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Diverging and Converging Pathways

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Workshop Theme 4: Emergence and application of new technologies

Workshop 4.1: Boosting research outputs: novel approaches for integrating research translation with interactive co-innovation

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Although innovation is understood to encompass much more than R&D, science continues to be an essential ingredient. Many EU and nationally funded research projects in the fields of agriculture and forestry have provided excellent scientific results. However, outreach and translation of these results into farming and forestry practices is limited. The challenge is to boost innovation by facilitating the uptake of formal and empirical knowledge, and its integration into field practices. With respect to research this requires a combination of science-driven research and interactive innovation-driven research (EU SCAR, 2012). New approaches are needed that integrate the translation of formal research into practice with interactive co-innovation within networks of actors. The European Commission-funded FP-7 project VALERIE (VALorising European Research for Innovation in agriculturE and forestry – www.valerie.eu) is applying such an approach to improve the exchange of information between agricultural researchers and practitioners to encourage the transformation of new concepts and results into practical use (in the context of management of soil, water, pests, waste; ecosystem services and supply chains).

This workshop invited papers to present novel integrative approaches (research methodologies and development and application of tools) applied in the context of sustainable agriculture that (i) facilitate access to, and application of, research information; (ii) enable a dialogue between stakeholders and researchers and promote mutual learning and co-innovation; or (iii) translate scientific research outputs into practical knowledge or innovation. The workshop comprised 4-5 fifteen minute sessions for the presentation and discussion of papers and a 30 minute session to demonstrate and discuss the developing “ask-Valerie.eu” stakeholder interaction and search tool and to summarise workshop findings on improving information exchange for innovation.

Inserting co-innovation into research translation: experiences from the VALERIE project

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Abstract: Although innovation is understood to encompass much more than R&D, science continues to be an essential ingredient. In particular translation, adaptation and 'valorisation' of research results, the responsiveness of research to users' needs and improved access to results are all regarded as important in achieving a more sustainable European agriculture. These challenges can be addressed in a number of ways including increased collaboration, networking, transdisciplinary research and co-operation between researchers and practitioners. From a theoretical and practical perspective such approaches often involve inserting elements of co-innovation into the traditional science-driven model. Whilst a number of studies have examined the processes entailed in co-innovation, such as co-reflection, learning, reflexivity, and co-creation of knowledge, less attention has been paid to integrating co-innovation processes into the translation of existing scientific research outputs. This paper examines this topic within VALERIE, a project using an iterative stakeholder-driven methodology to create an effective retrieval facility for science-driven research outputs. Specifically the paper aims to understand the interplay between users' identification and articulation of research needs and providers' matching of these needs. The evolving methodology provides useful insights into the process of, and highlights some challenges associated with, integrating co-learning and research outreach.

Keywords: Research translation, co-innovation, reflection, arable farmers, supply chain

Introduction

Although innovation is understood to encompass much more than R&D, science continues to be an essential ingredient, as international, EU, and national level policies reiterate (OECD, 2010). These argue that there is a compelling need for research[1] to play a significant role in meeting the innovation challenges of increased demand for food balanced against the need to deliver other ecosystem services. If this role is to be fulfilled, provision needs to be made for outreach and translation of research, to enable effective deployment of innovative research as an essential part of the process. How the innovation process operates has been the subject of much scholarship in which two broadly distinctive models of innovation have been described: linear science-driven research and interactive innovation-driven research (EU, 2012; Klerkx et al., 2012). The science-driven model is largely a linear process, characterised by publicly-funded research and carried out by research organisations with little involvement of users, where outputs are judged on scientific quality. In the interactive model, framed within innovation systems thinking, innovation is a collective process combining knowledge from many different sources, using networks of producers and users of knowledge, who become

[1] *Whilst it is acknowledged that 'research' can refer to outputs from a number of sources in a number of different forms, here the term is used to denote the formal scientific process, which produces scientific information as scientific literature, reports etc.*

integral to the agenda-setting and research process, and outputs are judged on user relevance.

Although distinguished by different motivations, drivers and processes, these models describe systems that often operate together. Indeed effective interaction between the two is seen as important for optimal functioning of the Agricultural Knowledge and Innovation System (AKIS - EU, 2012; McIntire et al., 2009). Critically, involving end-users is regarded as essential in achieving translation and boosting innovation by facilitating the uptake of formal and empirical knowledge, and its integration into field practices. The integration of different actors (farmers, advisory services, brokers, intermediaries, consumers, private sector, policy makers) in research agenda-setting and in the research process arguably strengthens the role of research (OECD, 2010). It is envisaged that such involvement of actors through innovative networks assists the translation and 'valorisation'[2] of results (EU, 2012). From a theoretical perspective this involves inserting elements of the interactive model, characterised by co-innovation processes, into the science-driven model.

Whilst a number of studies have examined the processes entailed in co-innovation (co-reflection, learning, reflexivity and co-creation of knowledge) less attention has been paid to understanding the integration of co-innovation processes into science-driven approaches. Equally, with respect to the latter, although adoption of innovations is well understood, there has been less focus on the multiple processes that underpin the translation of research. This paper examines these gaps drawing on experiences in the VALERIE[3] project which aims to boost the outreach of research in agriculture and forestry from national, international and EU research projects, using a co-innovation approach. As EU research is increasingly advocating co-innovation approaches it is particularly useful to reflect on the methodological challenges it brings (EU, 2013).

Conceptualising innovation processes

A prevailing problem identified in Europe is the increasing disconnect between research and farming, which means that research is often not sufficiently related to farm praxis (Leeuwis et al., 2004). In several EU countries there are challenges in transferring results from research into practice and in channeling practitioners' demands for knowledge into research and advisory agendas. In particular, it is argued that many users of knowledge need more adapted knowledge from research that is better translated to their understanding and needs.

Within the framing of the science-driven research model these challenges have been addressed by an emphasis on better adoption of innovations from research (OECD, 2010) as well as an emerging interest in translational research by enhancing 'valorisation' of research results, the responsiveness of research to users' needs and access to results; and by putting more emphasis on networking and transdisciplinary research (EU, 2012). This thinking is part of a wider realisation that research interventions can take many forms, and that the utilisation of scientific information is just one element of a much broader role that research can play in enhancing practitioners' capacity to innovate (Douthwaite et al., 2003).

The interactive model, drawing on Systems of Innovation (Smits et al., 2010) and Agricultural Knowledge Systems (Hall et al., 2006) approaches, recognises that innovation is distinct from

[2] *'Valorisation' is used here in the sense of giving meaning and (non-monetary) value to research*
[3] *(VALorising European Research for Innovation in agriculturE and forestry www.valerie.eu)*

research. Within this thinking agricultural research is re-conceptualised as part of increasingly complex, interactive and learning based systems, and research is seen as just one of the many 'stakeholders' within the system (Sumberg, 2005). Innovation is described as an emergent product 'co-produced' through interactions between heterogeneous sets of actors, such as farmers, input industries, processors, traders, and researchers, as well as NGOs and government actors at different levels; as the result of a process of networking and interaction (Hall, 2001). Research plays a role in this co-production, but the involvement of end-users is central in determining, undertaking and translating research results into technologies and practices so that such knowledge is co-produced (Klerkx & Nettle, 2013). In this sense both models are characterised by some form of translation of research.

Processes within the interactive model are widely referred to as co-innovation and are linked to a range of concepts such as reflexivity (Van Mierlo et al., 2010), knowledge co-creation and knowledge and innovation brokering (Klerkx & Leeuwis, 2008a). These have been well researched, however, the role of actors within innovative networks in the translation and 'valorisation' of research results is less well understood. In particular, how users express and communicate their research needs, how providers respond to these needs, and how users evaluate, utilise and adapt scientific knowledge, has received little attention.

The concept of matching supply and demand has been used to frame analysis of the user knowledge needs (and other resources necessary) for innovation and how these needs are met. Studies at different scales, focusing on the research-policy interface (McNie, 2007), the role of intermediaries (Klerkx & Leeuwis, 2008b), and innovation support services (Kilelu et al., 2014) offer some insights. They show that the diagnosis and analysis of problems and articulation of demands can be challenging, and that the process involves concretising unspecified needs into clear demands with continuous re-articulation through dialogue between the demand and supply sides (Klerkx & Leeuwis, 2008b).

These insights into the role of users and providers in the translation of research results offer a framework for the VALERIE methodology to integrate a co-innovation approach into a more traditional model of science-driven research. This paper aims to understand the interplay between users' identification and articulation of research needs and providers' matching of these needs in the context of the VALERIE project. Specifically it looks at how stakeholders in case studies concerned with arable agriculture identify, formulate and articulate innovation issues (research demands) and how project researchers search existing scientific research outputs to suggest solutions to these issues, and in turn how stakeholders respond to these efforts.

Context and Methodology

The premise of the VALERIE project is that many EU- and nationally-funded research projects in agriculture and forestry provide excellent scientific results but that outreach and translation of these results into farming and forestry practices is limited. The challenge is therefore seen as boosting innovation by facilitating the uptake of formal and empirical knowledge, and its integration into field practices. Overall the project's objective is to translate research outcomes, with a special interest in innovative and applicable approaches, into end-user content and format (for farmers, advisers and enterprises in the supply chain), and to provide easy access to it. This is through the development of a smart retrieval system (ask-Valerie) for use at a European level. It does this by extracting and summarising knowledge from national, international and EU research projects and studies concerning innovations in agriculture and forestry; with a focus on six selected themes. These outputs are screened, filtered and tested with stakeholders (SH). Essentially the methodology understands that solutions derived from research need to be re-built on the farm, with the involvement of relevant actors.

The project methodology is based on a structure that links three research approaches and activities integrated in iterative cycles, driven by stakeholders. These '*extract knowledge*', '*coordinate co-innovation in case studies*', and '*create an ontology* (a structured vocabulary)'. Case studies (CS) and their stakeholder communities (SHC) are at the core of this iterative process, they are organised around a particular supply chain, a farming / forestry sector, or a landscape, and so cover different scales and dimensions.

This paper concentrates on the *co-innovation in case studies* and *extract knowledge* cycle within four case studies (Table 1), which involve SH demand articulation and the supply of scientific knowledge. The *ontology cycle* (also stakeholder driven) which is concurrently developing a digital but knowledgeable 'assistant-expert' (ask-Valerie) is described elsewhere (Willems et al., 2015). The cycle starts by SHs in each CS identifying innovation issues (research needs) in participatory meetings facilitated by Case Study Partners (CSPs). The project Thematic Experts (TEs) then search existing scientific literature, EU reports etc. and extract information for innovation solutions to address these issues. They synthesise this and prepare end-user formats (factsheets) and the CSPs present these to the SHC to apply, test, refine and screen for their innovation potential in the local context. The SHC then feedback their evaluation of the solutions to the TEs, thus completing one cycle. The cycle is repeated and at each iteration innovation issues are reviewed and refined, further information or clarification is sought and new, or more detailed, innovation issues are generated. CSPs use a Dynamic Research Agenda (DRA) tool for monitoring and evaluation of this process allowing the SHs to revisit and refine the innovation issues at each SH meeting, developing the Dynamic Agenda (DA) described by Van Mierlo et al. (2010) . Reflection on the process is built in at SHC, CS, TE and project level. As meetings have progressed the SHC have identified trials to apply and test the potential of selected innovations in the local context using SH farms. These trial results will be integrated into the ask-Valerie retrieval facility.

Data analysed for this paper are derived from three cycles using meeting reports and DRAs, semi- structured interviews with CSP, CSP training and discussion/reflection workshops and discussion with TEs. The following analysis is drawn from four agricultural CSs (Table 1) and looks specifically at the first stage of innovation: issue identification, factsheet preparation, evaluation and feedback. These CS exhibit a range of SH innovation issues as well as different contexts and CSPs. The SHC in all these CS were already connected by a previous project activity and a common interest.

Identification of innovation issues and finding solutions: the influence of context and process

The results to date have shown that the way SHs identify their innovation issues and articulate these differs according to an interaction between *contextual* and *procedural* influences. Identifying issues and problems and articulating these has taken different forms in the CS. This is influenced firstly by the CS context: the CS goals, the innovation system and SH experience of innovation support, the actors involved, the composition of the SHC, their interests, their 'professionalism' or research literacy, the CSPs and the TEs; and secondly by processes within the project: the nature of participation and SH engagement, participatory methods used to ascertain their innovation issues and their prioritisation. Results from four CS are summarised in Table 1.

Context

The CS are diverse in terms of their social and technical context and history and this has a strong influence both on what and how innovation issues are identified and articulated as well as on the solutions found and the responses to these proposed solutions.

Identifying innovation issues

The influence of existing project or group activity on SH identification of innovation issues was evident. Although briefed to encourage SH to step back from existing interests and boundaries and identify broad goals and visions, CSP either decided this was not appropriate or found that SH had difficulty in doing this. Furthermore, SHs in some CS found it hard to focus on research needs, straying instead into wider systemic issues related to markets or other factors which could not be addressed with scientific information. This could reflect poor understanding of the task, or difficulty in distinguishing problems and ways of addressing them, but primarily it reveals how SHs operate in innovation systems; where agronomic issues are only one factor of concern and where scientific knowledge is not particularly regarded as contributing to problem solving.

Articulating the innovation issue in terms of concrete and manageable questions or topics for researchers at an appropriate level of detail was something that some SHs found hard to do. Existing activity and innovation support in CSs influenced both the process of identification and articulation, and the SH's level of understanding and therefore expectation. SHs had all engaged in previous projects or supply chains with technical support and were already accessing up-to-date specific agronomic information. In supply chains, there has been a substantial amount of research already undertaken and utilised. The potato supply chain SHs included some professional growers who regularly sought, and were familiar with, scientific information, and they were able to focus on specific questions about causes of poor crop quality. Equally, innovative farmers in the CS concerned with soil management, with a long history of support from an agronomist, demonstrated a certain level of understanding of soil science which allowed them to define their innovation issues and questions in detail. However, those in the bread wheat supply CS, who were also well supported, found it harder to identify issues where solutions were not already available.

Finding innovation solutions

Assumptions are made that TEs could interpret and understand the SH's issues and questions. TEs' searching, extraction, retrieval and summarising of research has been highly responsive to SHs' needs and provided some up to date and useful information. However in a number of cases there has been difficulty in understanding the CS context and in finding relevant information or research that is solution-oriented. There were also apparent challenges in translating the scientific information into a usable and acceptable format.

Whilst some CS SH articulated their issues clearly, the difficulty others had in expressing their issues of concern in terms of concrete or manageable research questions at appropriate levels of detail is something the TEs found challenging. In some cases issues and associated questions were too generic and this created a difficult task for TEs who encountered a vast array of scientific literature on the topic and needed to filter down to a more specific enquiry. Establishing a dialogue between CSPs and TEs was important (as well as TEs attending meetings) so that where questions or needs were not concrete enough TEs could seek clarification and SHs could reformulate issues and questions.

The first stage of factsheet preparation, setting out selected solutions to SH issues, met variable responses. Some CS SHs (e.g. in the UK) have found them helpful in providing useful information. However other CS SHs rejected the factsheets as not being very useful because they proposed infeasible approaches or were not specific enough, or they were detailed but the SHs were already well served with similar information and the factsheets added nothing new. In the potato supply chain, although the SHs found the factsheets quite general, their expectations were not too high. The CSP described the SH as "*a critically positive group of SH; they have very specific questions related to their business. SH don't expect a complete and concrete solution. When this is available, fantastic, but also information that can help to find or create a solution is fine."*

Mismatching of issues and solutions was attributed by some project partners to poor formulation of issues, as one remarked *"Sometimes farmers don't ask good questions, they sometimes have the answer in the question"*. The effective translation of scientific information into a format and content that is useful for farmers was also revealed to be a challenge. One CSP highlighted the difference between farmer information needs and what was viable from research, saying *"the challenge for VALERIE therefore is to reconcile their expectations for contextualised data of practical and validated information with the available [scientific] documents which are characterised by …reports and scientific articles".* Where factsheets were not helpful, issues were reviewed, refined, removed or added to in subsequent CS meetings using the DRA tool.

The project's aim is to be solution-oriented, with the intention that innovation issues would be identified by SHs, and innovation solutions can be derived from scientific information. However, the ability of research to provide answers to innovation issues and problems is questioned, both in terms of the delivery format and, more fundamentally, in terms of the utility of the scientific information. Significantly, one CSP said that SH were not so interested in the factsheets and scientific information as they "*aren't looking for research per se they are looking for solutions".* Another CSP reiterated this saying *"(Some) SH don't have any research gaps, they are not aware that they need innovation"*.

Co-innovation process

A central part of co-innovation reported in this paper is the identification of innovation issues (research needs), and a key process for this is stakeholder engagement using participatory approaches. The project approach recognises that achieving consensus is difficult, that the co-innovation process is a dynamic and evolving process that requires re-articulation and reflection. By building on existing CS SHC relationships and holding a series of interactive meetings, the intention was to establish a dialogue between users and providers of innovation solutions over the project period of four years. Methods used in the meetings (Table 1) followed a similar format of progressively building up from individual identification of issues to group consensus and prioritisation. Two years into the project provides an opportunity to reflect on this process.

The nature and extent of SH participation is contingent on a number of factors, most of which were in the hands of the CSPs. CSPs clearly have an important role, not only in selecting and convening the SHC, in facilitating the meetings, explaining the nature of the project and the aims of the meetings and exercises, but also in implementing the methods, prioritising the innovation issues and communicating these back to TEs. Although CSP were guided, trained and given a common format for approaches and methods to use and reports and DRA to prepare, inevitably different interpretations appeared.

The CSPs are thus key actors in steering the co-innovation process. They are also important intermediaries acting as interpreters for the project and gatekeepers controlling access to the SHs for the SHC. They have to manage expectations for both the SHC and the project and as such have a divided identity. CSPs have to manage project fatigue amongst SH, and disappointment and scepticism which some SHs have expressed when the project has not been able to meet their innovation needs. CSPs align themselves to their SHC (often their 'clients'), they acknowledge steering SHs towards pragmatic or easy to answer innovation issues that can be trialed within the project period, protecting their interests and in doing so maintaining their relationship. In CS where SHs were found to prefer to have an immediate solution rather than invest time in a dialogue, CSP selected issues with quick positive outcomes, which did not always match those from the research retrieval process, to sustain SH interest. The project's timetable and the CSPs' desire not to overload SH also meant the SH meetings were restricted to 4-5 with 6 month intervals between. This in turn limited SHs' opportunity to understand and engage with the project aims and to consider and articulate their innovation issues in a thorough and meaningful way.

Discussion and Conclusions

The iterative methodology of identification and articulation of innovation issues and supply of innovation solutions from scientific knowledge is at an early stage of development. As the project progresses this process is evolving, assisted by reflection throughout, at project, case study and SHC levels. The DRA has been a useful tool in monitoring the process, allowing SH to review, reiterate and refine their issues, as well as evaluate the proposed solutions. Experience to date reveals that operationalising co-innovation is challenging, as described in other studies (Botha et al., 2014), with no set recipe or protocols to follow. The process is complex and the outcomes unpredictable due to the variable context and procedural influences in the CSs. Involvement of end-users in determining, undertaking and translating research results (as others have shown) can be demanding (Klerkx & Nettle, 2013), with SHs differing in the way they identify, formulate and articulate issues, and respond to researchers' proposed solutions.

More fundamentally, the results reveal the assumption that innovation issues equate to research demands and that scientific knowledge equates to innovation solutions to be quite simplistic, as in reality the process is far more nuanced. Producers already have a high degree of experience and complex knowledge which they use for everyday problem identification and solving (Baars, 2011). Asking them to externalise this process and to articulate issues in an explicit way that can be interpreted by researchers is not a straightforward process and in some cases requires sustained dialogue, clarification and a number of iterations. Furthermore, the assumption that scientific information will provide a solution to these innovation issues as opposed to other sources of knowledge, or indeed other factors, is also revealed as a rather one dimensional view. However, despite these challenges, experience to date has shown that involving end users in the translation process provides opportunities to facilitate the uptake of formal scientific knowledge.

The aim of the paper was to understand how translation of research could be enhanced by combining the benefits of interactive learning networks with those of linear dissemination models. It has done this drawing on the VALERIE project which set out to translate research outcomes. The co-innovation process is complex and, in particular, reconciling the supply and demand of scientific information can be highly pragmatic and contextual in nature. However, the VALERIE project is helping us to better conceptualise and plan for a more effective translation of research for different types of practitioners in contrasting local situations, and how better to foster coherence between co-innovation and broader scientific research agendas and processes. This project will provide important insights for the European Innovation Partnership with respect to its thinking and support of interactive innovation (e.g. through Horizon 2020 research and Rural Development Programme operational groups).

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Table 1. Description of context and process factors that influence identification of innovation issues and solutions in VALERIE Case Studies

Context: Background, goals, SH characteristics	Process: Participatory method for issue identification & CSP influence	Innovation issues	Innovation solution, Factsheets (FS) and initial SH response
Innovative Arable Cropping group, France Farmer group active since 2005, working with an agronomist to test techniques (tillage, legumes, cover crops) to improve soils, reduce weeds. **SH:** mainly farmers, technical services, field advisers , co-operatives; Agricultural Chambers; institutes	Farmers each wrote keywords on a flipchart. Through successive rounds, farmers clarified and explained underlying ideas to the group. So the research questions were formulated progressively and collectively. CSP tried to steer SH away from previous topics. TE attended meetings	What are the effects of direct sowing, cover crops and tillage on the N and SOM cycles? What influences the end of weed dormancy? How to evaluate field soil properties? What are the effects of direct sowing, cover crops, tillage, on varieties of rape, wheat, sunflower, legumes?	**FS:** 1. Low volume spraying; 2. Recovery of chaff; 3. Herb-sowing: sowing and combined application of localised herbicide. SH are concerned about validity - if the FS report trials, they should describe the experimental conditions and make clear/explicit the context
Potato supply chain, Poland Supply chain linked to a processor company with a large farm and 60 contract farms. The company invest in research to improve quality and yield **SH:** suppliers of seeds, fertilisers, pesticides, processors & professional farmers already accessing research	Individual participants were asked to think what the main issues are, this was followed by a plenary discussion about the topics raised and then prioritised CSP filtered the issues according to: what VALERIE can offer, filtering out systemic constraints and well known solutions	A suite of specific problems were mentioned mostly concerning potato quality. Internal brown spots in potato tubers was prioritised due to Tobacco Rattle Virus (TRV) transmitted by nematodes but also associated with Ca deficiency	**FS:** Integrated management of TRV in potato production: 1. General information; 2. Control methods; 3. Which cultivar to choose? Response to FS was positive but SH already know about general solutions, they want specific solutions
Bread wheat supply chain, Italy Quality is a key concern for this supply chain **SH:** Farmers, supply chain players, cooperatives offering storage, millers	A moderated poster circuit method was used. Participants circulated in groups, filled and reviewed the posters for each step of the chain: production, inputs supply, technical assistance, storage.	Quick methods for quality assessment of grains Agricultural practices to save inputs and increase quality Economical evaluation of the most innovative practices	**FS:** 1. Use of catch crops to reduce nitrate leaching; 2. Use of a drone to monitor crop situation; 3. Late fertilisation for high-protein milling wheat varieties.

, input suppliers, retailers and processors	CSP guided SHs in selecting issues. TE attended meetings		FS do not offer solutions, approaches are not feasible, do not focus on bread or biscuit varieties
Catchment management in arable cropping, UK A partnership comprising individual farmers, local authorities and government agencies, farming representatives, NGOs to enhance catchment management **SH:** 4-5 farmers participated in meetings	Paired discussions between farmers then a group discussion to rank and prioritise the issues CSP selected a small number of SHs and steered them towards pragmatic issues.	Nine issues listed and summarised as: 1. Management practices to release P and K from soils; soil amendments; role of trace elements in nutrient availability. 2. Soil management and crop rotations to improve resilience (cover crops and tillage techniques to improve soil health).	**FS:** 1. Catch crops to reduce N leaching; 2. Allelopathy: a tool for an integrated management of resistant Black grass. FS relevant and helpful but issues were revisited and re-prioritised in the next meeting

References

Baars, T. (2011). Experiential science; towards an integration of implicit and reflected practitioner-expert knowledge in the scientific development of organic farming. Journal of Agricultural and Environmental Ethics 24(6): 601-628.

Botha, N., Klerkx, L., Small, B., & Turner, J.A. (2014). Lessons on transdisciplinary research in a co-innovation programme in the New Zealand agricultural sector. Outlook on Agriculture 43(3): 219-223.

Douthwaite, B., Kuby, T., van de Fliert, E., & Schulz, S. (2003). Impact pathway evaluation: an approach for achieving and attributing impact in complex systems. Agricultural Systems 78(2): 243-265.

EU (2013). Agricultural knowledge and innovation systems towards 2020–an orientation paper on linking innovation and research. European Commission, Brussels.

EU (2012). Agricultural knowledge and innovation systems in transition–a reflection paper. European Commisssion, Standing Commitee on Agricultural Research-Collaborative Working Group on Agricultural Knowledge and Innovation System (CWG AKIS), Brussels.

Hall, A., Mytelka, L., & Oyeyinka, B. (2006). Concepts and guidelines for diagnostic assessments of agricultural innovation capacity: UNU-MERIT, Maastricht Economic and Social Research and Training Centre on Innovation and Technology.

Kilelu, C.W., Klerkx, L., & Leeuwis, C. (2014). How dynamics of learning are linked to innovation support services: insights from a smallholder commercialisation project in Kenya. The Journal of Agricultural Education and Extension 20(2): 213-232.

Klerkx, L., & Leeuwis, C. (2008a). Balancing multiple interests: embedding innovation intermediation in the agricultural knowledge infrastructure. Technovation 28(6): 364-378.

Klerkx, L., & Leeuwis, C. (2008b). Matching demand and supply in the agricultural knowledge infrastructure: experiences with innovation intermediaries. Food Policy 33(3): 260-276.

Klerkx, L., & Nettle, R. (2013). Achievements and challenges of innovation co-production support initiatives in the Australian and Dutch dairy sectors: a comparative study. Food Policy 40: 74-89.

Klerkx, L., Van Mierlo, B., & Leeuwis, C. (2012). Evolution of systems approaches to agricultural innovation: concepts, analysis and interventions. In Farming Systems Research into the 21st Century: The New Dynamic pp. 457-483. Dordrecht: Springer Netherlands.

Leeuwis, C., Leeuwis, C., & Ban, A. (2004). Communication for rural innovation: Wiley Online Library.

McIntire, B., Herren, H., Wakhungu, J., & Watson, R. (2009). Agriculture at a crossroads: international assessment of agricultural knowledge, science and technology for development. Synthesis. Washington DC: Island Press.

McNie, E.C. (2007). Reconciling the supply of scientific information with user demands: an analysis of the problem and review of the literature. Environmental Science & Policy 10(1): 17-38.

OECD (2010). The OECD Innovation Strategy: getting a head start on tomorrow: Organisation for Economic Co-operation Development, Publishing.

Smits, R.E., Kuhlmann, S., & Shapira, P. (Eds.) (2010). The theory and practice of innovation policy: an international research handbook. Cheltenham (UK) and Northampton, MA (USA): Edward Elgar.

Sumberg, J. (2005). Systems of innovation theory and the changing architecture of agricultural research in Africa. Food Policy 30(1): 21-41.

Van Mierlo, B., Regeer, B., Van Amstel, M., Arkesteijn, M., Beekman, V., Bunders, J., . . . Leeuwis, C. (2010). Reflexive monitoring in action. A guide for monitoring system innovation projects: Communication and Innovation Studies, WUR; Athena Institute, VU.

Willems, D.J., Koenderink, N.J., & Top, J.L. (2015). From science to practice: bringing innovations to agronomy and forestry. Agrárinformatika/Journal OF Agricultural Informatics 6(4): 85-95.

Agronōmics – an arena for synergy between the science and practice of crop production

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Abstract: Progress towards sustainable intensification depends on effective exchange of knowledge and data between industry and academia. This requires engagement of both farmers and researchers, recognition that innovations can occur in the field as well as in the lab, and that researchers have as much to learn from farming and farmers as vice versa. A number of initiatives in the UK are recognising the value of farm networks for effective knowledge exchange and for asking questions of relevance on-farm; however the value for science is less well recognised. Uptake of digital record keeping and precision farming technologies is now becoming ubiquitous, providing new opportunities for farmers to share data amongst themselves and with researchers to generate new insights, but crucially also allowing farmers to make interventions in-field and to measure their impacts on-farm, for example by yield mapping. New statistical approaches are required to draw robust conclusions from this sort of data, but the authors believe its use could be transformative of agronomic science, so much so that we have created a new term to describe the approach; namely, 'agronōmics'. The major benefits of experimenting in fields with farmers are: i) working at a relevant scale with the ability to test treatments not possible at the plot scale; ii) the potential to assess treatment interactions with soil differences (experimenting with soils is challenging with conventional plots); iii) the potential for greater precision to evaluate treatments with confidence intervals of less than 0.5 t/ha; and iv) engagement of farmers, hence embedding knowledge exchange within research. However, it is crucial for effective knowledge exchange that farmers and researchers share the same concepts and metrics. ADAS has thus established the Yield Enhancement Network to allow both arable innovators and researchers to compare actual farm yields with theoretical 'potential' yields (estimated using conventional crop science concepts) and hence to develop the common conceptual framework necessary to underpin yield-targeted innovations.

Keywords: Tramline comparison, precision farming, participatory research, knowledge exchange, statistics, experimentation, network, yield, data

Connecting science with practice for sustainable intensification

Biology extends physics and chemistry into the heightened complexities of life, and agricultural science extends biology because it invokes human intelligence to manipulate life. However, we submit that science has yet to recognise and achieve significant intimacy with the fascinating emergent properties that determine field and farm-scale production processes. As a consequence, there remains significant potential, both for systems-thinking and agricultural progress in developing new approaches and conceptual frameworks for application at the broad (field to region) scales of most agricultural outcomes and decisions. A new holistic approach to agriculture should augment and complement conventional reductionist research of plants in pots or plots, where fine scale effects of genes, proteins, cells, tissues and organs are studied; we call this new arena 'agronōmics' [1]. Timescales for implementation of agronōmics are short because the challenge facing agriculture of producing more whilst impacting less is very real and immediate (Foley et al., 2011), yet current progress is slow, especially in crop productivity (Grassini et al., 2013). To be successful in meeting the challenges it is crucial that researchers, farmers and food supply chains engage effectively (Klerkx et al., 2010). It is increasingly recognised that knowledge generation and exchange is not a one way process from the researcher's lab to the farmer's field, yet the UK has largely dismantled its infrastructure for agronomic research, exchange and education (Royal Society, 2009). Funding and operation of relevant knowledge generation are currently separated (Wielinga, 2014); the two communities habitually work at different scales and in different places, their concepts for analysis of crop performance differ, and any extrapolation between small (science) and large (industry) scales has to entail large untestable 'leaps of faith'. We contend that what is needed is a shared interest in the challenges and constraints faced in farmers' fields.

Participatory research has long been practised in developing agriculture but it has seldom occurred in developed agriculture, particularly in the UK (Edwards-Jones, 2001) and it has yet to make a tangible impact in science. It is our contention that a detailed consideration of the problems and limitations faced in the field and at larger scales (as in the supply chain) is needed by the research community in order that scientific understanding can be enhanced and appropriate solutions developed. In addition to translating scientific innovations from the laboratory, science is incomplete and ungrounded whilst it is disconnected from the innovations and observations made by practitioners in the field or in the supply chain. Researchers need to understand, develop, test and assimilate these innovations and the underlying problems that they address.

Knowledge exchange networks

Whilst there have always been social networks of growers around agronomy groups, clubs, societies and farming associations, a number of recent initiatives have sought to augment these with new networks, often exploiting new IT capabilities. Many new networks concern one-way extension of scientific programmes. However, the European Innovation Partnership (EIP) programme under the EU Horizon 2020 programme challenges traditional ideas about Agricultural Knowledge and Innovation Systems (AKIS) and pursues an 'interactive innovation model' seeking to link farmers, advisors, researchers, businesses and other actors in 'Operational Groups' (Wielinga, 2014).

In addition, acknowledging the primacy of industry practitioners, the Agriculture and Horticulture Development Board (AHDB) Cereals and Oilseeds sector has established over 24 Monitor Farms across the UK. Each Monitor Farm is 'owned and operated' by groups of around 20-30 local farmers and advisors, and set their own agenda around issues of local concern from which they find relevant solutions (http://cereals.ahdb.org.uk/get-

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[1] The line over the second 'o' signifies that it is pronounced long, as in genomics, and means the science of field-scale agriculture, as distinct from agronŏmics, sometimes used to mean the existing branch of economics that deals with agriculture, pronounced with the second 'o' short.

involved/monitor-farms.aspx). The emphasis here is on farmer to farmer learning rather than top-down dissemination of ‘best practice’.

Field Labs

It is becoming acknowledged that ‘best practice’ is not a rigidly defined recipe, rather it continually evolves through recent innovations and experience. Furthermore, best practice is quantitative, involving adjustment of chemical quantities or dates of sowing or of chemical applications; optimal crop management in each field depends on the specific combination of soil, weather, genetics and a myriad of environmental interactions, such that ‘best practice’ for one farm system and in one location cannot be expected to hold for another similar one hundreds of miles away, and often not for one next-door! This points to the importance of local generation and adoption of optimal practices for individual farm circumstances. MacMillan & Benton (2014) recognise that farmers are practical experimentalists who continually innovate, test and adapt agronomic practices, cultivations and technologies, but until now this has been largely unrecognised and uncollated by formal science; refereed scientific papers with farmer authorship are extremely rare.

However, a recent UK farmer-focused innovation programme set up by Duchy Originals Future Farming Programme with funds from the Prince of Wales Charitable Foundation is adapting participatory approaches used in developing countries to help UK farmers assess their own ideas in ‘Field Labs’ (MacMillan & Benton, 2014). Small groups of farmers tackle identified problems in workshops with a facilitator and relevant researcher to advise on experimental designs and existing knowledge. Around 450 farmers have participated in the field labs so far on 20 different subjects. Given their recent introduction, there is as yet little evidence to say that Field Labs will hasten progress or precision in crop management, or hasten progress in crop science, but if farmers are measuring (therefore studying) the most telling metrics then at least the introduction of a scientist, who can suggest advise and analyse the data, offers the prospect of more impact, both on practice and science. We therefore hope that participation in Field Labs will spread more widely, and we are encouraged that a network for ‘Innovative Farmers’ has been formed (www.innovativefarmers.org) and that individual groups are eligible to receive financial support under the EIP scheme administered in the UK with CAP Pillar 2 funds.

Yield Enhancement Network

In response to cereal yield stagnation (Knight et al., 2012), and in recognition of the need to engage and energise farmers, suppliers and scientists in joint understanding of yield and its limitation, ADAS set up the Yield Enhancement Network (YEN; www.yen.adas.co.uk) in 2012. The YEN’s aim is to identify arable innovators and support them in testing yield enhancing ideas (Sylvester-Bradley & Kindred, 2014). Thus far the YEN has been entirely industry funded, it engages with many farms including several AHDB Monitor Farms, and rather like the ICI ‘10 Tonne Club’ in the 1970-80s (Weir et al., 1984) it engages with research organisations such as ADAS, NIAB and Rothamsted Research. It runs a yield competition, and uses the yardstick of biophysical yield potential (based on light energy and water availability) to allow fair engagement of farms with lower yield potential as well as those able to achieve high absolute yields. The competition element provides a focus for the YEN and ensures capture of trustworthy yield values, along with associated data on crop development and management; crucially the YEN includes analysis of crop samples to explain the variation in yields. In its first three years the winning yields were 13.6 t ha^{-1} in 2013, 14.5 t ha^{-1} in 2014 and 16.5 t ha^{-1} in 2015. The latter yield broke the previous official world record (Sylvester-Bradley et al., 2016).

The YEN has achieved broad engagement of the arable industry, farmers and the farming media through workshops and 'Ideas Labs', and it is now working to become a vital platform for scientific engagement by: i) providing ideas and hypotheses on routes to yield enhancement for researchers to test; ii) generating a growing dataset of yields with associated soils, meteorological, physiological and agronomic data; and iii) providing a network of farmers who are keen to interact with scientists and conduct or host experiments on-farm. A key element of the YEN is the establishment of a common conceptual framework and quantitative metrics to analyse yield, in order to ensure effective industry-science dialogue. Interestingly, whilst most current research investment is seeking yield enhancement through genetic advances, analysis of YEN data indicates that the technologies required to overcome yield shortfalls are just as much logistical, mechanical and chemical, as they are genetic.

Precision farming technologies

Farm data capture

Most large arable farms now use farm management software to record cropping information and an increasing proportion of arable farms utilise precision farming technologies to monitor and treat their crops (Defra, 2012). Yield monitors are ubiquitous now on modern combine harvesters, giving farmers instantaneous measures of yield during harvest and yield estimates by field. Whilst there are many issues around the calibration and accuracy of yield monitors (Ross et al., 2008) it is clear that these provide the best (and often only) measure of yield on a field by field basis. Connecting the yield monitor to GPS allows yield mapping, thus recording and reporting spatial variation in yield within fields. In addition to these new yield measurements, many crops are now assessed in-season via measurement of spectral reflectance, either by on-tractor sensors (e.g. N-Sensor, OptRx and Isaria systems), unmanned aerial vehicles (UAVs or drones), manned airplane flights (e.g. Spectrum Aviation, 2Excel) or by satellite imagery (e.g. SOYL and AgSpace in UK, FarmStar Expert in France). Soil variation is also commonly assessed by soil electrical conductivity (Corwin & Plant, 2005).

Technologies on modern application equipment such as seed drills, fertiliser spreaders and sprayers allow application rates to be varied on-the-move. When combined with global positioning systems (GPS) and crop sensing technologies, variable rate applications can be set up, informed by the variability seen in yield maps, crop sensing, satellite imagery and soil sensing.

Earth Observation by satellite is now widely used at national and regional scales to judge crop condition and expected yields. With the launch of the Sentinel satellites by the European Space Agency, satellite data are increasingly available at a scale and frequency to monitor and compare crops at the field scale. Wide opportunities exist for the exploitation of this free data both commercially and by researchers.

Thus there is a rapidly increasing wealth of spatially defined data available at scales relevant to farm decision-making, and thereby a new arena for research is being created. We call the new science being generated at this scale 'agronōmics'.

Using farm data

Despite the wide commercial uptake of precision technologies, questions remain over appropriate management responses to spatial data; benefits of variable rate applications are often difficult to prove and appear relatively small (Kindred et al., 2016). It is of concern that many farmers have collected large volumes of data without extracting good value from them; once the obvious lessons have been learned (e.g. the extent and positions of consistent yield variation within a farm) there can be an element of 'so what?' The science of agronōmics is still too immature even to offer routine means of data processing and analysis at this scale, let alone guidance on how best to derive understanding and to optimise industry practices.

However, there is a lot of current interest in 'big data' from both industry and academia. Initial plans, for example of the new Agri-Tech Innovation Centre 'AgriMetrics', are to both amalgamate multiple sets of farm records and integrate these with spatially referenced measures such as of meteorology, soil and satellite imagery. Commercially, the big interest is in using such datasets to develop algorithms for decision support. However, in order to realise the benefits from such datasets, new statistical techniques and analytics are needed; even the seemingly simple notions of just collating and then viewing data from different precision technologies and different systems over multiple years should not be under-estimated. Our experience is that collating such data across farms presents significant challenges and, whilst automation will eventually be possible, data preparation and analysis are currently time-consuming. Cloud based systems clearly now offer the best theatre for integration of spatial datasets, with potentially far easier data transfer (e.g. via telematics), processing, storage, viewing, amalgamation, interrogation and computation, especially for analysis across large numbers of farms. However, cloud based systems are as yet far from ubiquitous, and their functions still require development.

Given the vast expansion in farm-generated data, their often novel constitution (e.g. multi-spectral reflectance, magnetic inductance, lidar), and their direct availability to practitioners rather than to crop scientists, approaches to spatial data analysis and interpretation have commonly been simple, superficial and empirical. On the other hand, the sciences of crops and soils have built comprehensive and mature conceptual frameworks for measurement, analysis and explanation of performance over recent decades. The immediate and vital challenge for agronōmics is thus to effectively integrate the various data sources currently available (e.g. soil, weather, crop sensing, satellite sensing, historic yield maps and imagery) into meaningful metrics that are of value both in practice and in science. Based on the farmer-researcher networking initiated in the YEN, we believe there is now an urgent need to translate the data appropriately and devise 'Crop Intelligence Systems' that sense and report crop growth and development in relation to available resources (light energy, water and temperature). This would provide a platform for comparing crop performance between fields, farms, regions and years, and a framework for drawing inferences on the impacts of management decisions in relation to impacts of soil, climate and environment. It would also provide the rational basis from which to drive algorithms to support strategic and tactical decision making in crop management.

On-farm testing

It is our contention that the most valuable attribute of precision farming technologies is the capability they provide to farmers of assessing the effects of management decisions. On-farm testing has long been carried out by interested farmers in tramline or split field comparisons, often with support from the agricultural supply industry in the form of free products to test. The advent of GPS, yield monitors, yield maps and variable rate application equipment has made setting up, measuring and recording these treatment comparisons easier. Farmers can and do set up comparisons on farms to address a range of questions, including choice and optimisation of varieties, cultivations, fertilisers, pesticides, biostimulants, organic additions and cover crops. In the past these sorts of 'demonstration' trials have generally been ignored by scientists; they are considered inexact, unscientific and inconclusive, due to the lack of quality control, randomisation, replication and statistical analysis. Furthermore, as any cursory examination of farm yield maps will show, considerable care is needed in drawing conclusions from farm trials; spatial variation is such that no two areas in a field will yield identical average measures. As Fisher identified when devising conventional methodology for field experimentation (e.g. Fisher & Wishart, 1930) proof is not just required of a difference between two treatment areas, but that the difference is due to the treatment and not just inherent spatial variation. Some studies have however recognised the potentially greater measurement replication available from mapping harvesters and have developed approaches for using farm strip trials with more scientific credibility, often for use in developing and evaluating variable rate applications (e.g. Hicks et al., 1997; Plant, 2007; Griffin et al., 2008; Whelan et al., 2012; Lawes & Bramley, 2012).

We believe that it is feasible that the greater replication of individual measures from yield mapping and crop sensing, combined with the right geospatial models and statistical tests, could provide credible high precision comparisons. If a farmer can see a difference in the crop 'to a line' coinciding to a known management difference, this provides the farmer with overwhelming evidence that the intervention has had an effect. Within standard conventional science and agricultural statistics however there is no current framework for accepting such evidence as 'proof' of a causal effect.

Spatial experimentation, a useful addition to conventional plot experiments

Conventional crop experimentation relies on small plot trials laid out in replicated, randomised blocks analysed by 'analysis of variance' as set out by Fisher in the 1920s (Street, 1990). This approach effectively separates the spatial variation and measurement errors in order to conclude on the significance of treatment effects and has served agriculture well for the past 80 years. However, these experiments only compare treatment effects over relatively small areas; the same relationships might not apply over larger management zones, whole fields, whole farms or regionally. Also, the limited replication within the experiments may limit their precision. The precision of conventional trials with 3 or 4 replicates harvested by small plot combine harvester typically can't significantly detect differences of less than 0.5 t/ha, yet many individual agronomic decisions made by farmers cost in the region of £10 to £30/ha, equivalent to less than 0.3 t/ha.

In addition, choice of uniform land and randomisation of treatment positions in conventional experiments is specifically used to minimise effects of soil variation, thus disabling the ability to test soil differences or any effects that soil differences might have on treatment effects. The conventional approach to assessing soil differences is simply to compare multiple experiments from fields with different soil types. However, soil differences between fields are confounded by many other differences, including farmer, variety, management, previous cropping and weather. In contrast, most fields vary significantly in soil properties, and these offer opportunity to examine soil effects and variations in response to farm interventions with minimal confounding effects (i.e. where crop management etc. are identical); indeed soil attributes can be used as explanatory factors in an analysis of experiments involving systematic treatment allocation across known soil variation. This approach is best exemplified by the chessboard experiments conducted by ADAS to evaluate variation in nitrogen fertiliser requirements across fields, with systematic N response treatments (0,100, 200 & 300 kg N/ha) set up by the farmer at multiple grid points across a field (Figure 1).

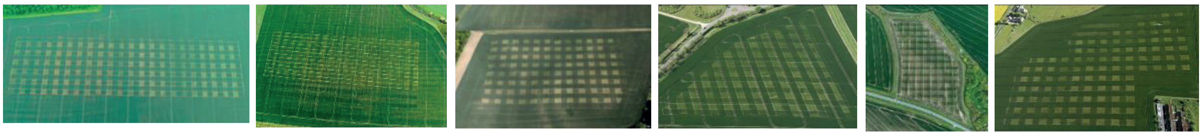

Figure 1. Aerial photographs of chessboard N response trials 2010-2012 *(Source: Kindred et al., 2016)*

These experiments have transformed our interpretation and understanding of variation in N responses and the role of soil variation (Kindred et al., 2016). Also, because these trials were set up by farmers using commercial application equipment they have also demonstrated the power and relevance of working with farmers at a field scale. Whilst these experiments were highly replicated with ~10m plots harvested by plot combine, they demonstrate the potential for learning about soil variation at larger scales, and potentially using commercial 'yield mapping' combine harvesters to measure the ultimate outcomes.

Developing agronōmic systems

Recognising the potential of spatial experimentation and farm-run trials to support a shared arena for investigation between scientists and farmers, to provide greater precision in treatment differences, and to allow evaluation of soil interactions, ADAS is developing agronōmics systems. These exploit many of the emerging technologies for on-farm automation and precision farming so as to enable quantitative crop phenotyping at the scales of field and farm, and to provide new understanding of spatially variable factors, particularly soil, through scaling-up field experimentation.

As seen at present, the essential components of effective 'agronōmics' systems will be: (i) motivated and coordinated networks of farmers with regional and landscape dimensions; (ii) more precise on-farm and experimental machinery; (iii) new spatially-referenced statistical techniques for on-farm testing; (iv) facilitating software; and (v) accepted explanatory concepts, such as the analysis of crop yield in terms of 'resource capture'. ADAS has initiated work to support the development of 'agronōmics' (funded by Innovate_UK), collaborating with British Geological Survey, AgSpace, BASF, Trials Equipment Ltd., and VSNi. We are developing the farmer networks, harvesting protocols and machinery, software and spatial statistics that should enable farmers and researchers to establish and harvest tramline-scale treatments, transfer and store yield data in a standard format, clean the data to remove outliers, add information on combine run, direction and position, correct data for time lags, locate tramlines, treatments and wheelings and allow calculation of means and variances by combine run and by tramline. We have also devised 'Spatial Discontinuity Analysis (SDA)' (i) to test for differences in yields on either side of a treatment boundary, and (ii) to assess how treatment responses vary within-field e.g. due to soil variation (Rudolph et al., 2016).

Example yield maps of tramline trials are shown in Figure 2 where comparisons were made of fertiliser nitrogen (N) rates of 60 kg/ha more and less than the standard field N rate. Whilst spatial variation within fields is generally larger than the effects of imposed treatments, we have been able to assess treatment effects at tramline scale with detection limits of between 0.05 and 0.8 t/ha, dependent on the quality of the yield data and the inherent spatial variation. Whilst there are still improvements to be made in quality of data from yield monitors, and in statistical approaches, it seems that comparable precision can be made in tramline-scale comparisons as is currently achieved in conventional small plot trials.

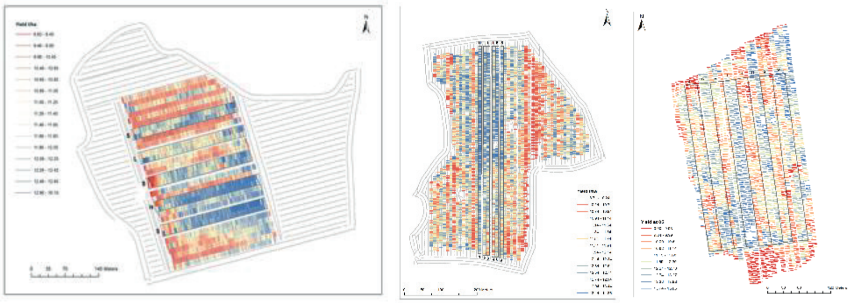

Figure 2. Example yield maps showing effects of different N treatments applied to tramlines, red = low yield, blue = high yield. Yield (t/ha) ranges: 9-12.5 t/ha.

ADAS is also investigating the use of plot combine harvesters fitted with continuous weighing hoppers and GPS to derive finer-scale yield maps than are possible with current commercial harvesters and that should enable higher precision treatment comparisons than can be achieved through commercial farm operations.

Farm Research Networks

Wielinga (2014) holds that effective interactions between farmers, advisors, researchers, consumers, policy makers and other stakeholders should increasingly be seen as the most important means of achieving joint learning and innovating for sustainable intensification. This could supersede the old model of innovations supposedly flowing from the researcher to farmers as end users. The European Innovation Partnership scheme under Horizon 2020 explicitly seeks to support such networks of farmers, advisors, industry and researchers in order to develop farm innovations.

There are a number of farm networks in the UK that now act (or could be held to act) as ‘farm research networks’, where farmers are working with researchers to gain new knowledge. The Field Labs organised by Innovative Farmers and the YEN are two examples of this already mentioned above. In addition:

- The AHDB LearN project is working with 18 farms across England using simple tramline comparisons by farmers on 3 fields per farm over 4 years to assess variability in N requirements between fields, farms, regions and years, and to determine better ways of judging how much N to use farm by farm.
- As part of the Cost-Effective Phosphorus Project funded by AHDB Cereals & Oilseeds Frontier Agriculture Ltd. is developing a network of farms using tramline trials to test how the value of phosphate placement interacts with soils of different P status.
- Working with Sainsbury’s, the co-operative Camgrain, millers and around 30 growers in the Sainsbury’s Wheat Development Group, ADAS has conducted research to seek better understanding of variation in grain protein and its effect on breadmaking, and identify routes to predict and improve protein content. Insights have been gained from the pooling of farm data across fields and years with known yields and protein contents, analysed by multi-variate analysis. This generated hypotheses on fertiliser use that were later tested using tramline comparisons, providing grain and flour samples for quality

measures and baking tests giving useful conclusions on farmer decisions that affect the quality of the end product, as well as farm profitability and environmental efficiency.

- In support of marketing hybrid barley varieties, Syngenta has organised a series of 20 reference fields per year, where their hybrids' performance is compared in split fields with conventional varieties.
- The AHDB Monitor Farms offer the potential to act as a Farm Research Network, though is not currently set up to fully engage research & development with knowledge exchange.

Thus there is an increasing experience amongst farmers of engagement in research activities. The vision for Agrōnomics is to develop the facilities, techniques and infrastructure (virtual, web-enabled networking) whereby increasing numbers of interested farmers with yield mapping capability can elect to take part in structured tramline comparisons to address their most compelling questions. For the existing research community such networks should offer significant new opportunities for progress in the sciences of both soils and crops.

Opportunities in evolving agronōmics

The idea that investment in science naturally delivers innovations of use to industry is patently too simplistic. Any analysis of agricultural progress (e.g. Sylvester-Bradley, 1991) reveals that it is the farmers, or those close to farms, who make the most numerous and telling innovations. Science creates understanding, so provides the arena in which innovation can take place, but it is industry practitioners who know the detail and can tailor innovations to fit the farming jigsaw. Thus, whether on-farm or in lab, effective innovators usually 'know farming'. Unfortunately, in many developed regions of the world over recent decades, we have largely lost the intimacy between farming and science that existed hitherto.

Furthermore, it is the nature of innovation that initial ideas or discoveries are often rough, and need honing; this process takes time and needs investment. Ideas often come to nothing, failures exceed the successes and successes tend to be haphazard so, for rapid progress, lots of ideas are needed. However, there are now fewer farms and farms have far fewer staff and make less profit than during the first green revolution 50 years ago. Whilst innovators are often passionate people, willing to put in much effort to prove their idea, they and their businesses must be able to cope with failures. Also, farm innovations commonly involve several technologies including engineering, chemistry, genetics and logistics, so effective innovations commonly depend on integration and collaboration between disciplines, facilitated by effective integrators. Benefits of farming innovations are often difficult to exploit commercially, as most involve making changes to systems rather than using new 'widgets'; the benefits may be big but are often diffuse, being spread across many products and businesses, and without protectable IP for the innovator.

We believe that the new technologies available within this innovation arena now create a major opportunity for the research community. They should now recognise and act in the gap between conventional applied science and field-scale crop production. However, their success will depend on working with different communities, different technologies and different methodologies than hitherto. For example, traditional crop research employs experimental designs that minimise effects of uncontrolled environmental variables so that measured responses to controllable inputs can be tested, but the small area of these plots trials commonly restricts the relevance of their results to one soil, and it limits precision. We maintain that, in addition to the scientific challenges at lab scale, research scientists could recognise a big opportunity in investigating the multiple unknowns involved in extrapolation between small and large scales; not least amongst these are the interactions between agronomic innovations – new germplasm, chemistry or machinery – and soil variation. New research programmes are needed to understand such interactions, using the new methods of investigation now in prospect.

In this new arena it will be well to note that standards of proof are commonly much lower for farmers and industry than they are for scientists; farmers don't need to be 95% sure that a decision that costs £10/ha will deliver a yield benefit of >0.5 t/ha, they just need to be confident that the extra investment will pay for itself with yield benefits of >0.1 t/ha most of the time. Finding no significant differences between product comparisons in conventional trials isn't necessarily proof that a treatment is uneconomic, just that the effect can't be proven beyond the detection limits of the trial. However, farmers and industry need to appreciate the common extents of experimental and spatial variability in order to avoid drawing flawed conclusions from comparisons of simple averages. There are thus opportunities for scientists to be more respectful of farm experiences, and to be more helpful in devising ways of integrating farm datasets such that results are assimilated and conclusions are drawn with appropriate levels of confidence.

With the extensive support for networking amongst farmers, we conclude that adoption of an agronōmic approach offers powerful opportunities for both farmers and researchers to work jointly on questions that matter to both, at a scale that is relevant to commercial cropping, and that enables new understanding of soil (and other spatial) interactions. The use of remote sensing and 'big data' together with precision farming technologies and web-enabled networking confers exciting opportunities for not just translating research, but also conducting it. By providing tools for scientists and farmers to collaborate and network in testing hypotheses in fields across farms we believe that the agronōmics approach has potential to transform agronomy worldwide.

Few lines remain to consider the interplay between agronōmics and education, but it is important to recognise the vital potential role of students and teachers in affecting agronōmic progress, and to consider how agronōmic knowledge may best evolve through the generations. A difficulty arises in comparison with the more conventional fine-scale sciences in that soil and weather dominate agronomic phenomena, so agronōmic processes will be best understood over large scales of space and time. Clearly the agronōmics arena promises to be data-rich yet, for the foreseeable future, much agronōmic intelligence will be subject to much uncertainty. Given that experience will be a vital precedent to effective agronōmic reasoning, students of agronōmics may well be best distributed widely, in virtual classrooms across the farming landscape so that, with virtual support and coordinated activities, they can acquire their farming experience whilst playing an essential role in the aggregation, assimilation and interpretation of the large farm-derived datasets that will be so crucial to developing agronōmic laws for the future.

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References

Corwin, D.L., & Plant, R.E. (2005). Applications of apparent soil electrical conductivity in precision agriculture. Computers and Electronics in Agriculture 46(1-3 SPEC. ISS.): 1.

Defra (2013). Farm Practices Survey 2012: https://www.gov.uk/government/statistics/farm-practices-survey-october-2012-current-farming-issues

Edwards-Jones, G. (2001). Should we engage in farmer-participatory research in the UK? Outlook on Agriculture 30(2): 129-136.

Fisher, R.A., & Wishart, J. (1930). The arrangement of field experiments and the statistical reduction of the results. Imperial Bureau of Soil Science, Technical Communication 10, 23 pp.

Foley, J. A., Ramankutty, N., Brauman, K.A., Cassidy, E.S., Gerber, J.S., Johnston, M., Mueller, N.D., O'Connell, C., Ray, D.K., West, P.C., Balzer, C., Bennett, E.M., Carpenter, S.R., Hill, J., Monfreda, C., Polasky, S., RockstrÃ¶m, J., Sheehan, J., Siebert, S., Tilman, D., & Zaks, D.P.M. (2011). Solutions for a cultivated planet. Nature 478(7369): 337.

Grassini, P., Eskridge, K.M., & Cassman, K.G. (2013). Distinguishing between yield advances and yield plateaus in historical crop production trends. Nature Communications, 4.

Griffin, T.W., Dobbins, C.L., Vyn, T.J., Florax, R.J.G.M., & Lowenberg-Deboer, J.M. (2008). Spatial analysis of yield monitor data: case studies of on-farm trials and farm management decision making. Precision Agriculture 9(5): 269.

Hicks, D., Vanden Heuvel, R., & Fore, Z. (1997). Analysis and practical use of information from on-farm strip trials. Better Crops 81: 18-21.

Lawes, R.A., & Bramley, R.G.V. (2012). A simple method for the analysis of on-farm strip trials. Agronomy Journal 104(2): 371.

Kindred, D., & Sylvester-Bradley, R. (2014). Using precision farming technologies to improve nitrogen management and empower on-farm learning. Aspects of Applied Biology 127 Crop Production in Southern Britain: Precision Decisions for Profitable Cropping 127: 173-180.

Kindred, D., Sylvester-Bradley, R., Milne, A., Marchant, B.P., & Storer, K. (2016). Automating fertiliser N for cereal crops, Research Report: AHDB.

Klerkx, L., Aarts, N., & Leeuwis, C. (2010) Adaptive management in agricultural innovation systems: the interactions between innovation networks and their environment. Agricultural Systems 103(6): 390-400.

Knight, S., Kightley, S., Bingham, I., Hoad, S., Lang, B., Philpott, H., Stobart, R., Thomas, J., Barnes, A., & Ball, B. (2012). Desk study to evaluate contributory causes of the current yield plateau in wheat and oilseed rape, Project Report No. 502: Defra & HGCA.

MacMillan, T., & Benton, T.G. (2014). Engage farmers in research. Nature 509(7498): 25-27.

Plant, R.E. (2007). Comparison of means of spatial data in unreplicated field trials. Agronomy Journal 99(2): 481.

Ross, K.W., Morris, D.K., & Johannsen, C.J. (2008). A review of intra-field yield estimation from yield monitor data. Applied Engineering in Agriculture 24(3): 309.

Royal Society, The (2009). Reaping the benefits: science and the sustainable intensification of global agriculture. The Royal Society, London. 86 pp.

Rudolph S., Marchant P.B., Gillingham V., Kindred D., & Sylvester-Bradley, R. (2016). Spatial Discontinuity Analysis a novel geostatistical algorithm for on-farm experimentation. In Proceedings of the 13th International Conference on Precision Agriculture. Monticello, IL: International Society of Precision Agriculture.

Street, D. (1990). Fisher's contributions to agricultural statistics. Biometrics 46: 967-945.

Sylvester-Bradley, R. (1991). Modelling and mechanisms for the development of agriculture. Aspects of Applied Biology 26, The Art and Craft of Modelling in Applied Biology 55-67.

Sylvester-Bradley, R., & Kindred, D. (2014). The Yield Enhancement Network: philosophy and results from the first season. Aspects of Applied Biology 125, Agronomic Decision Making in an Uncertain Climate 125: 53-62.

Sylvester-Bradley, R., Kindred, D., Smillie, I., & Berry, P.M. (2016). Enhancement of European crop yields without agronomic 'Intensification'. Paper submitted to the European Society of Agronomy, Edinburgh.

Weir, A.H., Rayner J.H., Catt, J.A. Shipley, D.G., & Hollies, J.D. (1984). Soil factors affecting the yield of winter wheat: analysis of results from I.C.I. surveys 1979–80. The Journal of Agricultural Science 103: 639-649. doi:10.1017/S0021859600043756.

Whelan, B., Taylor, J., & McBratney, A. (2012). A 'small strip' approach to empirically determining management class yield response functions and calculating the potential financial 'net wastage' associated with whole-field uniform-rate fertiliser application. Field Crops Research 139: 47-56.

Wielinga, E. (2014). Concepts for Co-Creating Innovations in the EIP. Farming Systems Facing Global Challenges: Capacities and Strategies. International Farming Systems Association, Berlin.

Co-innovating in agroecology: integrating stakeholders' perceptions of using natural enemies and landscape complexity for biological control into the research and innovation process

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Abstract: Scientific findings in landscape ecology suggest that a patchy landscape including hedgerows, meadows and woods favours insect pest biological control by conservation of habitats for natural enemies. Some scientists foresee the possibility for farmers acting together in order to generate such conditions in their landscape. For such grass-root collective action to be possible, local stakeholders must first perceive landscape elements and/or natural enemies as resources; and the same stakeholders must be willing to co-operate through a collective management approach. Our objective was to investigate stakeholders' perceptions of landscape elements and natural enemies in relation to the potential for innovation in the form of coordinated management of the landscape. To do this, we used a participatory research approach in an area specialising in fruit tree production in south-west France, known for its high pest pressure and use of insecticides in orchards, and consequently high risk associated with any alternative approach in this domain. We conducted thirty comprehensive interviews with stakeholders about their pest control strategy to explore their perceptions of landscape elements and natural enemies in particular. The results indicated that natural predators were regularly perceived as resources. Stakeholders mostly perceived them as public goods requiring public institution interventions for their conservation, acclimation and management. Some interviewees perceived natural enemies as private goods where they can be captured and released onto specific crops, as is the case in greenhouses and with new technology such as anti-insect nets surrounding orchards; a practice on the rise in the region. By contrast, landscape elements were not perceived as resources in biological pest control. Our analysis of stakeholder perception indicates that a public or private approach to natural enemy action are favoured in natural predator management. Finally, most farmers did not relate landscape to any biological control benefit and were therefore not motivated to act in this regard. Consequently, our co-innovation process with stakeholders will be oriented towards questioning the knowledge gap between scientists and local stakeholders regarding the effect of landscape on natural predators and biological control.

Keywords: Landscape, biological pest control, uncertainty, collective action, action-research

Introduction

It is well established that farming practices are one of the major phenomenon contributing to biodiversity loss worldwide (McLaughlin & Mineau, 1995). In particular, the use of chemicals as biocides has been under scrutiny for their impact on biodiversity as well as on human health. In 2009, the European Commission established a directive aiming at achieving "a sustainable use of pesticides" in order to reduce their negative impacts. Each member state was invited to introduce its "National Action Plan" by 2014 in the spirit of "*promoting the use of integrated pest management and of alternative approaches or techniques such as non-*

chemical alternatives to pesticides". In France, the national plan was named "Ecophyto" and aimed at 50% pesticide use reduction by 2018.

In this context, there is a growing interest for research in agroecology and biodiversity-based agriculture that favours and makes use of biodiversity (Duru et al., 2015). Findings in landscape ecology demonstrate in particular that complex landscapes can enhance biological control on farms through their positive impact on the abundance and/or diversity of insect pests' natural enemies (Bianchi et al., 2006; Rusch et al., 2010; Chaplin-Kramer, 2011). Natural enemies include all types of predators and parasites which reduce insect pest populations through their life cycle. Complex landscape is understood as an agricultural patchy landscape with a high proportion of semi-natural and wooded habitats.

While such findings open up new possibilities of pest control practices at the landscape level (Cong et al., 2014), little is known about the concrete feasibility of such practices (Tscharntke et al., 2005; Schellhorn et al., 2015). Stallman (2011) suggested that, among different kinds of ecosystem services, biological pest control was potentially highly suitable for collective landscape management. It is also our point of view that because agricultural landscapes are produced collectively by many individuals, a biological control strategy using complex landscape regulation properties might require co-ordinated action among these individuals. However, as Cong and his colleagues state *"scant attention has been paid to the question of whether it is in the interest of farmers to manage habitats at the landscape scale for generating ecosystem services"*. Our research aims to fill this gap and reach a better understanding of stakeholders' views on managing habitats for pest control; in particular to see whether or not collective action could be an option for pest regulation at the landscape scale.

We explored collective action as defined by Ostrom (1990), namely the possibility of collective self-organisation in managing complex socio-ecological systems (SES - Ostrom, 2009) as an alternative to top-down natural resource management (Holling & Meffe, 1996). However, in Ostrom's work, the "resource" (water, forest, fisheries) tends to be obvious to users because SES were studied where such elements were well established and key to users' survival (Ostrom, 1990). In our case, elements such as "insect natural enemies" or "landscape" are only potential resources. As we have seen in the landscape ecology literature they can potentially bring a benefit, but it is not known whether or not users perceive them as resources. In the field of agro-ecological design innovation, resources and users are indeed often not pre-defined (Berthet, 2013). The specific purpose of our work is to add a constructivist approach to resource qualification prior to the Ostrom framework on collective action. Constructivism considers that it is the interaction of individuals with their environment that creates meaning. In this regard we used the definition of a resource given by Raffestin and Bresso (1979). For these authors, a resource is an element of an individual's environment in which they have invested time and energy in prospect of a benefit. In our research it means that a natural enemy or landscape as a resource does not exist *per se* unless an individual interacts with these elements. This approach is notably different from a naturalistic view on resources, which describes resources as objective elements independent of an individual's interaction with them (Kebir, 2006; Labatut, 2009). This constructive approach, where resources are the result of individual interactions within a socio-ecological system, is an original addition to SES frameworks (Binder et al., 2013).

Ostrom's framework distinguishes different types of resources according to their subtractability and their excludability: a subtractable resource means that if someone uses this resource, there will be less for someone else, and an excludable resource means that someone can easily keep someone else from using it. She studied collective action in the specific case of common pool resources (CPR), which are subtractable and non-excludable resources, such as irrigation water or fisheries. Her work stresses that different types of resources imply different kinds of management strategies and that the collective action she studied was specific to CPR situations. It was therefore important for us to analyse what type of resource local stakeholders perceived “insect natural enemies” and “landscape” to be within Ostrom’s resources framework, and consequently what management strategies might be relevant.

In summary, the objective of this study was to investigate local stakeholders’ perspectives in terms of the potential for innovative collective action in integrated pest management (IPM) at the landscape scale. To do this, we explored how local stakeholders related to and perceived their environment within the context of their current pest management strategy in order to see whether or not they perceived “insect natural enemies” and “landscape” as resources for pest management, and what the characteristics of these resources were (subtractability and excludability) (Figure 1).

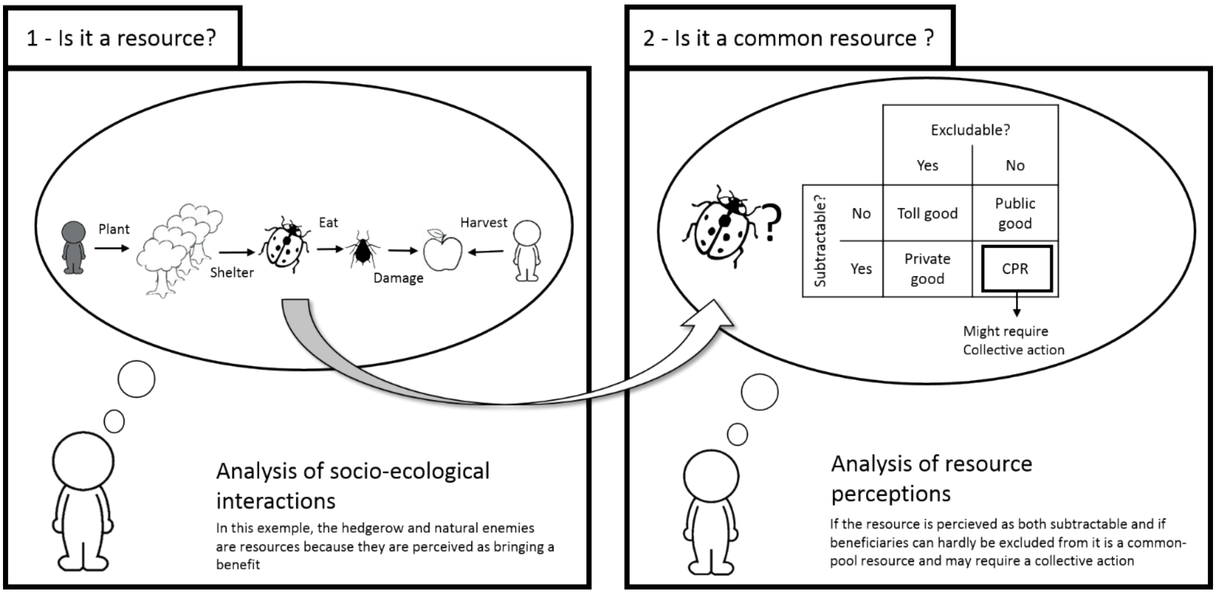

Figure 1. Our two step theoretical approach to explore the social construction of a resource.

Method: comprehensive interviews and mental models

The research was carried out in south-west France in an area close to the Aveyron River that is dominated by orchards (mainly apples) and cereal production. This area, chosen in partnership with local agricultural public institutions, was particularly interesting for our investigation because fruit tree production is a capital intensive crop with a high level of pesticide use. As pest damage can have dramatic economic impacts, many producers tend to rely on chemical spraying to secure their investment.

We conducted thirty individual interviews, mainly with farmers, but also with local landowners and agricultural technicians. Individuals interviewed covered the diversity of systems of production in the area. Each interview followed the comprehensive interview approach (Kaufmann, 2011), a semi-directive form of interview recognised for its capacity to let interviewees express their personal views as well as acknowledging the inter-subjectivity between the interviewer and the interviewee. Each individual interview included three steps: the interviewee was first asked for a general description of his actual and past activities; secondly for a description of his view and practices regarding pest management; and thirdly about his perception of landscape elements and natural enemies in his pest management strategy - in case it was not spontaneously mentioned during the interview. To help the discussion, a google map of the farm was provided to discuss the influence of the local environment on farm and pest management.

Each interview was recorded and the speech was translated into a conceptual model of their mental model of pest management using the Cmap programme (Novak & Canas, 2006). This model allows all socio-ecological interactions mentioned by the interviewee about their personal view on pest management to be represented in a single graph. When the interviewee mentioned a relationship between elements involving a benefit we indicated this element as a resource (for example, in the phrases “use of a pesticide against a pest” and “planting fruit trees”, the elements “pesticide” and “fruit trees” were considered as resources for this interviewee. The graphic formalism used the ARDI (Actors, Resources, Dynamics & Interactions) methodology to represent socio-ecological interactions (Etienne et al., 2011). These graphs allowed us to evaluate the importance of landscape and insect natural enemies in their description of pest management, both quantitatively (how many times they were mentioned) and qualitatively (how did they mention it?), ultimately allowing us to determine whether the elements were perceived as resources and common pool resources.

Results

Results are presented in two steps:

(1) we explore cases when natural enemies were perceived as resources and detail the six situations identified;

(2) we introduce our findings regarding landscape perception.

Natural enemies as resources

Two thirds of interviewees mentioned insect natural enemies in their pest management. Thus, a majority of interviewed farmers perceived natural enemies as a resource and integrated them into their pest management mental model as a regulating benefit. The natural enemies and effects mentioned are summarised in Table 1. In the following section we detail the different perception of natural enemies as resources and also qualify the type of good they represent according to their excludability and subtractability expressed by interviewees. An overview of this resource perception qualification is summarised in Table 2.

Table 1 : Synthesis of natural enemies mentioned as resources involved in pest control during individual interviews

Natural Enemy mentionned	Pest controlled	Effect on pest	Instances in interviews	Socio-ecological interactions involved
Aphelinus Mali	Eriosoma lanigerum (Wolly aphid)	Parasiting	10	Chemical application (Emamectine) may kill second generation A. mali..Chemical product (Vamidothion) against woolly aphid (Killval) has been banned.
Ladybug (Coccinelidae)	Aphids	Predating	10	Anti-insects nets may interfere, Harmonia axydris releases compete with endemic coccinelidae
Phytoseids mites	Red acaris	Predating	8	Chemical products killing phytoseids have been banned by public authorities
Hoverflies (Syrphidae)	Aphids	Parasiting	3	
Neodryinus typhlocybae	Metcalfa pruinosa	Parasiting and predating	3	Official pest control institutions (FREDON) released it
Lacewings (Chrysopidae)	Aphids	Predating	2	Anti-insects nets may interfere
Trichogramma	Ostrinia nubilalis (European Corn borer)	Parasiting eggs	2	
Asobara japonica	Drosophila suzukii	Parasiting	1	Acclimation studied by researchers
Aphidoletes aphidimyza (Aphid midge)	Aphids	Predating	1	
Rhagonycha fulva (Common red soldier beetle)	Aphids	Predating	1	
Pear aphids	Cacopsylla pyrisuga	Niche competition	1	
Anthocoridae	Psyllids	Predating	1	
Forficula auricularia (Earwig)	Aphids	Predating	1	Anti-insects nets practices may interfere with them

IPM development identified natural enemies as key resources for pest control

In the 80's and 90's there was a significant development of the IPM approach to pest control. Orchard managers and especially fruit tree technicians involved in IPM development programmes were encouraged by public policies to integrate this new perspective on pest control. As a consequence, many natural enemies were mentioned in fruit tree technicians' mental models. This specialised knowledge is consistent with some farmers relying heavily on their technician for advice as they did not always acquire IPM techniques, and thus knowledge of natural enemies, individually.

Among producers, IPM development and the consideration and use of natural enemies in their farming practices was not driven by public intervention, but rather by personal experience that revealed the efficiency with which natural enemies can control some pests. For illustration, the most quoted story is related to the 1991 frost, which had a significant impact on the apple harvest. As a consequence, orchard managers applied minimal chemical treatment that year, and yet no damage from red acaris (locally called "red spiders"; a major pest in the area) was observed. Many orchard managers discovered at that moment the effectiveness of phytoseids (a family of mites that feed on thrips and other mite species) in regulating the pest. For example, one producer stated that: "*We realised that there were no more spiders because they had been predated by acaris and phytoseids. So it's from this point that our approach started to change".*

Red acaris predators clearly appear as a resource for many apple producers and technicians, but perceptions of how the resource was developed vary according to the perspective of different stakeholders. Individuals who were close to public IPM development programmes described concrete actions that led to the use of natural predators on red acaris, such as chemical bans, machinery improvements and observation routines limiting systematic treatments. One individual close to local agricultural administrations illustrated this by stating that: "*the evolution happened in the years 1985-90 when we adopted integrated pest control. Today, red spiders are not a problem anymore because we developed natural enemies".* By contrast, for many apple producers, the strategy was happened upon by accident*: "I went on holiday for a week and wasn't dealing with spiders. When I came back there were no spiders left".*

In the 80's and 90's, public authorities took the lead in IPM development and the use of natural enemies within orchard production systems. Farmers were not directly included in the process, and so public institutions and farmers viewed natural enemies in this context as a public good; the benefit from natural enemy action was for every farmer, and there was no intention to prevent any potential user from benefiting. IPM development followed a top-down linear approach and farmers were not directly involved in the social construction of this resource.

Natural enemies as resources in response to a chemical product ban

Aphelinus mali is a parasitic wasp and natural enemy of the woolly aphid, which is a sap sucker that impacts apple quality through honeydew production and the subsequent development of Sooty mould. Woolly aphids were apparently not a problem for most apple farmers until the pesticide Vamidothion was banned in 2003. As one technician stated: *"it has become more difficult to control Woolly aphids since KILVAL [Vamidothion] was unexpectedly banned …overnight a product that had provided effective control was no longer available to us, presenting us with a new challenge".*

As a result, *Aphelinus mali* has become a key resource that is under close scrutiny from local agricultural public institutions, fruit selling companies and experimental stations. *Aphelinus mali* is monitored in many different fields and experimental plots around the region. One technician from a fruit cooperative mentioned that "*we try to pamper them as much as we can".* Another stated that they *"try to remove all pesticides which were negative to Aphelinus mali"*. In contrast to red acaris and phytoseids, the solution to woolly aphids was not developed by public authorities. On the contrary, the woolly aphid pest problem was initiated by public authorities through removing a pesticide from the market for toxicity reasons. *Aphelinus mali* is now a key resource because authorised chemical treatments are no longer sufficient to control the woolly aphid and significant investment has been put into *Aphelius mali* monitoring and the integration of such practices into apple production systems. *Aphelinus Mali* as a resource is clearly a public good as provision of the aphid control service is not subtractable (use of the resource does not mean there will be less for someone else) or excludable (no one can exclude another person from using it).

Natural enemies as resources against increasing invasive pest pressure

Eight out of seventeen individuals involved in fruit tree production mentioned *Metcalfa pruinosa*, an invasive pest from North America, in their mental model. Three mentioned its natural enemy, *Neodryinus typhlocibae*, which was successfully introduced to control it (Malause et al., 2003). Its acclimation was managed and monitored in a top-down manner by public institutions. Even though pest invasion is not a new phenomenon, with increasing globalisation in recent decades, its occurrence rate has increased significantly for invertebrates due to increased economic activity and transport efficiency (Hulme, 2009). The acclimation process of natural enemies for these invasive pests is also not new. For example, the acclimation of *Aphelinus mali* to limit woolly aphids was managed by an international network of researchers in the 1920's (Howard, 1929). Understandably, an increasing number of pest invasions puts increasing pressure on the need to introduce corresponding natural enemies.

Farmers themselves are not involved in the growing need for research on natural enemies for invasive pest control. Natural enemy introduction is mainly managed by researchers whose role is typically to identify and test the ability of natural enemies to adjust to a new environment (i.e. acclimation) and to regulate invasive pests. Public institutions then validate each approach and implement the most viable option. This process is a very clear resource construction process as there is significant investment from well identified agents (researchers and public institutions) into establishing a pest regulation resource. This type of resource is a public good as these pest control insects, once released and acclimated, are beneficial to whoever might need them and there is no exclusion from any potential beneficiary.

Natural enemies as part of a holistic view on pest control

Two interviewees had a holistic view of insect pest control and considered that efficient global ecosystem functioning would provide sufficient pest regulation. This type of thinking is consistent with perceptions expressed by farmers positively inclined towards organic production and who have a more complex and philosophical attitude towards biodiversity (Kelemen et al., 2013). For example, one respondent stated that *"We're not alone on Earth (…) animals have a right to live and I think that if birds (…) and other organisms in the ecosystem that prey on leafhoppers were removed, we would be reliant on a lot more agro-chemical use"*

In this regard these stakeholders with a holistic view of the environment have built a different type of relation with natural enemies as resources. Firstly they focus less on one species in particular and more on the belief that a global ecosystem can regulate invasive pests. Attitudes towards individual components of the system tend to be more ambivalent as an element can be perceived both as a benefit and a cost: *"Falcons eat my chicks but also eat field mice and snakes… it's the circle of life". T*his trust in the ecosystem to balance out all the components is sometimes established through practices favouring global biodiversity. For example, an organic orchard manager provided food and egg-laying sites for natural enemy insects by maintaining a herbaceous inter-row in his orchards. For this type of actor, investment in natural enemies is achieved by allowing ecosystems to reach a natural balance of species. This kind of perception is consistent with a less anthropocentric view of agriculture that considers elements of ecosystems not only as a support for production but also as an integral part of the production process itself (Barbier & Goulet, 2013).

Many farmers with a holistic view of ecosystems were in part-time organic production and therefore, compared with conventional, full-time orchard managers, were less exposed to ecosystem and economic uncertainty due to price premiums provided by organic sales and/or from income security provided by having a secondary activity. By contrast, conventional producers generally felt more reluctant to rely on ecosystem services. For example, one conventional technician stated that: *"Natural processes can be random and I don't like being reliant on a parasitic wasp (e.g. Aphelinus mali) to control aphids. One day, these wasps will prevent me from spraying against acaris and this will cost me money".*

Stakeholders with a more holistic view considered the general ability of on-farm biodiversity to regulate pests and reduce pest damage to an acceptable level as a key farm resource and a public good. Furthermore, growers that perceived the environment in this way did not mention any aspect of their off-farm surroundings or neighbouring land that would impact on their ability to benefit from natural enemies, suggesting that there was no competition or subtractability associated with such a resource.

Natural enemies as a symbolic resource in communication with their buyers

Natural enemies were occasionally mentioned as a symbolic resource by small scale growers selling their fruits in open-air and farmers' markets. Some growers saw the use of natural enemies as an opportunity to differentiate their produce from growers that are reliant on agro-chemicals, thereby appealing to consumers concerned with biodiversity and health issues associated with pesticide use. Some growers even used features associated with natural enemies to market their produce to customers. For example, one grower highlighted lacewing eggs on peaches and apples as symbols of care for the environment, stating that *"lacewing threads and eggs are a common feature of my top fruit. In the open-air market they ask me - what is that? – and I explain that these are natural enemies that protect my fruit from pests, and without them I would have to use products that would kill the pests and their natural enemies and leave residues on the fruit"*. Such dialogue is not possible within longer supply chains as producers are separated from their consumers.

Natural enemies as a symbolic resource for communication or marketing purposes are a public good as they are not subtractable or excludable. The use of a natural enemy feature does not mean there will be less for someone else and does not prevent anybody else from using it.

Natural enemies for biological control by augmentation

Some interviewees mentioned the use of natural enemies by augmentation, meaning the practice of releasing natural enemies on a farm to boost their population. For example, as part of the production contract with a seed buying company, some corn seed producers are required to release trichogrammas (a parasitic wasp of Lepidoptera eggs). Another example is a market gardener who uses a local company specialising in biological control to release diverse natural enemies in his greenhouses. Both examples illustrate that a certain degree of isolation is required to ensure the maximum efficiency of the release. For example, a corn field targeting seed production must be isolated from conventional corn fields to limit corn hybridization and to increase the likelihood of the trichogramma remaining in the field. For the market gardener, the greenhouse plastic creates a boundary that prevents any "dilution" of natural enemy insects in the surroundings.

This perspective on natural enemies clearly indicates that this type of resource is a private good, because farmers mentioning them explicitly try to limit their neighbours' access to the resource by creating some kind of boundary or buffer. Their mention of a risk of "dilution" indicates that they perceived the scarcity of natural enemies released as a threat to efficacy, and that to maximise effectiveness the intention is for the natural enemies to be focused on their crop rather than a neighbour's crop. The private nature of this natural enemy augmentation is consistent with an "input" approach to natural enemies and by the presence of private companies organising their supply and sales.

Biological control by augmentation could herald a significant development in the study area with the introduction of anti-insect nets that entirely surround orchards to focus the activity and intensity of natural enemies and avoid dilution into surrounding neighbours' plots. It is quite possible, following the "isolation" rationale for biological control by augmentation, that anti-insect nets could become a general feature of orchards in the area.

Table 2 : Overview of the context of natural enemy seen as resources

Type of resource	Social Construction of the resource	Actors for whom it's a resource	Type of good
Natural enemy against invasive pests	Study by research institutions Acclimation by public institutions	Researchers Technicians	Public
Natural enemy as a tool within IPM program	Public policy for IPM development	Administration Technicians	Public
Natural enemy as secondary solution to pesticide bans	Pesticide ban by public authorities Monitoring from technicians	Technicians Orchard manager	Public
Natural enemy as an element of a holistic view of pest control	Philosophical relationship to nature and ecosystems	Organic producers	Public
Natural enemy as a symbolic resource	Marketing argument	Small scale growers involved in direct sales	Public
Natural enemy for biological control by augmentation	Companies selling natural enemies Companies imposing Natural enemies in production contracts	Farmers Grain companies Natural enemy sellers	Private

Landscape as a resource in pest management?

Findings in landscape ecology suggest that complex landscapes can enhance biological control (Thies, 1999). The landscape itself can therefore be considered as a resource that needs to be managed to favour the proliferation of natural enemies. In this section we analyse whether the landscape is perceived as a resource by the interviewees.

Landscape mainly perceived as a threat in pest management

One of the most surprising results of this study was that landscape elements were almost never perceived by any of the interviewees as having a positive influence on natural enemies and thus bringing a benefit. This result was not consistent with scientific findings of landscape ecologists suggesting that landscape complexity can enhance pest control (Bianchi et al., 2006).

One hypothesis could be that stakeholders only have a plot or farm scale perception range and do not perceive a landscape effect. This was supported by the fact that the only positive landscape elements mentioned were on-farm hedgerows that provide habitats for generalist predators. However, many stakeholders also mentioned that their off-farm surroundings could have a modest negative effect by stimulating diverse pests (see Table 3). However, negative effects were not always considered to be modest; in the case of *Drosophila suzukii* (fruit flies), landscape elements were thought to favour significant and uncontrollable damage to cherry trees.

Some technicians who regularly visited growers across various sectors mentioned that they saw no difference in pest pressure or natural enemy presence when they compared farms in different areas with contrasting landscapes (e.g. in terms of the proportion of semi-natural habitat). Other technicians shared experiences of establishing hedgerows in terms of their ability to increase natural enemy numbers, with the effect being relatively disappointing. For example, one fruit tree technician stated that*: "it was very fashionable in the 90's to establish hedgerows (…) there was a great push for integrated pest management and hedgerows to shelter a wide variety of things (…) everybody, including myself, thought the method had great potential to increase natural enemy populations and many hedgerows were planted but many were not effective; there are even some places where hedgerows have been removed. What seems straightforward in the literature does not necessarily materialise in reality".*

Table 3 : Synthesis of landscape elements mentioned during individual interviews and their effect on insect populations

Landscape mentioned	Effect on insect populations	Effect of insects mentionned	Instances in interviews
Uncultivated land and hedgerows especially with nettles and blackberries, kiwi trees	Favours Metcalfa pruinosa	Honeydew production favors fungus damage on fruits	4
Woods	Favors Rynchites	Sting fruits	3
Hedgerows, woods and fallows	Favours Drosophila Suzukii	Sting fruits and lay eggs in diverse fruits (cherries, strawberries, raspberries)	2
Walnuts	Favours codling moth	Eat and dig apples	2
Absence of orchards around an orchard	Limit general insect pest pressure in the orchard	Less attacks on orchards	2
Peach orchards	source of Grapholita molesta to neighbouring apple orchards	Attack peaches and apples	2
Uncultivated land	Favours rose tortrix (archips rosana)	Attack young fruits	1
Acacia hedgerow	Favours Scaphoideus titanus (American grapevine leafhopper)	Attack grapes	1
Dead tree	Shelter Xyléborus dispar	Attack weak orchards trunks	1
Corn field	Source of Corn borer attacks on low apple tree branches	Attack apples on low branches	1
Poplars and willow	favors Zeuzera pyrina	Dig young trees trunks	1
Forest	favours Anthonomus pomorum (apple weevil)	Eats and lay eggs in apple flower buds	1
Malus in hedgerows	Source of woolly aphids	Suck apple sap, honeydew production favors fungus damage on fruits	1
Wheat field	Flows of ladybugs in July after harvest	no particular effect noted	1
Meadow	shelter Ladybugs	no particular effect noted	1
Hedgerows without rosacea	shelter, feed and provide egg-laying sites for generalist predators	Eat aphids sucking apple tree sap	

The perception of landscape diversity as a threat stimulates enclosure

As stated above, the landscape was mostly perceived as a threat to the farm (Table 3). As a consequence, isolation from negative landscape effects was sometimes perceived as a benefit, because pest pressure was perceived to be reduced when neighbouring fields were not growing the same crop. As one orchard manager stated: *“15 to 20 years ago there were 110 hectares of orchards round here; whereas now the area is much reduced… for a very, very long time I was under very, very strong pressure from pest insects”.* In this regard, isolation from fields producing the same crop was perceived to be a benefit due to reduced pest pressure, although not many growers actively sought this situation. By contrast, the use of anti-insect nets to completely surround an orchard is on the rise in the area because it opens up deliberate action from farmers to isolate their plots from external negative influence. A local perspective is quite clear on this prospect*: “More and more new plantations, and even old ones, are covered with anti-insect nets… to suppress insects…and reduce insecticide use (…) I think this trend for using protection nets against insects will continue“.*

The use of anti-insect nets creates a new resource which is an air space surrounding the crop in which pest insects are controlled. Through insect-nets, producers can control insect flows in and out of their plot and monitor pest pressure. Enclosure of the air space above plots opens up new biological control strategies because natural enemy releases can be more effective if they are guaranteed to stay within the plot. As one farmer stated: *“For this fly [Drosophila suzukii], I don’t know any predators. If there were any I would release them inside my nets. In this situation I would be confident of my strategy”.* The use of nets favours a strategy oriented towards privatisation of the environment surrounding the crop, which can be complemented by an economic sector selling natural enemies as described above.

Discussion: perception analysis as a reflexive tool for action-researchers

Exploring perceptions and the social construction of resources revealed a significant knowledge/perception gap between fruit producers and landscape ecology scientists. While the latter regularly demonstrate the positive influence of landscape complexity on natural enemies (Bianchi et al., 2006), the former, as we have reported, do not perceive this benefit and on the contrary rather state a regular positive influence of the landscape on their different pests.

The results of this research significantly changed the focus we had on using enhanced landscape complexity to control pest pressures as a potential innovation. While we thought initially that our action-research process was a means of opening up stakeholders to a potentially useful piece of knowledge to innovate in biological pest control, it turned out to reveal divergent perceptions between scientists and local stakeholders about the effects of landscape complexity on pest populations.

Participatory research is about including stakeholders to guarantee the best outcome possible for those who participate. The prospect is about the production of knowledge adapted to the stakeholders’ situation and needs. However, in this case the stakeholders’ perception shifted our research towards the exploration of this knowledge gap. This shift not only changed our focus, but also had significant influence on our methodology. While our research was first engaged in a companion modelling process (Etienne et al., 2010) in which perception analysis was a first step prior to participatory modelling with the objective of stakeholders discussing coordination to achieve better pest control through employing and enhancing the landscape factor, we had to turn to different tools to explore this knowledge/perception gap.

The uncertainty between scientists' and local stakeholders' points of view about landscape effects oriented us towards uncertainty exploration tools. In this regard, participatory belief Bayesian networks are widely recognised for their ability to "*represent and integrate knowledge and spheres, explicitly support the inclusion of stakeholder knowledge and perspectives, and take into account the uncertainty of knowledge*" (Düspohl et al., 2012).

Clarification of perceptions between those who hold a potential innovation and potential stakeholders benefiting from it appears to be a key step in engaging both on similar ground in an action-research process by eventually disambiguating uncertain knowledge, if possible, or at least identifying the root of the perception gap; thus eventually clarifying the science behind the landscape pest control innovation. Science questioning science is an important part of a functioning action research agenda (McNiff, 2013). To do so, we will assist local stakeholders as well as landscape ecologists in modelling a common Bayesian network structure about biological pest control. We will assist each participating individual in order to calibrate a common network with their personal knowledge on biological pest control and landscape effect. Individual networks will be compared and uncertainties discussed among participants.

Conclusion

It is clear that top fruit producers perceived natural enemies as a valuable resource in biological pest control. However, they did not consider that biological control could be enhanced by the nature, connectivity and diversity of landscape elements. Most stakeholders perceived the landscape as a threat and a source of pests. The absence (within stakeholders' perceptions) of the landscape or its elements as a resource in biological pest control challenges scientific findings that highlight the potential for using landscape complexity to enhance pest control, especially as mostly disservices were described by interviewees. The action-research framework will therefore need to be adapted to allow scientists to question the scientific knowledge at the root of their action and to integrate stakeholder feedback.

None of the stakeholders mentioned natural enemies as common pool resources (CPR), but rather as private or public goods. Technology and public policies seemed to be the main drivers of resource construction in the study area. Innovations such as anti-insect nets and the localised release of natural enemies (within enclosed plots) distance stakeholders from collective landscape management as they encourage the private management of individual plots within the landscape.

Public policies may eventually provoke a change in perception regarding the effect of landscape elements on natural enemies. This could potentially result from the promotion and adoption of biodiversity-focused agri-environment schemes or the withdrawal of some agro-chemicals, which might encourage greater reliance on natural enemies for pest control.

References

Barbier, J.-M., & Goulet, F. (2013). Moins de technique, plus de nature : pour une heuristique des pratiques d'écologisation de l'agriculture. Natures Sciences Sociétés, 21(2): 200-210.

Berthet, E. (2013, September 23). Contribution à une théorie de la conception des agro-écosystèmes : Fonds écologique et inconnu commun. Ecole Nationale Supérieure des Mines de Paris.

Bianchi, F.J.J.A., Booij, C.J.H., & Tscharntke, T. (2006). Sustainable pest regulation in agricultural landscapes: a review on landscape composition, biodiversity and natural pest control. Proceedings of the Royal Society B: Biological Sciences 273(1595): 1715-1727.

Binder, C.R., Hinkel, J., Bots, P.W.G., & Pahl-Wostl, C. (2013). Comparison of frameworks for analyzing social-ecological systems. Ecology and Society 18(4).

Chaplin-Kramer, R., O'Rourke, M.E., Blitzer, E.J., & Kremen, C. (2011). A meta-analysis of crop pest and natural enemy response to landscape complexity: pest and natural enemy response to landscape complexity. Ecology Letters 14(9): 922-932.

Cong, R.-G., Smith, H.G., Olsson, O., & Brady, M. (2014). Managing ecosystem services for agriculture: will landscape-scale management pay? Ecological Economics 99: 53-62. http://doi.org/10.1016/j.ecolecon.2014.01.007

Düspohl, M., Frank, S., & Doell, P. (2012). A review of Bayesian networks as a participatory modelling approach in support of sustainable environmental management. Journal of Sustainable Development 5(12): 1-18.

Duru, M., Therond, O., Martin, G., Martin-Clouaire, R., Magne, M.-A., Justes, E., … Sarthou, J.P. (2015). How to implement biodiversity-based agriculture to enhance ecosystem services: a review. Agronomy for Sustainable Development 35: 0. doi:10.1007/s13593-015-0306-1

Etienne, M. (2010). La Modélisation d'Accompagnement. Versailles: Quae.

Etienne, M., Du Toit, D.R., & Pollard, S. (2011). ARDI: a co-construction method for participatory modelling in natural resources management. Ecology and Society 16(1): 44.

Holling, C.S., & Meffe, G.K. (1996). Command and control and the pathology of natural ressource managment. Conservation Biology 10(2): 328-337.

Howard, L.O. (1929). *Aphelinus mali* and its travels. Annals of the Entomological Society of America, 22: 341-368.

Hulme, P.E. (2009). Trade, transport and trouble: managing invasive species pathways in an era of globalisation. Journal of Applied Ecology 46(1) : 10-18.

Kaufmann, J.-C. (2011). L'entretien compréhensif - L'enquête et ses méthodes (3rd Edition). Paris: Armand Colin.

Kebir, L. (2006). Ressource et développement régional, quels enjeux ? Revue d'Économie Régionale & Urbaine (5) : 701. http://doi.org/10.3917/reru.065.0701

Kelemen, E., Nguyen, G., Gomiero, T., Kovács, E., Choisis, J.-P., Choisis, N., … others. (2013). Farmers' perceptions of biodiversity: lessons from a discourse-based deliberative valuation study. Land Use Policy 35 : 318-328.

Labatut, J. (2009). Gérer des biens communs: processus de conception et régimes de coopération dans la gestion des ressources génétiques animales. École Nationale Supérieure des Mines de Paris.

Malause, J.-P., Giuge, L., & Fauvergue, X. (2003). Acclimation et dispertion en France de Neodryinus typhlocybae (Ashmead)(Hymenoptera, Drynidae) introduit pour lutter contre Metcalfa pruinosa (Say) (Hemiptera, Flatidae). Bulletin de la Société Entomologique de France 108(1) : 97-102.

Marchenay, P. (1993). Un insecte au statut incertain : l'abeille. Études Rurales 129(1): 117-128.

McLaughlin, A., & Mineau, P. (1995). The impact of agricultural practices on biodiversity. Agriculture, Ecosystems & Environment 55(3): 201-212.

McNiff, J. (2013). Action Research: Principles and Practice. Routledge.

Novak, J.D., & Cañas, A.J. (2006). The theory underlying concept maps and how to construct them. Florida Institute for Human and Machine Cognition. Technical Report IHMC CmapTools 2006-01.

Ostrom, E. (1990). Governing the commons: the evolution of institutions for collective action. Cambridge; New York: Cambridge University Press.

Ostrom, E. (2009). A general framework for analysing sustainability of socio-ecological systems. Science 325(5939) : 416-419. http://doi.org/10.1126/science.1170749

Raffestin, C., & Bresso, M. (1979). Travail, Espace, Pouvoir. L'Age d'Homme.

Rusch, A., Valantin-Morison, M., Sarthou, J.-P., & Roger-Estrade, J. (2010). Biological control of insect pests in agroecosystems: effects of crop management, farming systems, and semi-natural habitats at the landscape scale: a review. Advances in Agronomy 109: 219-248.

Schellhorn, N. A., Gagic, V., & Bommarco, R. (2015). Time will tell: resource continuity bolsters ecosystem services. Trends in Ecology & Evolution 30(9): 524-530.

Stallman, H.R. (2011). Ecosystem services in agriculture: Determining suitability for provision by collective management. Ecological Economics 71: 131-139.

Thies, C. (1999). Landscape structure and biological control in agroecosystems. Science, 285(5429): 893-895.

Tscharntke, T., Klein, A.M., Kruess, A., Steffan-Dewenter, I., & Thies, C. (2005). Landscape perspectives on agricultural intensification and biodiversity – ecosystem service management. Ecology Letters 8(8) : 857-874.

Lessons learned from the implementation of three different research postures within a participatory research framework

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Abstract: This paper analyses how the use of different research postures (participatory, ecocentric and technocentric approaches) in participatory research with organic farmers can lead to misunderstanding and legitimacy questioning, and therefore to tensions between the different actors involved (funding administrators, advisory services, farmers and researchers). This underlines the importance of clarifying the commitment of different partners involved in participatory research as early as possible in the research process to limit any misinterpretation, develop trust and enable collaboration. To ensure an effective process, including agreement of targets, it is recommended that funding should be made available to allow sufficient time for a staged approach with a diagnostic phase, including characterisation of the diversity of farming systems within a sector, followed by a participatory research phase to test innovative approaches to solve a shared problem. Finally, for a successful outcome, researchers must be equipped and trained in the implementation and facilitation of participatory research methodologies.

Keywords: Participatory research modes, innovation, development, tension, legitimacy

Introduction

To support the development of organic farming in Wallonia (Belgium), the Walloon Government commissioned the Walloon Agricultural Research Centre (CRA-W) to define and complete a global research programme dedicated to the organic sector. Up until this point, with the exception of a few short projects conducted by 2-3 researchers interested in the potential of this mode of production, the CRA-W had not developed expertise in this sector. To initiate the project, a working group was set up and a research programme proposed and validated by institution, administration and sector representatives. The programme included the three research postures proposed by Bawden (1997): (1) technocentric approaches aiming to investigate the effect of individual factors of production (e.g. bio product treatments, plant varieties, weeding techniques etc.); (2) ecocentric approaches focusing on the characterisation and performance of organic farming systems (the analysis of nutrient, biomass and cash fluxes/flows); and (3) holocentric approaches that aim to implement a participatory approach involving organic farmers, organic farmer representatives, researchers and advisers in the definition of research questions (Barnaud, 2013) and of possible solutions they are interested in exploring.

As defined by Hess (1989), participatory research can be defined as "*a collective process linking researchers and practitioners to solve a problem, (enabling access to) knowledge (that is) directly relevant to actors' practices".* Such an approach aims to encourage: (1) social and individual learning; (2) improved understanding of the issues from multiple perspectives, and therefore the selection of appropriate solutions; and (3) collaborative relationships (Blackstock et al., 2007). Involvement of practitioners in the definition and/or validation of potential solutions is also expected to improve transfer of research and innovation into practice, as underlined in the EIP (European Innovation Partnership), ‘bottom–up’ (as opposed to ‘top-down’) dynamic.

To develop and support this participatory research dynamic, groups of pilot farmers were set up under the responsibility of a ‘moderator’. This moderator was a researcher whose mission was, on the one hand, to manage and sustain the interactions between the farmers involved in the group (individual visits, group dynamic development, thematic meeting organisation and circulation of information between group members) and, on the other hand, to perform research to characterise farming systems, and to identify and test innovative practices. The researcher/moderator had to meet the expectations of: (1) their institution, testing this participatory research model as a prototype that could potentially be promoted in future research programmes; (2) the farmers within the group expecting rapid and reliable feedback; and (3) the administration and organic sector representatives charged with validating the research programme and providing annual funding. Researchers were therefore expected to perform the dual roles of moderator (for a diversity of farmer, advisory service and administration expectations) and researcher, mobilising a diversity of disciplines to employ a systemic participatory approach.

This situation gave rise to tensions between groups and individuals that were linked to multiple “misunderstanding” and legitimacy issues including: legitimacy of the researcher’s moderator role; the method used; the knowledge provided; and the research questions produced (Barnaud, 2013).

The main objective of this paper was to highlight how the adoption of contrasting research postures can, on the one hand mitigate, or on the other hand exacerbate, these tensions. Participatory research methods are presented, with analysis of the ways that different researchers involved in these methods have addressed these tensions. The characteristics of the results obtained and how they are perceived by sector representatives are also highlighted. This is a working paper that uses an ex-post approach to understand the challenges faced by different researchers during their interactions with farmer groups.

Initiation of the interactions

The initiative was launched in November 2013 with an invitation to tender in the agricultural press describing the project context and aims: to understand farm practices and farm system functioning through observation of soil/plant/animal interactions; to identify ‘brakes’ on production and their origin; and to test solutions in partnership with scientific institutions. Ninety applications were received and two members of the project team (Dalley et al., 2014), one junior and one senior scientist, visited the potential monitor farmers to discuss their farming system, their interest in joining the project and their main research questions (Stilmant et al., 2015). Over 40 organic farms, covering a wide diversity of systems, were invited to join the project, share their expertise and provide access to their farms; thereby forming a regional farm network (Dalley et al., 2014). The farms were allocated to three groups (dairy & meat, monogastric & crop, and fruit & vegetable). Each group was moderated by a researcher. An agreement was signed with each farmer. The farmers agreed to participate in 2 to 3 collective meetings each year, and to record and share farm performance indicators, while researchers agreed to provide confidentiality, anonymity and frequent feedback on their assessments. It was also made clear that this collaboration would follow a research rather than an advisory framework.

Different dynamics were initiated by the researchers in charge of the facilitation of each group, in line with: (1) the questions highlighted in farmer interviews and in independent focus groups with farmer unions, administration, advisory service and research teams (Stilmant et al., 2015); (2) the interest of the farmers involved; and (3) researcher expertise. Group discussions and interactions were also influenced to some extent by pressure from public administration and organic sector representative organisations.

Setting up participatory research

At project inception, working groups agreed the research approaches or postures to be used, the methods and frequency of communication between different groups (e.g. farmers and researchers) and the common actions to be carried out on each farm within the different sectors (dairy & meat, monogastric & crop, and fruit & vegetable). This initial process involved researchers acting as moderators and socio-anthropologists to facilitate and prepare the working group for participatory research at an early stage in exchanges between farmers and researchers.

Following discussions within the dairy & meat cluster, the researcher, who was a junior scientist qualified in livestock production, proposed to characterise feed and fodder use and to evaluate the diversity and autonomy of production systems. Farmers were then invited to join one of a number of topics (e.g. dairy cattle grazing management, heifer parasitism under grazing, performance of multi-species grassland swards and beef fattening). The process dynamic initiated with the farmers focused on characterising the performance of existing production systems and on regular exchanges with the farmers on these points.

In the monogastric & crop cluster, the researcher was a senior scientist with some experience in participatory research and in systemic approaches; although mostly in ruminant based systems. His involvement in the project began relatively late in the cropping season (in spring 2015), which limited opportunities to organise focus groups. Consequently, the researcher proposed to meet farmers individually during “field tours” to discuss and capture the main goals of their agricultural production system and the potential for a research partnership. Based on these initial interactions, the need to develop more sustainable crop rotations was identified and agreed; and, based on contacts with colleagues working on organic crops in France, on his own expertise on legumes and on a literature review, the researcher proposed to test innovative schemes using legume-rich cover crops. In proposing this innovation, the researcher also took into account: (1) limited opportunities to mobilise other research units within and outside CRA-W; and (2) the need to minimise, for the farmers, the invasive nature of the research intervention. In addition, to maintain the systems focus of the research, while also investigating the link between soil fertility maintenance and crop management (the main challenge underlined by farmers and advisory services), the performance of companion cropping (i.e. cereals and cereal/legume mixes grown together) was characterised. This was done at plot level, using a standardised methodology, on all the farms of the group. In addition, to maintain communication and provide feedback to farmers within the group, a newsletter was produced every month during the growing season, including seasonal information and field observations together with literature reviews on key issues highlighted by the farmers.

In the fruit & vegetables cluster, two researchers, senior scientists with considerable expertise in fruit production in low input and organic systems, followed the innovations set-up by the farmers, which were: (1) weed control management strategies and soil fertility maintenance using cover crops and mulch; and (2) agroforestry combining fruit trees and vegetable production. Technical questions, such as variety resistance to disease (leek rust) or disease treatment efficiency (for post-harvest fruit diseases), were addressed using field trials. In most cases, to provide meaningful and scientifically robust results, field experiments were set up at an experimental station and duplicated using a simpler field trial approach on a limited number of farms. External expertise was regularly mobilised to address some specific issues and themes (e.g. rodent control and the use of no-till in vegetable production systems).

Outcomes

The researcher in the dairy & meat cluster had some experience as a sales representative for a feed producer and his academic background was in livestock nutrition. Based on this experience, the researcher felt that he was justified in adopting an “advisory posture” in these areas. This position allowed him to have regular exchanges with the farmers in his group and to learn from them. He also engaged external expertise to answer farmers’ questions on specific topics. To support this advisory posture, the researcher collected samples (soil, grass, silage, etc.) and took various measurements (heifer weight, sward height etc.) to assess specific performance criteria (e.g. grazed grassland productivity and parasite pressure). On each farm, the quantity and quality of fodder crop production was assessed along with one additional topic. In these farm specific topic areas, the moderator used an ecocentric approach (i.e. to characterise the farming system qualitatively) that was not reliant on the capture and analysis of quantitative data. The farmers were not required to take numerous measurements, but were asked to record certain practices (e.g. grazing calendar, silage cutting dates etc.). Two farmer discussion group meetings were held at 12 and 18 months after project inception. To drive and stimulate interactions, the moderator used the farm data and other information gathered by farmers and the research team during the project to relate management practices to system performance (e.g. soil fertility analysis, grass feed value related to grazing management and overall economic analysis). Farmers found these discussions useful and appreciated the facilitation and guidance from the moderator; and the information provided in response to their specific needs (e.g. access to data on manure analysis, forage analysis, feeding rations, average daily weight gain measurements and grassland productivity). After two years of group interaction, some farmers asked to receive a more integrative analysis of their system so they could gain a better understanding of how management practices related to system performance; the group dynamic followed a diagnostic approach to identify aspects of the farming system that could be improved without providing or testing innovative solutions. However, the researcher, more at ease with an advisory role, felt that integration of the data to assess system performance as a whole was too ambitious and decided to leave the process. The transition from one moderator to another will be the next challenge for this farmer group.

In the monogastric & crop cluster, the moderator had less regular contact with each farmer, and focused on identifying questions through two to five ‘field tours’ per farm. ‘Field tour’ frequency depended on the specific motivations and feedback from each farmer. A common theme emerging from the farm visits was the need for sustainable crop rotations for fertility enhancement and weed/disease control and improved agricultural and economic performance; particularly in systems without manure. Therefore, with the aim of improving soil fertility and increasing biomass production and nitrogen fixation, the researcher proposed that legume-rich cover crops be established early, within the main cereal crop, during the last mechanical weeding. Initially, the farmers were skeptical, as some of them had already tried to implement this technique with varied degrees of success. Nevertheless, they accepted the challenge. This innovation was tested in a network of 10 field trials implemented on four farms located in the four main Walloon agricultural regions. Each trial included six legume-rich cover crops under-sown into cereal crops. The main aim of the field trials was to test the feasibility of this innovation under real farm conditions, to quantify its impact on the next crop, compared with cover crops sown after main crop harvest.

Unfortunately, cereal yield measurements had to be made during the busy harvest period, and this led to reduced interaction with the farmers and the development of some misunderstandings in relation to the aim of the field trials.

Based on these dynamics, at the end of 2015, the frequency and quality of exchanges with the different farmers of this group was unbalanced, with some farmers engaging with the project more than others. As a consequence, during farmer discussion group and project steering group meetings, at which project results were presented and discussed, numerous tensions emerged with some farmers as well as sector representatives and researchers from other research institutes expressing concerns. These tensions were linked to numerous misunderstandings and the questioning of moderator legitimacy within the context of the group.

In terms of misunderstandings:

(1) Some farmers questioned the need to adopt a participatory research posture rather than an advisory or services posture expected by the majority of farmers experiencing specific technical or economic issues and expecting an answer in the short term;

(2) The funding body, the Walloon administration, questioned the establishment of trials to validate innovative solutions instead of gathering efficient and validated practices currently adopted by farmers in other areas to define turnkey solutions that could be disseminated through various channels (farming press, discussion groups, online etc.) and/or encouraged by advisory services supporting numerous farmers converting from conventional to organic production.

In terms of legitimacy:

(1) The unsymmetrical nature of the interactions with the different farmers within the group and across the different years was questioned;

(2) The farmers' representatives considered the research institution to be focused on conventional (non-organic) production. As a consequence, they found it difficult to accept that such an institution could lead a research programme that included cooperation with organic farmers on innovations aiming to improve, in a systemic way, the performance of organic farming systems. Moreover, they questioned the legitimacy of the researchers to select the themes to investigate with farmers (i.e. cover crops in this case);

(3) Other research units and conventional advisory services, both organised around specific domains of expertise, questioned the legitimacy of carrying out systemic research that involved direct interaction with farmers. Indeed, it was considered that this direct interaction interfered with the work they were doing with farmers in specific competency domains, since the moderator had no recognised specific crop production expertise and was affiliated to a farming systems unit rather than a crop production unit. As a result, the project often met with resistance from these groups rather than collaboration.

In the fruit & vegetables cluster, researchers maintained a classical research posture based on the 'laboratory model' (Bawden, 1997), with the implementation of field trials to compare varieties, investigate techniques to control weeds, and test alternative bio products to control disease. These field experiments, set up in a replicated four block design, were formulated by comparing the experience, expertise and demands of the researchers and farmers. They were implemented with the most motivated farmers, on a limited number of farms. To reduce the risk of field trials failing to produce meaningful results, a duplicate was set up at an experimental station. In this cluster, the legitimacy of the researchers was not questioned to the same extent as in the monogastric & crop cluster, since:

(1) The researchers were working in their field of technical expertise, within the research unit dedicated to this domain and, for this reason, additional expertise from other research units was not needed (apart from laboratory analysis to characterise soil fertility);

(2) The researchers were working with a limited number of farms (five farms per researcher with half their time allocated to this project compared with more than 15 farms per researcher, working at full time, in the other groups). This allowed researchers to maintain regular individual contact with the different farmers.

However, it was challenging for these researchers to adopt a true participatory approach; the oligopolistic nature of the fruit and vegetable sectors in the Walloon area made it more difficult to set up group discussions and dynamics, as this was not within the strategic interest of (often) competing producers. Furthermore, the two senior researchers confirmed that they were not well equipped to use participatory approaches and felt uncomfortable in the role of moderator.

Discussion

More time committed to establishing a clear and detailed agreement at the outset could have resulted in a more productive and efficient research process. Within each cluster, even when an approach had been agreed between researchers and farmers, there was still a degree of uncertainty around farmers' expectations and personal investment in the process, on the one hand, and around the actions plans associated with the different research approaches (technocentric, ecocentric and holocentric), on the other hand. A deeper and more precise description in the agreement of the level of commitment required from farmers and the overall research process could have resulted in a greater level of trust and collaboration. Indeed, as underlined by Restrepo et al. (2014*), "the first difficulty (in participatory research) is to create a joint definition of a problem, where researchers and practitioners together decide upon the need to organise the process, and how to ensure that a project's goals, tasks and activities do not depart from a common reference point".*

The level of innovation that could be explored varied widely between clusters and this appeared to be related to the research method or posture adopted by the moderator (Table1). Indeed, the moderator (in the dairy & meat cluster), by adopting an advisor posture, was able to improve farmer skills while mobilising existing knowledge without exploring innovative approaches that could have been proposed by the farmers. The advisor/moderator therefore retained a top-down knowledge transfer dynamic. By contrast, within a moderator/researcher mode (closely aligned with a holocentric approach), innovations can come from literature or from any part of the value chain. A systemic/integrative approach strongly involving the farmers could have had a clear added value. Nevertheless, in some chains, with a limited number of actors and a limited market, the oligopolistic position of some actors may limit knowledge transfer and information exchange/sharing. These limitations were more associated with the nature of the market than any technical limitations of the approach. By integrating expertise in system and participatory research, the moderator/researcher mode questions farmer practices and allows participants to explore innovative practices and how they impact the entire farming system.

The main tensions underlined in the implementation of these dynamics, whatever the group, can be connected to the two main (and partly conflicting) objectives agreed when the farm networks were established:

(1) To characterise organic farming systems under a diversity of soil and climate conditions, production types and management strategies;

(2) To implement a participatory research approach to identify problems recognised by the sector and to explore potential and innovative solutions.

The first objective led to the establishment of a large number of diverse groups while the second objective required the mobilisation of farmers sharing similar questions in a limited sector to promote interest and exchanges within the farmer groups and with the moderator.

In such a context of farming system diversity, the advisor posture allows (as a first step) identification (in a superficial way) of the diversity of questions posed by the farmers, with the satisfaction of the different farmers involved in the dynamic. Nevertheless, this posture does not allow sufficient time or resource for the group to explore innovative solutions that could resolve a variety of specific issues. The group can only remain in a relatively superficial diagnostic phase.

Table 1. The link between the research posture of the animator and the potential for innovation exploration and farmer involvement in a participatory research dynamic.

	Research posture of the animator of the group		
	Advisor (moderator)[1]	Advisor / Researcher[2]	Moderator / Researcher[3]
Example	Dairy & meat group	Fruit/vegetable group	Monogastric/crop group
Farming system diversity characterised	+	+/-	+
Farmers' questions identified	+/-	+	++
Potentialities for innovation explored	+/-	+	++

Farmer motivations - temporality	+ in a first step +/- thereafter with farmers demanding a systemic approach	+ for the farmers sharing a common issue	+/- in a first step (objectives are fuzzy) ++ thereafter for the farmers with a common issue

[1] Closest to an ecocentric approach; [2] Closest to a technocentric approach; [3] Closest to a holocentric approach.

By contrast, in a participatory research dynamic, the researcher/moderator aims to highlight questions shared by the different farmers within their group to initiate a collective dynamic around trials exploring innovative solutions to address the identified challenges. Nevertheless, due to the diversity of these groups, the legitimacy of the choice of the questions, and of the associated innovations explored, is questioned by some farmers of the group and by the organic sector. Moreover, due to the significant investment in time associated with participatory research and the limited time and financial resources available, researchers were unable to fully invest in characterising the diversity of farming systems. The size of the groups and the diversity of the objectives limited the level of research investment in each farm and on each of the research objectives, leading to frustrations and, therefore, tensions for both farmers and researchers. As noted by Restrepo et al. (2014), trust building is a key element for collaborative success in the learning and research process. It is the result of a well-structured process where actors have sufficient time to integrate their knowledge, gain a common understanding of the problem and contribute to the definition of goals, tasks and activities (Restrepo et al., 2014).

Under the conditions encountered in some research projects where: (1) the demand is research driven; (2) the role of each stakeholder in the process is not clear or explicit enough; and (3) the target of the research is too broad and the role of the researcher is too ambitious without mobilising all the necessary expertise; tensions can be exacerbated and the risk of researcher divestment is high. This can lead to departure of key staff and result in a loss of momentum in the interaction until newly recruited staff can be fully integrated into the project (Dalley et al., 2014).

In legitimacy terms, different issues were pointed out by different stakeholder groups that related to their particular perception and expectations of the research process. For example, even if the Walloon administration supported a participatory approach, they associated the process more with a development objective than with a research objective. They therefore expected results in the short term, in contrast to the delays necessary to develop a participatory research dynamic; questioning in this way, ex-post, the legitimacy of the dynamic initiated by some of the groups. In line with administration perception, the legitimacy of participatory research was also questioned by the scientific community, who often linked this practice to an over-complicated development process (Barnaud, 2013). Moreover, ongoing interactions also highlighted the questioning of the legitimacy of a generalist researcher working in a diversity of interconnected research fields in which he shares some expertise, even under a collaborative arrangement with specialised teams. Finally, due to the perceived association of participatory research with sector development, the legitimacy of the dynamic was also questioned by the group in charge of the development of the organic sector. It was thus challenging to develop a good level of trust between the actors involved in the participatory research interactions, leading to the exacerbation of any tensions.

Conclusions

The contrasting objectives assigned to this project made it challenging to complete the first task in any collaborative learning dynamic; that is to create a joint definition of a problem, where researchers and practitioners together agree how the research process will be carried out (Restrepo et al. 2014). This first step in the research process provides an opportunity, for each researcher, to adopt a research posture that is most in line with their expertise, ranging from an advisor to a moderator/researcher posture. These differences in research posture or approach lead to a diversity of results in terms of characterising farming system performance, innovation exploration and actor interaction. This underlines the need for the formulation of clear objectives and processes and recognised expertise to equip and sustain the involvement of researchers and practitioners in participatory research. A participatory approach can be useful when the process is effectively facilitated, with research questions identified that address shared issues (i.e. research is demand driven) and clear trust is developed between the actors involved.

In retrospect, it may have been more effective to address partly conflicting objectives in sequence with a first phase of one to two years to characterise the diversity of farming systems in terms of structure, management and performance. This diagnostic period, with regular communication, knowledge exchange and feedback with participating farmers, would have allowed a good level of trust to build between the actors and to clarify their roles. It would also have allowed the researcher to acquire the necessary skills to start a participatory dynamic with a limited number of actors sharing a common problematic as part of a second phase. Nevertheless, this sequential approach would not have been possible within the temporal constraints of the project specification.

References

Barnaud, C. (2013). La participation, une légitimité en question. Natures Sciences Sociétés 21: 24-34.

Bawden, R. (1997). Learning to persist: a systemic view of development. In F.A. Stowell, R.L. Ison, R. Armson, J. Holloway, S. Jackson and S. McRobb: Systems for Sustainability pp 1-5. Plenum Press.

Blackstock, K.L., Kelly, G.J., & Horsey, B.L. (2007). Developing and applying a framework to evaluate participatory research for sustainability. Ecological Economics 60: 726-742.

Dalley, D., Pinxterhuis, J.B., Hunter, M., Geddes, T., & Tarbotton, I. (2014). A co-development approach to investigating wintering options on dairy farms in southern New Zealand. http://ifsa.boku.ac.at/cms/fileadmin/Proceeding2014/WS_1_7_Dalley.pdf

Hess, R. (1989). Recherche-action et formation. Pratiques de Formation 18: 15p.

Restrepo, M.J., Lelea, M.A., Christinck, A., Hülsebusch, C., & Kaufmann, B. (2014). Collaborative learning for self-driven change in complex situations. http://ifsa.boku.ac.at/cms/fileadmin/Proceeding2014/WS_1_7_Restrepo.pdf

Stilmant, D., Vanwindekens, F., Decruyenaere, V., Vankeerberghen, A., Abras, M., Farinelle, A., Moerman, M., Lefevre, A., Froidmont, E., & Van Damme, J. (2005). Contribution to the definition of an overall research programme for organic farming in Wallonia: identification of priorities for the 2015-2020 period. Rencontres Recherches Ruminants 22: 337-340.