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Participatory research approaches to integrating scientific and farmer knowledge of soil to meet multiple objectives in the English East Midlands

SI: Soil information sharing and knowledge building for sustainable soil use and management: problems and prospects for the 21st century

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Running head: Exploring participatory research approaches

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Summary

Soil management influences food production, economic performance of farm businesses, and a range of public benefits such as water quality, flood control and aquatic and terrestrial biodiversity. The aim of this paper is to explore the role of participatory research in combining scientific and farmer knowledge of soils to meet these multiple objectives. We use five separate research studies involving communication, consultation and co-production, carried out in the English East Midlands between 2014 and 2018. We compare the participatory processes for knowledge exchange and their material outcomes and assess them retrospectively against specified criteria for successful application of participatory research. We conclude that, depending on context and scalar fit, multiple approaches to participatory research can be complementary, strengthen engagement and build trust within a farming community, resulting in a greater shared understanding of how to address the soil management objectives of farmers and wider society.

Keywords: soil management, soil quality, knowledge exchange, participatory research

Introduction

Soil conservation and management is an increasing focus for agri-environment policy internationally because of the implications for both crop production on farm and numerous public goods and services beyond the farm boundary (OECD, 2015). Objectives for improving soils are stated specifically in the UK government's 25-year Environment Plan (Defra, 2018a) and reduction of soil erosion and flood risk associated with sedimentation of

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drainage channels is of growing public concern and policy relevance following increasing prevalence of intense storm events (see also Tulau et al., this issue). Targets for water quality set by the EU Water Framework Directive are largely influenced by agricultural runoff.

There is increasing concern about soil erosion associated with compacted clay soils in upper catchments, with negative impacts both on crop production and on water quality (Stoate et al., 2017). Deteriorating field drainage systems on clay soils contribute to elevated surface runoff and erosion (Deasy et al., 2010). Phosphorus adsorbed to sediment particles contributes to eutrophication of fresh and coastal waters (Ulén et al., 2007). Within the field, compaction reduces crop rooting capacity and nutrient uptake and is thought to be a likely cause of the failure to increase crop yields for more than a decade (Knight et al., 2012). These soil conditions are also associated with increasing competition from the grass weed, black-grass (*Alopecurus myosuroides*) which suppresses crop yields across most of the UK (Moss et al., 2007). The need to control this weed has largely driven recent changes in crop rotation, including more diverse cropping and the introduction of grass leys.

Developing new methods of soil management to meet these multiple objectives requires the integration of scientific and farmer knowledges in a participatory approach. The aim of this paper is therefore to explore the role of participatory research in combining scientific and farmer knowledge of soils to meet these multiple objectives of farmers and wider society. We first provide contextual background to the participatory research approach

before describing the geographical context to the study area, an agricultural region of the United Kingdom. We then use five separate case studies of research carried out between 2014 and 2018. We compare the participatory processes for knowledge exchange and their material outcomes, and assess them retrospectively against criteria from Reed et al. (2017), specifically their 'Wheel of participation' approach, for successful application of participatory research. In doing this, we are drawing on the experience of independent research projects, each with different research objectives and approaches, but carried out in the same area.

Participatory research involving scientists and farmers

Participatory research to improve farm productivity or reduce environmental externalities of farming has been widely adopted for more than half a century in many parts of the world (e.g. Chambers, 1997) but has been applied to European farming systems only more recently (de Vente et al., 2016). In the 1980s, rural people were increasingly involved through more interactive methods, together comprising an approach known as 'Participatory Rural Appraisal' (Chambers, 1997). This involvement facilitated the widespread adoption of 'Participatory Research', or 'Participatory Action Research', in which researchers enabled farmers to set the research agenda, often carrying out research to meet farmer-defined objectives on their own farms.

Such a research approach recognises the differences in knowledge cultures between researchers and farmers, and specifically the focus of the former on 'bits of knowledge' and the latter on much broader agro-ecological and socio-political issues (Fairhead & Leach, 1994). For example, Sikana (1994) illustrated how researchers characterised Zambian soils according to consistently reliable physical and chemical properties of the subsoil, whereas farmers used dynamic characteristics associated with workability of the topsoil and constraints on nutrient uptake by crops. In Europe, Tsouvalis et al. (2000) argued that farmers emphasise the knowledge gained through experience of farming and value researchers or technology developers who work with farmers. However, farmers also draw boundaries between themselves and other (research, policy, public) groups and often feel threatened by them (Morris 2006 and Ingram et al. 2010). The longstanding existence of organisations which represent farmers and lobby government on their behalf has helped produce a different farmer-researcher power dynamic in European contexts (Smith, 1993).

Other authors have drawn attention to the complex relationships within and between participant groups. For example, Van de Ploeg et al. (2009) attribute the survival of family farms in France and the Netherlands to the diversity of styles of farming and pluriactivity (Fuller, 1990), also demonstrating the need for flexibility in terms of systems boundaries. Although Vanclay et al. (2006, p.79) question the value of a farming styles approach, they argue that "a general understanding of the existence of diversity, some understanding about how farm decisions are made and an awareness of the social legitimacy of different styles and their internal rationales" remains important. Likewise, Fish et al. (2003) identify a range of styles of practice in relation to farmers' participation in UK agri-environment

schemes and highlight the tension between the need to identify commonalities between farm(er) typologies, and to identify different styles of practice, which may differ with landscape feature, parts of the farm or type of agri-environment scheme. A similar argument can be applied to the research community, with approaches adopted by individuals being influenced by career pathways, institutional attitudes to interdisciplinarity, and constraints imposed by contracts for research projects by funders (Leland et al., 2011).

The approach taken to participatory research is likely to influence the nature and level of engagement, especially where a range of styles is represented within the farming and research communities. Arnstein (1969) described a 'Ladder of Participation' as a metaphor for increasing stakeholder engagement and ownership associated with a move from top-down (state or researcher led) to bottom-up (citizen led) involvement. Objectives concerned with wider environmental impacts also require the inclusion of multiple 'publics' beyond the farming community (Chilvers, 2009; Tsouvalis & Waterton, 2012). Keen et al. (2005) have argued that some citizens prefer to stay on the lower rungs of informing and consulting while Cook et al. (2013) have questioned whether the higher rungs lead to power-sharing by citizens. Reed et al. (2017) suggest that the choice of participatory method needs to take account of the situation, making some approaches more suitable in certain situations, and suggest a 'Wheel of Participation' as an alternative metaphor that accommodates the complexities described above.

Adopting the Wheel of Participation approach, Reed et al. (2017) describe four criteria that explain beneficial outcomes of participatory research. These comprise 'Context' (challenging or conducive), 'Design' (hierarchical and closed or systematic, transparent and structured), 'Power' (power dynamic unmanaged or managed), and 'Scalar fit' (late and poorly matched or early and well matched to spatial and temporal scale).

Methods

Geographical background

Given the context of the multiple considerations outlined above, we use five research projects to explore knowledge exchange between researchers and farmers and assess the various participatory approaches adopted against the criteria of Reed et al. (2017). The research is focused on farmer and scientific knowledge of soil with a wider public interest element running through it.

The common link between the projects is the Game & Wildlife Conservation Trust's Allerton Project, a 333 ha research and demonstration farm in the headwaters of the Welland river basin in the English East Midlands. The Allerton Project receives more than three thousand agricultural visitors on scheduled group visits each year. As well as experimental plot scale research, a landscape scale (3,000 ha) BACI (Before-After-Control-Impact) experiment, 'Water Friendly Farming', explores the relationship between land use and aquatic issues (Biggs et al., 2016). The combination of research, farm business and interaction with the

farming community provides an opportunity for knowledge exchange between researchers and farmers, and for participatory research.

The East Midlands is a predominantly rural region, in which agriculture is a major land use, and has a wide range of soil types from clays to lime-rich loam. Arable crops predominate, mainly comprising wheat (53%), oilseed rape (22%), barley (17%), vegetables (4%) and sugar beet (3%) (Defra, 2018b). Livestock systems are mainly sheep and cattle at a ratio of about 2.5 to 1.

Levy funded (Agriculture and Horticulture Development Board) benchmarking and discussion groups provide an opportunity for peer-to-peer learning amongst farmers. An 'Arable Business Group', hosted by the Allerton Project in the Upper Welland has carried out economic benchmarking of member businesses since 2014 and identified deteriorating soil conditions as a major factor limiting crop production and profitability. The group identified a lack of knowledge about soil organic matter levels on their own farms. Subsequently researchers surveyed the organic matter concentrations in soils across members' farms to build a shared understanding of this issue. This activity reflects the wider interest in this issue (Ingram et al., 2016) and is an illustration of the potential benefits of improved participatory soil assessment and subsequent management to both the environment and farm businesses. Assessing soil organic matter across farms creates an opportunity to combine the practical knowledge of farmers with the scientific knowledge of researchers to meet multiple objectives (Glenk et al., 2017).

We provide five more substantive examples of research that employs a participatory approach. The five projects were carried out in the same region in the period 2014 – 2018 but with different objectives, and involving different approaches to participatory research, thereby providing an opportunity for retrospective analysis.

Combining farmer and researcher knowledge within five soil projects in the East Midlands

While the five projects described here have the common purpose of combining farmer and researcher knowledge, each project has different objectives, and the approaches and methods used therefore vary (Table 1). The first project investigates the relationship between farmer and researcher approaches to characterising soils, while the second proposes a method to enable farmers to use science to benchmark their soil properties against others. The third project enables farmers to evaluate an existing soil management experiment from a farming perspective. The fourth project draws on the knowledge and values of both farmer and wider stakeholder communities to prioritise future research to meet objectives for both on-farm production and landscape scale environmental improvement. The fifth project brings together farmer and researcher communities to consider the implications of soil management practices and approaches for catchment scale water quality. These projects are described below and then the extent to which each of them meets the criteria of Reed et al. (2017) for successful knowledge exchange is considered in the discussion.

Project 1. Farmers' characterisation of soil quality

This research takes a transdisciplinary approach to the study of soil quality using methods from both social and soil science disciplines through the following three stage methodology:

1. Semi-structured interviews and participatory exercises with farmers to reveal the multiple dimensions which form and influence the relationship farmers have with their soil.
2. Soil quality analysis using a range of physical, chemical and biological indicators on areas of soil that farmers themselves have identified as “good” and “bad”.
3. A second interview with the farmers, discussing the results from the soil quality analysis, to see how they react to and make sense of the scientific assessments.

The aim was to gain insights into how farmers understand soil quality in general and on their own farms, how they react to soil science data analysis on their land, and the implications for soil management. The research approach takes account of a.) respect for farmer understanding of soils and the complexity of these understandings, b.) engagement with farmers to examine their soil knowledges vis-à-vis knowledge based on soil science techniques, and c) building from these knowledge encounters to consider how farmer and soil science understandings and practices might become more aligned.

A key element of stage one was investigating what farmers' understanding of soil quality is and what they regard as a “good” and a “bad” soil. This understanding was first explored using participatory graffiti wall exercises (Hanington, 2003) during two farmer workshops which took place at the GWCT's Allerton Project. Two flipcharts were displayed, one titled

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“Good Soil” the other “Bad Soil”. Attendees were given post-it notes on which to write their thoughts on what made a “good” or a “bad” soil. These words were chosen by researchers because they were simple to understand and sufficiently broad to allow the farmers to respond in their own terms, including discussion of the chosen titles themselves. The concepts of “good” and “bad” soil were further investigated during 20 semi-structured interviews with those farmers participating in all three stages of the research.

Comparison of the results from these two methods indicated how the context in which they are employed can potentially affect farmers’ responses when talking about “good” and “bad” soil. The responses from the graffiti walls, where the context encouraged farmers to consider *a soil* in an abstract sense, were largely dominated by what the scientific literature on the soil quality would term *dynamic* soil quality indicators, aspects which change over time as a result of land use or management (Wienhold et al., 2004). The most prominent property reported by the participating farmers related to soil physical structure and organic matter levels. However, in the interviews, where the farmers had been speaking at length about their own farm and were asked about *their* “good” and “bad” soil, while they might still mention dynamic indicators, the farmers were more likely to discuss what is referred to in soil quality literature as the *inherent* characteristics of their soil. These relate to characteristics which do not change in the short term as a result of land use or management (Wienhold et al., 2004). In particular the farmers referred to differences in soil texture as determining their own “good” and “bad” soil.

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These judgments are subject to several complexities that can make identifying a “good” or a “bad” soil a challenge. As the participating farmers explained, in wet years, faster draining “lighter” soils might be “good” because they allow the water to drain away and prevent waterlogging. However, the same soil in a dry period will become “bad” because it will not retain the water, causing crops to suffer from drought.

Added to this is the complication of how easy it is to work a soil versus what yield the area later supports. Farmers often spoke of how their better soils were the ones that were “easier to work” and required less work to establish a seedbed. Yet these “good soils” at the time of working are again the lighter-textured ones, which have a smaller water holding capacity and so will provide less water to crops when they have to rely on stored water. By contrast, areas described by one farmer as soils “that we battle with to actually get a seedbed or break down” were regarded more positively beyond this stage: “If we can establish a crop there, the crop tends to be quite good because it’s quite a heavy soil that produces a decent crop in an average or a dry year”. A further complexity that the farmers struggled with was trying to reconcile their practice-based views with how soil had been categorised within the Agricultural Land Classification (Natural England, 2012). Such classifications are complicated by the fact that what might be rated as better quality land due to inherent characteristics can then be managed poorly by the farmer – “You can treat good land badly”. Such complexities make any discussion about terms such as soil quality or even “good” and “bad” soil a challenge and this needs careful consideration when working with farmers.

Project 2. Benchmarking soil properties across farms

This project is based on an Australian web-based platform (www.soilquality.org.au), which enables farmers to compare soil physical, chemical and biological properties for their own land with those of other farms in the same region, or farms of the same type elsewhere. While not farmer-led, the Australian initiative has more than 3,000 farmers participating.

The proposal for the UK (www.soilquality.org.uk) is to replicate this system, ultimately as a focus for discussion between farmers and researchers about optimising soil function. The project involves collection of soil samples from a 5-metre radius sample site to enable the same site to be identified using GPS and resampled in subsequent years. Participating farmers decide whether this sample unit is repeated for different management practices or conditions within fields, or whether one sample is collected per field, but the specific sample collection process is defined by the researchers. A Visual Evaluation of Soil Structure score (Ball et al., 2007) is recorded at the time of sampling as an assessment of soil structure. Samples are sent to a laboratory for analysis of organic matter, pH, P and K. Data collected in the field are uploaded to the project portal by the participating farmer and the laboratory uploaded analytical data.

The concept was discussed with the Welland Arable Business Group and with another local farmer group to encourage participation. There was some concern that the sampling method was too restricted to be representative of a field, and therefore that the process may not be meaningful in terms of practical application. In the absence of an existing web-

based platform to demonstrate the system, farmers also struggled to understand how the initiative might be relevant to their businesses. However, farmers agreed to have samples taken from their fields and sent for laboratory analysis. The approach taken has therefore been to collect a set of data with which to populate the website and then discuss this further with the farmer groups who are invited to suggest improvements to the system. Some of the farmers who participated in the comparison of farmer and researcher characterisation of soil properties (Project 1) also expressed an interest in contributing to the development of the benchmarking project. The openness of the Project 1 graffiti wall exercise therefore stimulated interest in the initial more research science-oriented phase of Project 2.

Project 3. Farmer feedback on cover crop research

As part of a UK government initiative, the ‘Sustainable Intensification research Platform’ (SIP), two replicated plot experiments investigated the potential of different cover crop species to deliver multiple benefits through improved soil function. Cover crops are sown immediately after the harvest of a previous cash crop and provide a continuous green cover, thereby reducing surface runoff and erosion. In accordance with the requirements of the funder, research to be carried out was specified in the contract prior to the involvement of local farmers, and farmer participation was limited to sharing and discussing research results and inviting feedback to guide the development of plans for further research.

In 2015/16 three cover crop mixtures were tested against a control bare stubble, replicated across three fields (Crotty & Stoate, 2017), and in 2016/17 these cover crops species were tested as single species plots. There were consistent results in both years. Most notably, radish was associated with weed suppression and greater numbers of epigeic (surface dwelling) earthworms. Spring-sown cash crop yields were enhanced and weed cover was reduced following radish cover crops.

Farmers attending events on the farm were shown the cover crop experiments, which were then used as a focus for discussion about the results to date, and practical application on other farms. Farmers were asked three broad questions to stimulate feedback: are cover crops a good thing in principle, are they applicable to your own farming system, and how might they be improved?

It was generally agreed that cover crops had potential benefits, and some farmers were already using cover crops in some form. One farmer used oats for 'stabilising soils' and grazed this off with livestock. Another used a cover crop to improve water infiltration before irrigated lettuce. However, several concerns were voiced: Do we know enough about disease risk for following cash crops? Cover crops can leave the soil too wet for spring drilling. Seed costs are high – can home saved seed be mixed with bought seed? Some cover crops such as vetch have poor establishment. Cover crop establishment can be poor on some soils and in some conditions. What about spring sowing of cover crops as part of the rotation? Which cover crops can be grazed by sheep or lambs? We need to develop

opportunities for allelopathy. This feedback helped to inform discussions about future research, and development of a funding proposal for research that would have practical value to the farming community. However, the implication of this exercise is that farmer engagement at an early stage in research design is more likely to result in practical beneficial impacts.

Project 4. Research prioritisation involving farmers

Each of the previous projects highlights the need for further participatory research that involves farmers so that soil management practices will improve soil properties to meet farmer objectives. SoilCare is an EU Horizon 2020 funded project in which the Allerton Project is one of sixteen research and demonstration farms across Europe. The aim of the project is to conduct research at each of the sites into arable soil management practices that deliver both economic and environmental benefits. What soil management practices should be investigated at each of the study sites was not initially specified. A central part of the participatory approach was that local farmers and other stakeholders (water company, statutory agency, farmer organisations, advisors and environmental NGOs) in each of the study areas should set the research agenda for the project by prioritising the management practices that they felt were most appropriate for each area.

The first stage was to hold a meeting with stakeholders to discuss the broad issues, both positive and negative, associated with soil management. A problem tree was used to identify problems, their causes, and possible approaches to address them. There was then a

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discussion of potential soil management practices that might be adopted to address these problems. A list of soil management practices was drawn up as potential topics for research. Stakeholder analysis (Reed et al., 2009) was used by a subset of the initial farmer and broader interest participants to identify stakeholders with relevant interest and influence for further involvement in the project.

The second stage involved two identical workshops, one based on the Welland Resource Protection Group (farming organisations and the wider stakeholder community with an interest in landscape scale societal outcomes), and one linked to the Welland Arable Business Group (farmers with an interest in on-farm production and profitability). The reason for the two parallel groups was to ensure a balance between agri-environmental and agricultural economic interests and to manage power relations by avoiding misunderstandings associated with language and potential tension between regulators and farmers. Information was summarised on flip charts for each soil management practice and these provided a focus for discussion within small groups. A matrix was then drawn up listing the most relevant criteria for selection against six soil management practices.

Participants were each given ten sticky dots to allocate to the management practices against the selected criteria.

The scores from the Resource Protection Group and Arable Business Group workshops were broadly similar and were combined to give an overall score for each soil management practice. This resulted in five management practices with similar scores, but enabled one

with a lower score to be dropped from further consideration. Of these five, two management practices (direct drilling and cover crops) were not considered further as they were already the subject of active research in the Allerton Project. Two management practices (compaction alleviation and grass leys) were taken forward, each with an innovative theme, as the topics for research within the SoilCare project. The remaining management practice (application of soil amendments) was considered as a theme for further research. The process adopted in this project therefore ensured that the research that was subsequently adopted was relevant, both to farmers with primarily economic interests, and to stakeholders with broader interests in public goods and services associated with catchment management.

Project 5. Exploring links between herbicide use, soil management and water quality

Propyzamide is the main herbicide used to control black-grass in the oilseed rape phase of an arable rotation but regularly exceeds the 0.1µg/L pesticide concentration limit for drinking water supply in Europe. The herbicide is difficult for water companies to remove from water and its future use may consequently be severely restricted or stopped by law, constraining the ability of farmers to control black-grass. Propyzamide needs to be applied when soil moisture and therefore runoff risk are high and moves from arable land to water mainly adsorbed to soil particles. Managing soil to reduce erosion also reduces the movement of propyzamide to water.

Propyzamide therefore provides a focus for considering improved soil management to meet both farmer objectives for crop management and wider societal objectives for water quality.

Several management practices were considered for application to one of the two treatment catchments in the 3,000 ha Water Friendly Farming project (Stoate et al., 2017). These included riparian grass buffer strips, reducing the area of oilseed rape (and therefore the amount of Propyzamide applied), using hybrid barley with a highly vigorous growth habit as an additional stage in the rotation, temporal splitting of Propyzamide applications, adoption of direct drilling, monitoring soil compaction to guide remediation, and monitoring soil moisture to guide herbicide application, and soil management such as sub-soiling to improve infiltration.

Modelling data from previous years of the Water Friendly Farming project suggested that the oilseed rape area would need to be reduced to 2-5% of the catchment area to maintain a Propyzamide concentration below the statutory 0.1µg/L limit. Although in some years the proportion of land under oilseed rape was at this level, in others it occupied up to a third of the land area. Splitting the application reduced Propyzamide concentrations in some years, but increased the concentration in one year, when rainfall occurred shortly after application.

A workshop was held involving two facilitators and three catchment farmers. A representative from Dow Chemical Company, manufacturer of propyzamide, was present to answer technical questions about the use of the product. The aim of the workshop was to

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explore farmer engagement with the challenges of managing their land collaboratively, under conditions of constrained Propyzamide limits. The full discussion was recorded and later transcribed. Qualitative, textual data from the workshop transcript were analysed through an inductive approach, involving manual coding of the text and identification of commonly occurring themes as these emerged across the participants. Analysis of those parts of the text related to joint working was informed by a study of collaborative initiatives in agriculture (Morris & Jarratt, 2016) conducted within the UK government's Department for the Environment, Food and Rural Affairs (Defra) Sustainable Intensification research platform.

Farmers regarded soil moisture data as being potentially useful to them. Similarly, soil compaction maps were regarded as being helpful and one farmer already adopted a simple approach to assess compaction on his farm. Buffer strips were regarded as being standard practice. Splitting Propyzamide applications was felt not to be effective because of the long gap required between the two applications.

Without an authority defining where oilseed rape could be grown at the catchment scale, the farmers did not think restricting the area would be viable. Farmers would be unlikely to volunteer not to grow the crop without significant financial recompense. Hybrid barley helped with black-grass control and allowed earlier establishment of a following oilseed rape crop, improving Propyzamide efficacy.

Farmers thought that the main barrier to adoption of a full no-till system is the lengthy transition period, where there can be a significant drop in crop yield. This may be a significant barrier to adoption, especially on farms with short tenure arrangements. Farmers were concerned that there is no government advice about how to proceed with conversion and drew the contrast between good soil husbandry, and the life of a government and regretted that this prevents governments from taking a long-term view. The results of the project, including the output from the farmer discussions, were reported to Defra to provide a potential influence on future agri-environmental policy. Following this exercise, local soil moisture data have been shared with participating farmers to explore the potential value of this resource to meet multiple objectives, and one of the farmers has participated in an extension to Project 2.

Discussion

In this section we analyse the five projects against the criteria identified by Reed et al. (2017), which make different types of engagement more likely to lead to beneficial environmental or social outcomes and present the results of this analysis in Table 2. Criteria for each project are scored on a scale, with a score of 1 (the criteria were not met) to a score of 5 (the criteria were fully met). Scoring was a subjective process but usefully enables differentiation of the research projects in relation to each of the criteria in Reed et al. (2017).

In the case of the SoilCare project (Project 4), the process of identifying research priorities included stakeholder analysis (Reed et al., 2009) to ensure equitable representation of both interest and influence across a range of different stakeholders, a robust and repeatable structured process for prioritising future research, and a strategy for managing power relations between stakeholders. Stakeholders with personal interest in societal issues (such as non-local public) were not present, but were represented in by professionals with influence on the development or implementation of agri-environmental policy designed to modify soil management by farmers and deliver public benefits. While this process identified two areas of research that were already being practiced, it also identified new areas for research, shifting decision making power towards farmers and stakeholders concerned with societal benefits of soil management, and ensuring practical relevance and impact.

A structured process was also adopted for the Water Friendly Farming Propyzamide study (Project 5), although there were important differences. In the SoilCare project (Project 4), participants were largely self-selected and decision-making power was given to the Allerton Project, which conducted research on its research farm. However, in the case of the Water Friendly Farming project (Project 5), farmers involved were those farming within the hydrological boundary. The decision-making power for changes to soil management on their own farms rested entirely with them. Farmers are often high on the power scale due to property rights as owners of land and with a clear interest as productive users of soil, but in Project 5, participants highlighted externally-driven, short-term economic and tenure constraints on long-term planning of soil management.

Other projects were associated with a greater range of scores for the different criteria. For the cover crops experiment (Project 3), relatively low scores resulted from the fact that farmers visiting the project were not necessarily those with long-term engagement with the Allerton Project. They were invited to provide feedback but had little direct influence on future activity, and although each visiting group was asked the same questions, there was otherwise limited structure to the facilitation process. Benchmarking soil properties (Project 2) involved the application of a proven Australian procedure to the UK, but without adaptation, and farmers questioned the small scale and practical relevance of the sampling, in part because they had not been adequately informed of the temporal nature of proposed subsequent monitoring. The soil characterisation study (Project 1) set out to explore farmer understandings of soil through open language rather than using highly technical scientific soil assessments at the start. A PhD project such as this is of limited duration but can build into longer-term research, and as Kesby et al. (2005, p.145) recognise, “the road to ‘doing research differently’ has to begin somewhere”. Farmers involved with this project, and with others described here, expressed interest in continuing engagement with related initiatives. In these cases, the participation can be regarded as an active engagement process in which farmers are recruited to the network associated with the Allerton Project.

While some of the projects described in this paper involve communication and consultation rather than co-production, because the Allerton Project has been active within the farming community for more than a decade, these projects can be considered as a means of building trust and adapting language and research design to participants. This can take place independently, but more significantly as part of an integrated and ongoing process of

interaction between Allerton Project researchers, local farmers and wider stakeholders.

More immediately, projects involving co-production have, in the case of SoilCare (Project 4) enabled farmers and stakeholders with interest in societal benefits of soil management to prioritise research topics to meet business and environmental objectives, and in the Propyzamide study (Project 5), enabled farmers to explore options for catchment management and to convey their knowledge and experience to government, potentially influencing future policy.

By adopting the approach that has the most appropriate scalar fit to local circumstances, such flexibility modifies power dynamics and understanding of valid knowledge, building trust and mutual respect. Inman et al. (2018, p.18) acknowledge that farmers can deliver on environmental objectives, which also have a production-related rationale, but report the persistence of productivist values and argue that where environmental agendas 'challenge productivity goals' (context), they are 'likely to be met with resistance', as was demonstrated in Project 5. In relation to diffuse water pollution they propose that 'double loop learning' is necessary to enable farmers to move from productivist (farm scale) to multifunctional (landscape scale) outlooks and that localised networks are most likely to be able to achieve such changes. This is illustrated by Project 5 in which farmers are moving on to consider soil management in the context of catchment management through an ongoing iterative process.

Conclusions

Our aim in this paper has been to explore the role of participatory research in combining scientific and farmer knowledge of soils to meet multiple objectives of farmers and wider society with respect to soil management. Across five projects, our approach to engaging stakeholders has ranged from communication (e.g. Project 3), through consultation (e.g. Projects 1, 2 and 3) to co-production (e.g. Project 4), and in the case of the catchment scale work on Propyzamide (Project 5), a combination of each of these. In no instance has our research been genuinely bottom-up in terms of being instigated by farmers themselves.

The 'Wheel of Participation' advocated by Reed et al. (2017) allows for any combination of communication, consultation or co-production with either top-down or bottom-up approaches and the authors argue that either approach is equally valid if they achieve desired outcomes from engagement. While farmers and other stakeholders continue to engage with Allerton Project research, and the network of participants is growing, our analysis of recent projects against the criteria of Reed et al. (2017) can be used to guide improvements to future research.

The Allerton Project is adopting a combination of approaches according to the requirements of individual research contracts with the aim that different projects complement each other in strengthening long-term integration between farmer, researcher, and wider stakeholder communities. Fostering such a relationship between research and demonstration farms and

their local farmer communities is likely to build trust (Oreszczyn et al. 2010) and make soil research more relevant to soil management. It is also likely to make farmer practice more engaged with sustainable soil perspectives, and to identify potential constraints when societal objectives are not aligned with production-oriented soil management.

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Table 1. Overview of the five projects described in this paper.

	Name	Geographical context	Umbrella project and funding
1	Farmers' characterisation of soil quality	East Midlands region	Economic and Social Research Council PhD
2	Benchmarking soil properties across farms	Upper Welland river basin	Natural Environment Research Council. Sustainable Agriculture Research & Innovation Club
3	Farmer feedback on cover crop research	Experimental research at the Allerton Project	Department of Environment, Food and Rural Affairs, Sustainable Intensification research Platform
4	Research prioritisation by farmers and stakeholders concerned with broader societal issues	Upper Welland river basin	EU Horizon 2020 SoilCare project
5	Exploring links between herbicide use, soil management and water quality	3,000-hectare study area near the Allerton Project	Department of Environment, Food and Rural Affairs, Sustainable Intensification research Platform. Water Friendly Farming project.

Table 2. Evaluation of the five research projects according to criteria listed by Reed et al. (2017). Criteria that are not met scored 1 and criteria that are fully met scored 5.

		Context	Design	Power	Scalar fit
1	Farmers' characterisation of soil quality	3	5	4	3
2	Benchmarking soil properties across farms	4	4	2	1
3	Farmer feedback on cover crop research	2	3	3	3
4	Research prioritisation by farmers and stakeholders concerned with broader societal issues	5	5	4	4
5	Exploring links between herbicide use, soil management and water quality	3	5	5	4