of the inspector as well the way in which the inspection and certification are delivered by the inspector and the certification body may have, together with the communication of the goals of the regulatory framework, an intense impact on creativity at farm level and the innovative capacity of actors along the supply chain.

It will be important to pick up the insights on the relation between creativity and learning, e.g. for answering the question on how to facilitate creative learning processes that lead to creativity, farmers experimenting and relevant innovations for a sustainable future of farming.

We invite the audience to an open access assessment and debate on this paper, for contributing complementary insights and adding related references at www.researchgate.org, where this paper will be online at the authors' pages.

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