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Using co-constructed mental models to understand stakeholder perspectives on agro-ecology

Freddy van Hulst ^{a,b}, Rowan Ellis^a, Katrin Prager^{a,c} and Joshua Msika^a

^aSocial, Economic, and Geographical Sciences Group, James Hutton Institute, Aberdeen, UK; ^bSchool of Agriculture, Policy and Development, University of Reading, Reading, UK; ^cGeography and Environment Department, University of Aberdeen, Aberdeen, UK

ABSTRACT

Agro-ecology has been recognized as a potential route to realizing the multiple economic, social, and environmental benefits increasingly required of agricultural systems. However, views on what constitutes agro-ecology differ considerably between countries, and also between stakeholder groups such as natural scientists and farmers. To identify areas of convergence and divergence in understandings of agro-ecology in the Scottish context, we used a novel co-constructed mental modelling approach with a sample of 8 scientists and 7 farmers in the North East of Scotland. Results show that agro-ecology in Scotland is currently mainly understood as a scientific discipline applying ecological analysis to agricultural systems. Farmers' mental models show a wider consideration of the food system, including consumer health, markets and sustainable energy. Precision farming featured prominently in farmers' mental models but not in the scientists' mental models. Our discussion therefore raises the question to what extent precision farming and agro-ecology support or contradict each other. We conclude that although farmers and scientists differ considerably, there are areas of shared understanding, such as the potential of novel crops and new crop rotations, which could be the starting point of working towards an agriculture that delivers multiple benefits.

KEYWORDS



Cognitive maps; precision farming; sustainability; organic; ecosystem services; transitions

Introduction

The challenge of producing food sustainably is one faced by policy makers, researchers and farmers alike. Agricultural systems are geared towards providing food, but this comes at the cost of habitat and biodiversity loss, and land and water degradation (Henle et al., 2008; IPES-Food, 2016). Whilst food and fibre production remains a priority, there is increasing pressure for agriculture to deliver wider benefits including but not limited to ecosystem services. This is also evident from the 'sustainable intensification' agenda that gained traction in the last decade (Weltin et al., 2018) and the interest in functional biodiversity (Kazemi et al., 2018; Moonen & Bàrberi, 2008).

In Scotland, policy makers set out a vision of sustainable land management that delivers multiple

economic, environmental and social benefits (The Scottish Government, 2016b). A potential route to realizing the multiple benefits of agricultural land is through transition to an agro-ecological farming system (Ellis & Prager, 2017; Lampkin et al., 2015). So far, however, there is not a universally shared view of what agro-ecology is and how it should inform agricultural policy and rural development approaches going forward. In addition, the selection of agro-ecological practices that farmers are expected to implement is similarly open, and tends to escape detailed prescriptions due to the variability of farming systems, land capability and climatic settings. Even where concrete practices are recommended by scientists, farmers are not always able or willing to adopt them. In order to make progress towards

CONTACT Freddy van Hulst  f.vanhulst@reading.ac.uk  School of Agriculture, Policy and Development, University of Reading, Whiteknights, PO Box 237, Reading, RG6 6AR, United Kingdom

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transitioning to agro-ecological farming systems it is necessary to firstly understand the different conceptions of agro-ecology, and secondly bridge the divide between research and practical solutions adopted in the field. This paper proposes a method to explore farmers' and scientists' mental models of agro-ecological practices and advocates the identification of shared or complementary views as a means to enhance constructive exchanges between researchers and farmers.

Earlier work has focussed on identifying the differences between knowledge held by farmers and by scientists, partially based on different values, but also because the forms of knowledge held by these groups differ (Cleveland & Soleri, 2002; Dissel & Graaff, 1998; Eshuis & Stuiver, 2005; Gray & Morant, 2003). In contrast, Carr and Wilkinson (2005) found that the roles of scientists, extension officers and farmers are converging and there are fewer differences in how each group produces and uses knowledge. Ingram et al. (2010) explained the difference between scientists' and farmers' understanding of soil by drawing on various theoretical perspectives (forms of knowledge, the production of knowledge according to aims, methods and context, and the conceptions of reality) but without deriving practical or policy recommendations.

In terms of methods, scholars have experimented with a range of methods to capture different knowledge systems held by different stakeholders. Several such examples exist with reference to environmental management (Raymond et al., 2010) or watershed management (Henze et al., 2018), where methods such as participatory observation, interviews, and focus group discussion were used with the aim to inform future planning processes in landscapes. In addition to conventional social science methods, mental models have been used to capture the different understandings held by farmers and scientists (Eckert & Bell, 2005; Halbrendt et al., 2014; Krauss et al., 2009; Vuillot et al., 2016). Prager and Curfs (2016) utilized mental models to elicit different understandings of soil management in order to identify where farmer and scientist's understanding overlapped so that research and action could focus on issues that were central to both types of actors. Building on this approach, this paper will further develop the method to elicit mental models to explore how ecological scientists and farmers think about agro-ecology, and map areas of convergence and divergence in these understandings. Drawing on these data we will provide an overview of the range of

understandings of agro-ecology in Scotland, critically discuss the method and findings, and identify areas for future research and policy recommendations.

Background: agro-ecology

What is agro-ecology?

Agro-ecology refers to the application of 'ecological concepts toward the design and management of sustainable agroecosystems'(Lampkin et al., 2015). The earliest references to agro-ecology can be traced back to the 1930s, emerging from the scientific fields of ecology and agronomy. Since that time, agro-ecology has emerged as a much more complex conceptual framework, fostering not only a growing academic discipline, but a set of agricultural practices, as well as a socio-political movement (Wezel et al., 2009).

Furthermore, there is a significant degree of geographical variation in the way agro-ecological terms and concepts are understood (Gallardo-López et al., 2018). For example, the French approach to agro-ecology seeks to transform the social, economic, and environmental performance of the agricultural sector by 2025 and is backed by an innovative regulatory framework and multi-pronged research program (Gliessman, 2014). Conversely, in Germany, agro-ecology exists primarily as a scientific discipline with its focus almost solely on agricultural innovations (Méndez et al., 2015). In parts of East Africa, agro-ecology has been implemented as part of a sustainable development programme, often with support from international donors, and with a focus on increasing yields and rural incomes (Francis et al., 2003). In the Americas, there is evidence of a growing social and political movement for food sovereignty and participatory development with the goal of creating a 'transformative agro-ecology' (Hill, 2014). In all contexts, advocates go as far as arguing that agroecology can and should be the successor to large scale, resource intensive industrial agriculture (De Schutter, 2010; IPES-Food, 2016).

A 2015 Land Use Policy Group report attempts to provide a definition of agro-ecology that is relevant particularly for the UK and Scottish context. They define agro-ecology as 'an approach emphasising ecological principles and practices in the design and management of agroecosystems, one that integrates the long-term protection of natural resources as an element of food, fuel and fibre production' (Lampkin et al., 2015, p. 9). Similar definitions are evident in

the scientific literature as well, all with a focus on the integration of ecological principles into agricultural production, with an aim to protect natural resources (De Schutter, 2010). To add specificity to these definitions, the literature highlights a common set of principles that underpin agro-ecology as a practice. These involve increases in 1) efficiency (for example, increasing production while decreasing external inputs), 2) substitution (substitution of one input or practice for another), and 3) redesign (of both the agricultural landscape, as well as the relationships between agriculture and other economies) (Hill, 2014; Wezel et al., 2014). The literature suggests that these principles evolve over time and in stages, with early adoption of agro-ecological principles usually involving increases in efficiency, whereas whole system redesign infers a much more fundamental re-orientation of the food system (Gliessman, 2014).

These principles are then translated into numerous approaches or aims and corresponding techniques or practices that are discussed, trialled, and implemented differently by those working in the ecological sciences and those responsible for managing agricultural land. By focusing on the differences between the ways scientists and farmers/land managers understand and negotiate the benefits and disadvantages of various agro-ecological approaches and practices, we can gain a better appreciation of Scottish agro-ecology in practice. What's more, this focus on diverging and converging understandings of agro-ecology acknowledges that there is potential for collaboration and co-learning between the various stakeholders in an agro-ecological transition. The research team also aimed to capture any novel ideas and practices that farmers may already be applying, unbeknownst to scientists working on agro-ecological approaches.

Scottish agro-ecology in practice

The Scottish agricultural sector is characterized by a large proportion (circa 84%) of agricultural land classified as low value or less favourable area (LFA) for agricultural production (The Scottish Government, 2016a). Most of this LFA land is in low intensity, upland rough grazing systems, with just over 2% of this LFA land in crop. This means that much of the Scottish agricultural land is already operating on a low intensity, low input model, supported by various agricultural subsidies. Meanwhile, the 14% of Scottish agricultural land that is of relatively higher quality is

geographically concentrated in the lowlands and is farmed intensively (ibid). Because of the predominance of low intensity upland farming in Scotland, there is already a fair bit of practical experience with lower input, diverse, and sustainable farming in these systems. However, there is still much work to be done in identifying a path toward more sustainable land management for high intensity, lowland farming. As such, the following discussion of what agro-ecology could and should be in the Scottish context focuses on the agricultural practices that prevail in these lowland systems.

Contrary to e.g. France, neither Scotland nor other UK countries have incorporated the pursuit of agro-ecology into farming policy. Some individual environmental practices and systems are promoted within the Common Agricultural Policy (CAP) of the EU. These include cross-compliance measures to ensure that farmers receive basic payments on the condition that they comply with environmental thresholds, and the CAP greening measures introduced in the 2014 CAP reform. Other practices are supported through voluntary incentive-based schemes as part of the Scottish Rural Development Programme, especially the Agri-Environment and Climate Scheme (AECS).

Methodology

Co-constructed mental models

The starting point for this research is the supposition that various stakeholders in the agri-environment possess distinct understandings of the relationship between agricultural and ecological systems. These tacit understandings are important for guiding the sorts of decisions these stakeholders make about land management practices. Our research methodology builds on recent (and not-so-recent) work on cognitive mapping, which highlights the importance of cognitive representational structures for how people interact with the external world, for guiding decision-making and as an important component of how people learn (Johnson-Laird, 1983; Jones et al., 2011). Cognitive map is a general term for describing an internal cognitive structure, of which there are many types.¹ Here we utilize the concept of mental models as a dynamic form of cognitive map, suited to capturing the internal conceptual representations of various stakeholders in the agri-environment. Mental models are often used to describe the

cognitive representations that individuals (and occasionally groups) develop to make sense of interacting social and ecological systems (Jones et al., 2011). As such, mental models are often of interest to those in the fields of natural resource research and management.

We believe that there are several methodological advantages to exploring mental models.

- First, a focus on mental models captures how people understand a system, the interactions within that system, and how the system may respond to interventions.
- Second, a focus on mental models might better acknowledge, account for, and capture the tacit knowledge of research participants, and ultimately engender more participatory research.
- Third, a focus on mental models might be useful in navigating trans-disciplinary research, where common disciplinary traditions, conceptual frameworks, or broader epistemologies cannot be taken for granted.

But for any sort of meaningful analysis to take place, these mental models must be externalized, or made tangible and explicit. This process of translation from internal model to external object is usually accomplished through various forms of diagrammatic representation (Wood et al., 2012). The precise form of diagrammatic representation is determined by the sorts of information researchers wish to gather and how this information will be interpreted and used. For the research presented here, the team was particularly interested in understanding the relationships between concepts within individual's mental models, as well as in making comparisons of these concepts across different mental models. Based on a review of existing methodologies, a semantic web approach was determined as the best suited form of diagrammatic representation. Semantic web-based representations aim to capture the relationship between concepts in a mental model in a qualitative way.² It relies on noun-based concepts as central nodes in the diagram, which are then linked, often with verbs or adjectives, to other nouns/concepts. These links capture the nature of relationships between concepts, as well as perceptions of causal relationships within the model (see also: Freeman & Jessup, 2004; Wood et al., 2012). The resulting diagram is similar in appearance to a concept map and facilitates the qualitative

analysis of the centrality of concepts, degrees of complexity, and the nature of relationships.

There is a wide array of possible methods for eliciting these sorts of insights and a comprehensive review of these is beyond the scope of this paper (see Jones et al., 2011). We sought specifically to avoid the 'expert' vs 'lay person' mental model approach which is common in the literature. To do this, we drew on some of the foundations of participatory modelling (Özesmi & Özesmi, 2004) as well as participatory social research methods in general to develop a methodology we call **co-constructed mental models**.

As with all novel methodological approaches, ours involved a significant amount of trial and error, reflection and adaptation. Specifically, the methodology evolved as we learned more about the object of analysis as well as the challenges associated with externalizing mental models. There was an interesting tension in this methodology around how to elicit the model in a way that avoided imposing a pre-conceived structure (in essence, our own mental models) but also retained a practical utility within the bounds of our research project. In the end, an emphasis on breadth allowed sometimes unexpected connections and relationships to emerge.

Study design

This research was conducted over 18 months among farmers and natural scientists with expertise in Scottish agricultural systems. The focus was primarily on lowland arable and mixed farming in the northeast of Scotland. These types of farms, in this region, represent relatively high intensity systems, with a resulting high 'potential' for environmental benefits if they were to successfully transition to more agro-ecological farming practices. There is existing work with UK farmers who have already made the transition to more agro-ecological farming (see Padel et al., 2017), but our relatively smaller study tightened the focus to those farmers who would normally be classified as 'conventional' (except for one certified organic dairy farmer in the sample).

In our sampling of farmers, we aimed to cover the diversity of dominant farm types in the study area, including arable contract farming, small and medium arable farming, mixed farms (with cattle, sheep and pigs) and dairy farming. Our sampling of researchers was also purposive, with a view of including a broad range of key investigators in North-East Scotland

studying different aspects of agroecological land management approaches in both arable and mixed farming systems. Our entry point was the interdisciplinary work package 'Alternative Approaches to Sustainable Land Management' work package of the Scottish Government's 2016–2021 strategic research portfolio into Rural Affairs, Food and Environment. These scientists are primarily based within research institutes, rather than universities, and thus tend to have a closer alignment with policy and government priorities. A profile of farmer and researcher respondents (including their research interests or farm characteristics) are described in the appendices.

Our research started with interviewing the natural scientists about what they understood by agroecology, the most promising farming and land management practices and approaches, and the wider benefits that would accrue from these. The interviews were then transcribed by hand into mental models (see [image 1](#)). These completed models were then sent back to the participants for comment and amendment, though in each case, participants responded to say that the models accurately captured their understanding and therefore, did not require amendment. This process was not only time consuming, but highly contingent upon the researcher's own understandings of the relationship between elements in the model. But this approach also had practical utility in that it was not particularly arduous for the participants, and the researcher's ease in contacting and meeting with the natural scientists meant that there were further opportunities for participants to provide feedback and input into the models.

As we moved in to the next set of interviews with farmers, we began to reflect on the processes of elicitation. It was likely that we would get just one opportunity to speak with the farmers, and their enthusiasm for providing feedback on their mental models was uncertain. To account for this field reality, we adapted the methodology to a more participatory format. This format combined semi-structured interview questions, concept sorting, and a 'talk through' exercise to build participant's mental models in a real-time, collaborative way (see [image 2](#)). Participants were able not only to directly build the concepts in their mental models, but also reflect upon, adjust and edit these throughout the elicitation interview. Once this process was complete, the mental models were digitized by the researchers and sent back to the farmers for a second round of feedback and editing. Fewer than one third of the participants in

the farmer sample provided feedback during this second round.

Analysis

The process of analysis was three-staged, and varied slightly between the natural scientists' and farmers' models. For the scientists, the first stage of analysis occurred when the interviews were transcribed, coded, and these codes were represented diagrammatically as a mental model. This stage of analysis involved picking out central concepts and drawing the connection between these and other concepts within the model. Also in this first stage, mental models were drawn in Microsoft Visio© to facilitate the digital sharing and editing of the models. The second stage of analysis looked at the scientists' mental models as a collection, highlighting broad structural patterns, recurring or clustered concepts, and general trends in how farming systems were conceived. The findings from this second stage also helped us to design the elicitation methods for the farmer interviews. The analysis of the farmers' models varied slightly because the mental models were created with the participants, rather than out of the process of transcription and translation. As such, the first stage of analysis focused on digitizing the mental models and validating these with the research participants (see [image 3](#)). The second stage mirrored that of the second stage with scientists as we explored the farmer group of mental models, picking out commonalities and differences among the set. The third stage of analysis brought together scientists' and farmers' mental models to identify areas of shared and diverging understanding around the various concepts, relationships, practices, and benefits of agro-ecological farming.

Sharing and engaging with mental models

The final models have been used in various workshop settings to facilitate discussions about agro-ecology. People engaging with the models, including the researchers, were surprised by the diversity in the mental models and valued the representation for inviting a systems perspective. Because the full models are not always intuitive to read and also for practical reasons (they take up a lot of space!) we have opted to include a simplified version of all models in the appendices. This allows the reader to see and compare *all models*, rather than only seeing

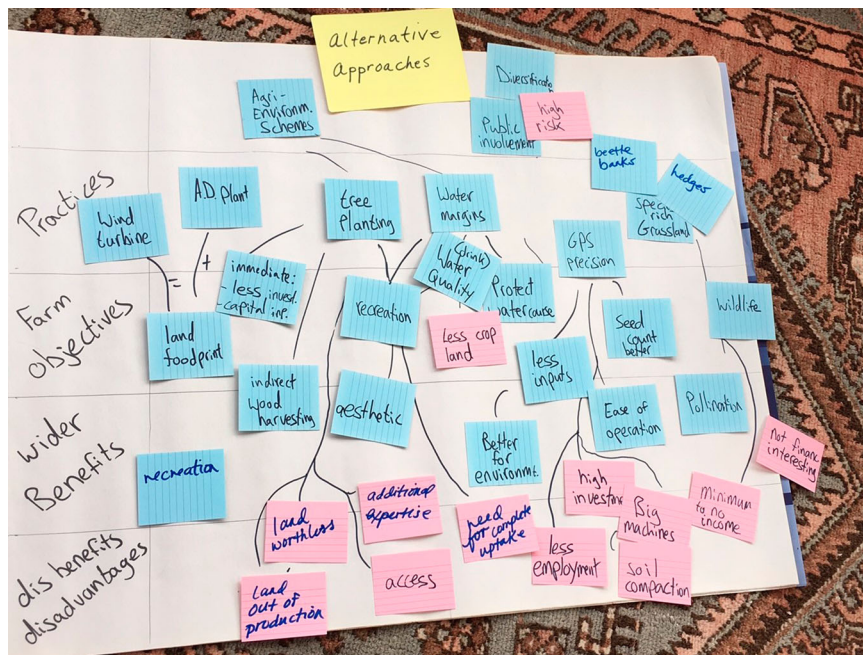


Image 2. Building a mental model with a farmer

a selection. It also allows a wider audience to engage with them, because they are much more intuitive. We simplified mental models by combining similar boxes, while keeping the structure of the model as close to the original as possible. To see how the simplified models compare to the full model one can compare the full model in [Image 3](#), with the corresponding simplified model in [Figure B2](#), appendix B.

Results

What is 'agro-ecology'?

The starting point of the interviews was for respondents to elaborate on the first associations with the term agro-ecology. The scientists were all familiar with the term agro-ecology and were often quick to cite the general definition of 'applying ecological knowledge to farming systems', although, looking more closely, different interpretations emerged. Some scientists (S1, S3 and S7³) maintained a relatively strict distinction between agro-ecology as scientific discipline (i.e. the creation of knowledge), and the application of this knowledge. The latter was referred to as 'agro-ecological practices' by scientist 3, but also defined more widely in terms of 'sustainable agriculture' or 'new/alternative agricultural systems'. Scientist

1 defines the word agro-ecology as a scientific discipline that can be applied in sustainable agricultural systems 'rather than the agro-ecology defining what would be a sustainable system' (S1). Others used a more normative definition, in which agro-ecology means a 'targeted ecological shift' (S2) which 'implies an agenda' (S4) towards more biodiverse farming systems. Scientist 4 further thinks that the concept of agro-ecology has the potential to bridge various ecology- and production-oriented concerns in a way that other concepts like 'ecological farming' are unable to do. On the other end of the spectrum, there is scientist 5 who focuses on the 'agro' part of the definition, maintaining that 'in the end [agro-ecology] should be about growing crops and rearing livestock' which, by definition, happens through manipulating an ecosystem in a strategic way. Three scientists cite 'reducing chemical inputs while maintaining yields' in their first definition of agro-ecology (S2, S3 and S7), which is achieved through 'more complicated systems, more varied rotations, more intercropping and novel crops' (S7). Scientist 2 and 6 link agro-ecology with organic farming as an important way of implementing agro-ecology in practice.

None of the farmers were familiar with the term agro-ecology and they certainly did not use it to think about their farming system. Three farmers (F1,

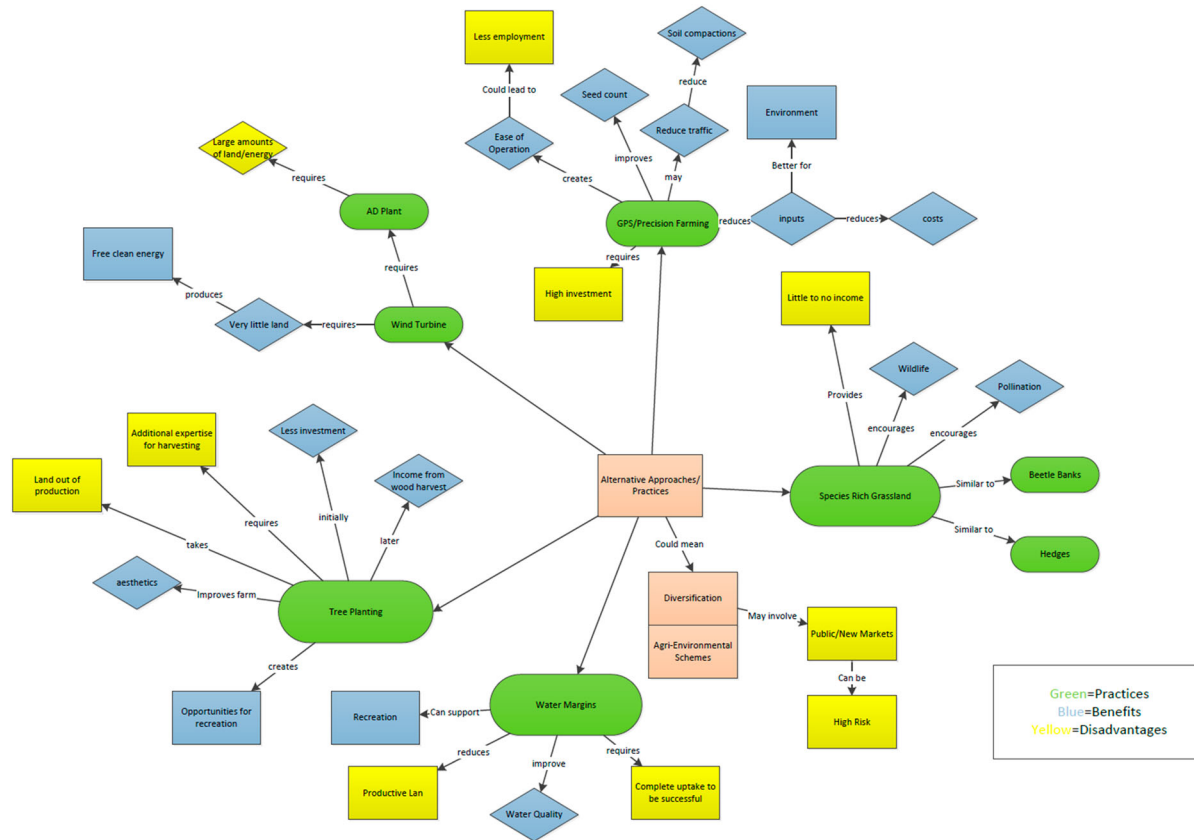


Image 3. Complete digitised mental model of a Farmer

F5 and F6) first associate agro-ecology with organic and 'environmental' farming, which they were all quick and resolute to dismiss as 'not something I am particularly interested in' (F1). And: 'I'm not the organic type by any means. No, that doesn't fit with my ethos. I'm high input, high output' (F5). Similarly, farmer 6 argues that the environment 'is important but shouldn't interfere with the business side of things'. Farmer 1 characterizes production-oriented farming as 'scientific' while organic/environmental farming is characterized as 'turning back time'. This is an interesting contrast with scientists who see agro-ecology as a scientific discipline. Farmer 2 associates agro-ecology with 'the many policies to support environmental practices these days', in particular Agri-Environment and Climate Schemes (AECS). Others associated agro-ecology first with precision farming⁴ (F3) and nutrient budgeting (F4). For the organic dairy farmer (F7), agro-ecology is a new term which he associates with his efforts to reduce the use of antibiotics.

These first interpretations of the word agro-ecology already show clear differences between and within the groups. The mental model methodology offers a way to unpack these differences and to highlight the potential for integrating farm benefits with wider environmental and societal benefits. After this initial question, we resumed the interview by discussing alternative approaches to land management in a broader sense, as was seen relevant by the respondents.

Scope and structure of mental models

Concepts versus practices

A first observation is that scientists' models (see appendix A) often start with defining and comparing various concepts and systems, and then go on to cite advantages of the approach, in some cases using practices *as examples* of how to achieve these advantages. For example, scientist 1 distinguishes an 'agro-ecological approach' from 'agro-ecology as scientific discipline' and considers some practices as examples of functional biodiversity which in turn provide ecosystem services. The practices that scientist 1 mentioned are also grouped along scientific categories of 'ecological engineering' and 'habitat amendment'. Farmers' mental models (see appendix B) are much more practice oriented, joined with an assessment of the benefits and drawbacks associated with these practices, which often include

management and economic aspects. For example, farmer 1 mentions minimum tillage as an alternative practice he has considered, but thinks it has negative impacts in terms of weed control, slug management and equipment needs, although he sees its time-saving potential as a benefit. This resonates with Ingram et al. (2010) who found scientists' understanding was 'deep' and 'know why' (to do something, why something happened), whereas farmers' knowledge was 'broad' and 'know how' (to apply a certain practice, how to address a problem).

Contrasting agro-ecology with conventional versus gradual adaptation

In their mental models, most scientists (S2, S3, S5, S7 and S8) contrast a type of agro-ecology (e.g. 'organic farming', 'new systems' or 'alternative systems') with a 'conventional' farm system, while the remaining three mental models (S1, S4 and S6) only covered what they considered agro-ecological without considering conventional farming. The farmers' mental models, in contrast, show a picture of them gradually integrating novel approaches into their farm, being very selective regarding which practices they adopt according to their objectives and farm management. No farmer is looking for a complete upturning of his system from 'conventional' to 'agro-ecological'. The scientists' mental model structure may be a simplification for arguments' sake, but the contrasting of conventional and agro-ecological farming risks overlooking the already existing, and in some cases well-established agro-ecological practices taking place on 'conventional' farms. In this respect the interview with scientist 6 was interesting, who said that his work aimed to make 'agro-ecological' or 'organic' practices acceptable to conventional farmers 'on merit' and without the 'environmental' label.

Scope of the models

In terms of the scope of the topics considered in the models, scientists were primarily focussed on field and farm-level characteristics of agro-ecology, while farmers also considered aspects of the wider food systems. Farmers' models included post-harvest considerations including marketing and meeting consumer demand and health concerns, as well as the energy dimension of farming, in terms of renewable energy and anaerobic digestion. Three farmers (F1, F4 and F6) had the objective of becoming more energy self-sufficient, and five farmers (F1, F2, F5, F6 and F7) reflected on how consumer demand was

changing which influences prices and therefore practices. Both scientists and farmers considered the importance of CAP greening and AECS as mediating factors that support some agro-ecological practices on the farm.

The role of agro-ecology in mental models

Agro-ecology in farmers' models

Although farmers were not familiar with the term agro-ecology, their mental models (see appendix B) show several agro-ecological features based on our broad characterization as defined in section 2.1. The small arable farmer (F2) was well aware of the various AECS and forestry grant options and had implemented several schemes, including species-rich grassland, water margins and trees, citing economic as well as aesthetic and environmental benefits. The larger intensive arable farmer (F5) was interested in crop rotations for pest and disease control and reducing costs of inputs. The arable contract farmer (F3) had few interests besides maximizing returns through precision farming, but nevertheless had to comply with CAP greening measures, including margins. One outcome of the heightened requirements for accountability and efficiency on a contracted farm is the ability to identify pieces of land where it makes more economic sense to leave the land fallow than to try and improve it with many inputs, which 'presumably has some environmental benefits' (interview with F3).

The mixed farms (F1, F4 and F6) are very consciously optimizing the nutrient cycles, citing a combination of motivations. Pig farmer 1 mentioned the area being classified as a 'phosphate risk' area as a driver to invest in slurry storage with the help of subsidies. This allowed him to spread the slurry on the land at the time when crops need it most, which optimized nutrient utilization, thereby reducing negative environmental impacts and also reducing costs. Additional benefits of optimizing nutrient cycles mentioned by the other mixed farmers included improving soil organic matter and soil structure as well as reducing 'food miles' by limiting the reliance on inputs from further afield. Although some scientists mentioned alternative sources of nutrient inputs, neither the farmers nor scientists specifically mentioned the idea of optimizing on-farm nutrient cycling on mixed farms as an agro-ecological principle. However, we think this could be seen as contributing to agro-ecological objectives, possibly with a relatively high net

impact on mitigating negative environmental impacts of intensive livestock keeping. In addition mixed farms, especially the extensive system (F4), have an almost intrinsic potential for several agro-ecological practices. For example, where hedges on arable land simply take land out of production, on an arable farm they also contribute to shelter from the wind for livestock. The organic farmer (F7) does not use artificial inputs and uses antibiotics differently than before his transition to organic. This has led to an observed increase in soil life (linked to using organic worming medication with no residual activity in the slurry) and more biodiversity (in particular birds).

Agro-ecology in scientists' models

In most cases, scientists' mental models gravitated towards their research interests, but some common patterns were identified (see scientists' mental models in appendix A). The mental model of scientist 1 focuses on integrated pest management and 'habitat amendment' for natural predators, contributing to 'functional biodiversity', that is associated with long-term benefits and ecosystem services. Both scientists 2 and 7 highlight the importance of alternative nutrient sources and the potential of legumes and crop diversity through mixtures and rotations to contribute to N/P from non-mineral sources; scientist 7 highlights wider concerns around political, social and farmers' acceptability of various practices. The mental models of scientists 3, 4 and 6 distinguish between environmental and economic benefits (S6) or environmental and economic sustainability, while considering yield reliability (S4). Scientist 3 sees agro-ecology as aiming to maintain yields, enhance biodiversity and reduce agri-chemical inputs, and identifies a trade-off between biodiversity and chemical inputs where more of the latter means less of the former. Scientist 5 sees conventional farming as prioritizing yields, whereas 'agro-ecological' farming improves biodiversity (through e.g. continuous crop cover and targeted spraying) and soil security (through continuous crop cover and reduced traffic). He also identifies farm demographics and demonstrations as contributing to the uptake of agro-ecology.

The individual agro-ecological practices that featured prominently in the scientists mental models were crop rotations and intercropping (S1, S2, S5, S6, S7 and S8), crop diversity (S2, S3, S4, S6 and S8) and new crops (S1, S4, S7 and S8), followed by legumes (S2 and S6), field margins (S3 and S4) and direct

drilling (S3 and S8). Practices that were mentioned by a single scientist were compost, use of crop residues, beetle banks/flower strips, green manures, targeted spraying and Ecological Focus Areas.

Areas of convergence and divergence

Livestock integration and nutrient cycling

One area of divergence concerns the integration of livestock into arable systems, and the corresponding importance of nutrient cycling. The mental models of the scientists in our sample did not consider livestock. This includes scientists with an interest in organic farming, who discussed the importance of 'alternative nutrient sources' in terms of nitrogen-fixing crops and diverse rotations rather than livestock. The farmers' mental models, however, covered the optimization of the livestock and arable side of their farm systems in great detail and in the case of the pig farmers this was a primary concern.

Profits trump environment

One feature that all the mental models share, is the assumption or observation that conventional farms are currently dependent on agro-chemicals for pest control and fertilizers, and are geared towards maximizing yields and productivity in the most cost-effective way. A difference is that scientists perceive this as a problem, while for the farmers in our sample, with the exception of the organic farmer, this is the only way that their systems make sense. This is linked to another fundamental difference between farmers and scientists, i.e. in how environmental and economic objectives relate. In scientists' mental models, agricultural systems have a dual purpose, in which 'environmental' or 'biodiversity' objectives go hand in hand with 'economic' or 'yield' objectives, mirroring policy objectives that support sustainable intensification. Indeed, scientists' mental models highlight the objective of sustaining biodiversity to sustain production. In farmers' mental models there is, without exception, the opposite hierarchical relationship in which yields, margins or profitability are more important than environmental benefits. 'If it's not profitable there isn't any money to do environmental things' (F3). This is even true to an extent for the organic dairy farm (F7) who transitioned to an organic system for the premium prices, which was the only way to stay in business.

Reducing costs versus maximizing yield

One subtle difference within farmers' mental models was that some farmers focus on reducing costs, others on maximizing yield.⁵ These are often seen as just two sides of the same coin, but they have different implications for the potential of agro-ecology. The first type of farmer has more potential for incorporating 'alternative' practices that help bring costs down by replacing external inputs, while the second type of farmer may be less inclined to do so because agro-ecological practices rarely increase yield (according to scientist interviews). Indeed, this is not the objective of agro-ecology as a scientific discipline – scientists' mental models highlight the need to 'sustain' or 'maintain' yields, and 'yield reliability' as opposed to maximizing yields. One 'maximise yield' type farmer (F5) in his interview explicitly criticized 'save cost' type farmers, saying: 'You can cut costs all that you like, but the best way to do it, and what I've learned from the benchmarking exercises, is that it's better to spread your costs over higher yields. Yield will always win, whatever you do. Everything I do is to maximize yield, but I try to do that as efficiently as possible'.

Novel crops and broader view of rotations

The mental models also point at potential areas of convergence: the development of new crops and new rotations with both environmental and production benefits. Novel crops were mentioned by scientists 1,4,7 and 8, and also by farmers 1,3 and 5. A scientist mentioned that the majority of plant breeding was historically done with tilled systems in mind, so it is hardly surprising they do not always perform under minimum tillage systems. So there is potential to breed new lines that do well in minimum tillage under Scottish conditions. The practice of 'crop rotations' was used by both farmers and scientists in a relatively undefined way to encompass a range of practices. At the simpler end, farmer 5 grows several cereals in a fixed order to maximize outputs. Farmer 4 experimented with a novel crop (rye) in his rotation, citing benefits of reduced costs and improved soil structure. Scientists seemed keen to include nitrogen-fixing crops in the rotations. This area of convergence offers the potential for a common starting point for scientists and farmers to develop rotations that deliver multiple benefits.

Precision farming

An apparent difference between the two samples is that in scientists' models, practices like rotations or cover crops are valued for being *nutrient-efficient*, while farmers value practices that are *cost-effective*. These are intimately linked, since using available nutrients efficiently helps to reduce costs for buying additional (synthetic) fertilizer. This observation suggests a more substantial difference between farmers and scientists. Both farmers and scientists reflected on the value of combining nutrient-efficiency (an agro-ecological principle) with being cost-effective (a major farm objective). In farmers' models, this overlap is mainly found in precision farming, while for the scientists this overlap lies in 'alternative nutrient sources' obtained through crop diversity and legumes. This is arguably the greatest divergence between the models we have found.

The important role of precision farming in the mental models was an unexpected outcome of this research. Six out of seven farmers elaborated on precision farming which shows it is a topic that takes a central place in farmers' understanding of the range of 'alternative' practices they can adopt. This is also clear from the mental models (appendix B). This is in stark contrast with the scientists, where only two scientists mentioned precision farming technology, in both cases under the 'conventional' part of the model (scientists 2 and 5), i.e. not necessarily as part of the agro-ecological approach. Indeed, one could argue that precision farming is reinforcing the high external input style of farming to maximize yields in a cost-effective way. In our interviews we asked explicitly whether precision farming leads to fewer inputs, but all farmers confirmed that precision farming is not leading to a reduction of inputs but rather to a better distribution of inputs, and therefore higher returns. This was true for varied rate application of seeds (F3), lime (F2), and Phosphate & Potash (F5).

Critical discussion

The results show that some of the research areas that scientists are concerned with regarding agro-ecological practices are outside the scope of farmers' mental models and as such are less likely to capture their interest or be seen as useful (e.g. continuous cover crop, increased use of legumes as alternative nutrient sources, habitat amendment for natural predators). Some types of practices may require a

compromise on the side of the farmer and may only be suitable to a subset of farmers, e.g. those with an interest in agri-environment schemes.

Some areas have the potential to converge but may need to be framed around a language that is common to scientists and farmers (e.g. improving yield, integrating livestock, reducing costs, targeted spraying and tramlines can be implemented through precision farming). Crop rotations may have potential as a fruitful ground for exchange between farmers and scientists (in particular if coupled with new varieties) although they require clear articulation of the objectives and specifications of the rotation.

Path-dependency and transitions

Scientists painted a picture of a fully transitioned system, without considering all the constraints that farmers currently operate under. Farmers do not see this picture as very attractive, and potentially see it as threatening to their identity as competitive and productive farmers. For all the farmers in our sample, the idea of precision farming is much more in line with their objectives, farm trajectory, farm identity and philosophy. As such, productivist ideas of being a 'good farmer' may contribute to resisting a transition to towards more agro-ecological modes of farming (see also Burton, 2004). Nevertheless, the farmers' mental models show that some agro-ecological components are present on farms and there are several mechanisms that encourage the uptake of agro-ecological practices. These are through:

- certification (e.g. organic, F7);
- incentives (e.g. AECS, F2);
- legislation (e.g. CAP greening and EFAs, all farmers); and
- optimized nutrient cycling (mixed farms F1, F4, F6 and F7).

This is not to imply that any one path featured prominently on the farms, and it was sometimes the case that any adoption of agro-ecological practices was no more than a side effect of compliance. For example, the large-scale contract farmer (F3) farmed more land than the other farmers combined, and although he complied with regulations (including margins and Ecological Focus Areas), he was otherwise not interested in anything that would compromise his profit margins.

Our focus on the four pathways to the adoption of agro-ecological practices partly eschews more linear

models of the transition to agro-ecology (e.g. Hill's, 2014, 1985 efficiency-substitution-redesign model), in favour of a focus on the multiple, often cohabitating motivations, calculations, and decisions that underpin the adoption of these practices. In doing so, we concur with Padel et al. (2017) that the experiences of adopting agro-ecological practices are highly varied, but often demonstrate forms of path dependency, with small changes to practice happening incrementally, whereby major, more strategic redesign decisions often only follow a significant 'trigger' event such as starting a new farm or taking over an existing business (see also Sutherland et al., 2012).

Our results also suggest that the phenomenon of path-dependency may not be limited to farmers (e.g. according to farm type), but may equally be valid for researchers (e.g. according to scientific discipline) or policy makers (e.g. according to current policy discourses) (see IPES-Food, 2016; Vanloqueren & Baret, 2009). Some of these forms of path dependency become more evident when using the mental models methodology.

Precision farming vs agro-ecology?

For the farmers in our sample, precision farming on their farm does not lead to fewer inputs being used, but to the inputs being utilized more efficiently. While nutrient efficiency is one of the core principles in agro-ecology, precision farming techniques remain fundamentally linked to the 'industrial' farming paradigm geared towards maximizing yields with few, if any, wider environmental benefits. The farmers' current experiences are in stark contrast to industry claims that precision farming can provide a technological 'fix' for unsustainable input intensive agriculture.⁶ There was, however, a recognition by at least one farmer (F3) that precision farming was useful in responding to growing concerns about high input systems, insofar as that the data generated through these techniques created a form of accountability for the use of inputs.

Dubious environmental claims aside, the increase in precision techniques may be further entrenching or creating new forms of path dependency because precision farming requires new skills and huge investments. This is likely to only reinforce farmers' commitment to external input systems (Wolf & Buttel, 1996) rather than supporting a move towards other, arguably more desirable but also more radical, agro-ecological principles of input substitution and system redesign. The unexpected question this study then

raises is to what extent is precision farming a continuation of the 'industrial farming' paradigm, and how compatible is this with agro-ecology and wider societal objectives?

Conclusions and recommendations

As agro-ecology becomes more prevalent in policy discourses about how to ensure agriculture delivers multiple benefits to people and the environment, there is need for greater clarity on how the objectives and practices that underpin agro-ecology are being supported and understood by scientists and farmers. Our co-constructed mental model method proved to be a useful tool for eliciting internal cognitive depictions of the world regarding concepts, practices and beliefs, and their qualitative relationships. This allowed us to identify areas of convergence and divergence in understandings of agro-ecology by farmers and scientists.

Our research has shown that farmers in Scotland are currently largely unfamiliar with the term 'agro-ecology' and associate it with 'sustainable', 'organic' or 'environmental' farming, to which not all farmers hold positive attitudes. As a scientific discipline however, agro-ecology is well-established, especially with a focus on ecological processes in agricultural systems, but less so as a complete food system science. Farmers' mental models showed a clear prioritization of economic over environmental objectives, while nevertheless adopting some practices that could be classified as 'agro-ecological'. Farmers' models were wider in scope than scientists' models, since most included energy and consumers in their thinking of 'alternative approaches' while scientists focussed on processes at field and farm level. Farmers were more 'gradual' in their change and adoption of new practices and new management, while scientists' models generally contrasted 'agro-ecology' with 'conventional', suggesting the need for a more fundamental transition but thereby potentially overlooking current patterns of path dependency and 'lock in'.

The main area of convergence in farmers' and scientists' mental models was the potential for novel crops and crop rotations. Farmers recognized various environmental benefits as well as production benefits of diversifying rotations, while scientists stressed the importance and benefits of increased diversity. However, more precise definitions of 'crop rotations' that make explicit both environmental and production objectives are critical. One area of divergence was the integration of livestock by farmers,

with scientists focussing on crop production in isolation. The most striking area of divergence was precision farming, which was central in the farmers' thinking about alternative approaches to farming but hardly touched on by scientists. Based on our discussion we suggest it is prudent to remain critical of the narratives surrounding precision farming with its claims of reducing inputs without solid evidence of environmental benefits. While precision farming can go a long way with the 'efficiency' dimension of agro-ecology, it is not contributing to the other principles of 'substitution'. Indeed, due to heightened path-dependency following the required investments in new equipment and knowledge, transitioning towards input substitution or system redesign may become less probable for farmers and thereby cements the increasing power of agri-tech companies and the industrial farming paradigm.

Our work also highlights four mechanisms that may support the implementation of agro-ecological practices: (organic) certification, financial incentives, legislation and optimized on-farm nutrient cycling. The mixed farms in our sample seem inherently more suited to several agro-ecological approaches, and farmers who find cost-cutting more important than yield maximization will find it easier to integrate agro-ecological concepts in their mental models of their farming systems.

Even in our limited sample of farmers there is considerable variation in farm types and individual farmers' mental models which influences whether farmers are likely to make use of voluntary subsidy schemes like AECS. Thus the mental models methodology underscores several areas that require further investigation. Firstly, how will different farms and farmers interpret and respond differently to research and policy that advocates agro-ecological transitions? What does this mean for the relative influence of agri-environmental research and policy, against the backdrop of competing voices that advocate precision farming? And lastly, what is the potential to scale up co-productive approaches like those utilized here to engage a wider range of agri-environmental stakeholders?

Notes

1. Much of the variance in terminology is rooted in different disciplinary traditions, including psychology, geography, sociology, planning, system dynamics and political science (Prager & Curfs, 2016, p. 37).
2. Our qualitative approach contrasts with the semi-quantitative concept mapping technique called fuzzy logic

cognitive mapping (FCM, see Glykas (2010)). FCM aims to generate (semi-)quantitative data to assess the strength (not the qualitative nature) of connections between concepts and is often used in participatory modelling and in many cases aims to run scenarios.

3. In the analysis we use S as short for scientist and F as short for farmer. The numbers correspond to the mental models in the Appendices.
4. With precision farming we primarily refer to varied rate application of inputs. The mental models in Appendix A show how precision farming applications vary between farms.
5. This observation links with theoretical work that distinguishes different farm objectives and modes of farming. For example, Ploeg (2018) distinguishes the 'peasant' and 'entrepreneurial' modes of farming.
6. See for example this blog, citing 'greater sustainability and environmental protection' from precision farming: <http://blog.agrivi.com/post/benefits-of-using-precision-farming-producing-more-with-less> [accessed 10-09-2018].

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Disclosure statement

No potential conflict of interest was reported by the author(s).

Notes on contributors

Freddy van Hulst is a researcher in the International Development Department at the University of Reading. He has an interest in inclusive agricultural innovation, agro-ecology and participatory approaches, and has research experience in various European and African contexts.

Rowan Ellis is a geographer working within the Social, Economic, and Geographical Sciences research group of the James Hutton Institute. She is interested in issues of environmental justice, water governance, and gender and development.

Katrin Prager is Senior Lecturer in Landscape Governance at the University of Aberdeen. Her research focusses on collaborative management of landscapes, land manager attitudes and behaviour, participatory policy processes and evaluation.

Joshua Msika is a transdisciplinary researcher within the Social, Economic and Geographical Sciences department of the James Hutton Institute. His research aims to contribute to the societal dialogue on the practical and conceptual challenges of (un)sustainability.

ORCID

Freddy van Hulst  <http://orcid.org/0000-0001-8106-875X>

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Appendices

Appendix A: Simplified mental models of scientists

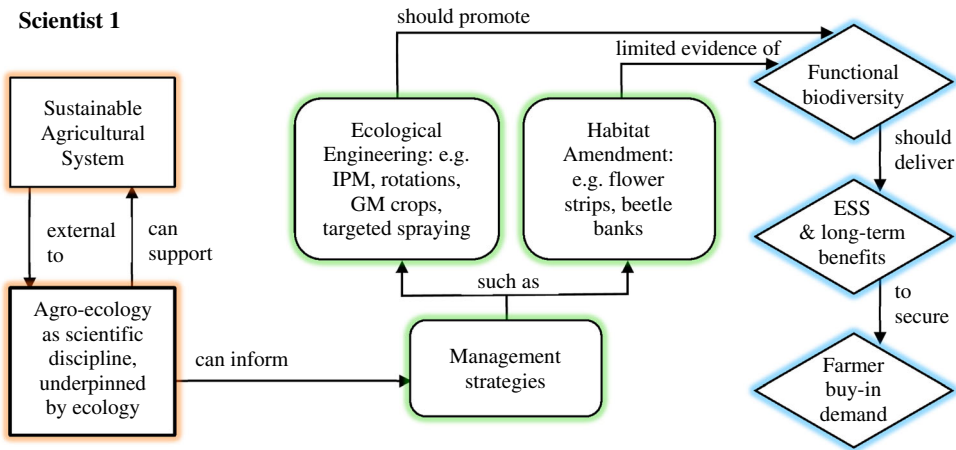


Figure A1. Mental model of Scientist 1, an ecologist with an interest in pest regulation in farming systems. [Legend of shapes: rectangle is concept/system; diamond is advantage/mediating factor; circle is disadvantage; rounded rectangle is a practice].

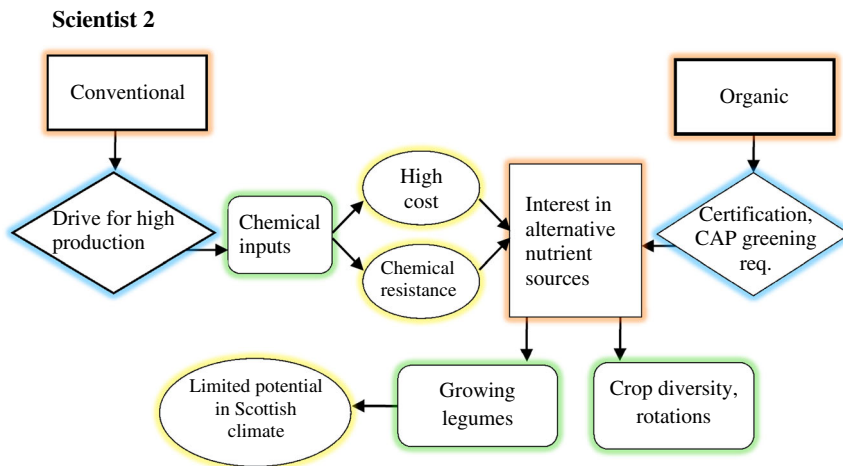


Figure A2. Mental model of Scientist 2, an environmental scientist with an interest in legumes and crop rotations. [Legend of shapes: rectangle is concept/system; diamond is advantage/mediating factor; circle is disadvantage; rounded rectangle is a practice].

Scientist 3

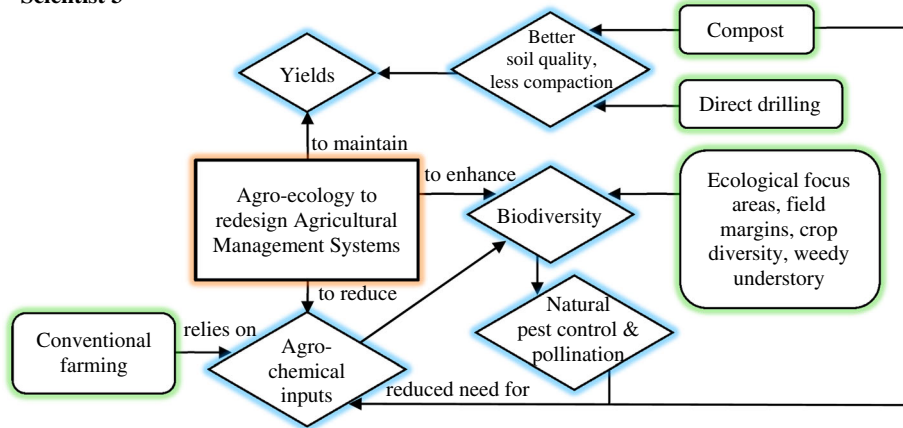


Figure A3. Mental model of Scientist 3, an ecologist with an interest in insect-crop interactions and forestry. [Legend of shapes: rectangle is concept/system; diamond is advantage/mediating factor; circle is disadvantage; rounded rectangle is a practice].

Scientist 4

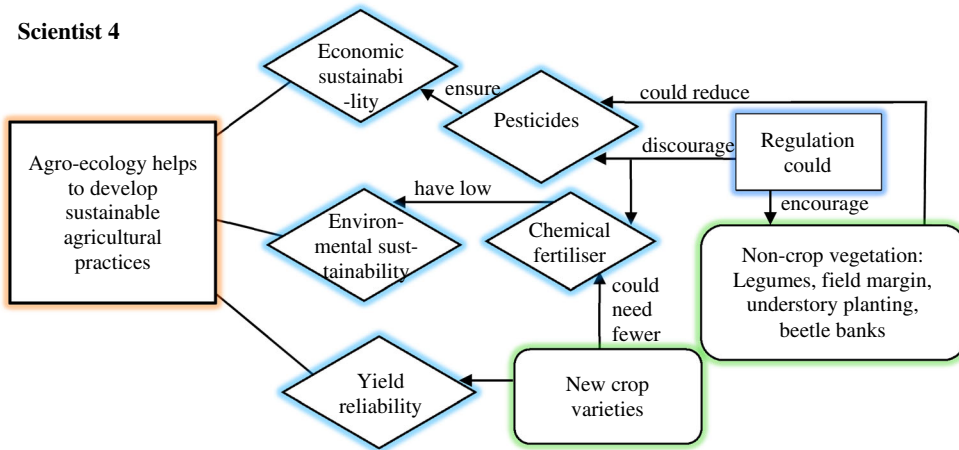


Figure A4. Mental model of Scientist 4, a plant scientist with an interest in agro-ecology and ecosystem services. [Legend of shapes: rectangle is concept/system; diamond is advantage/mediating factor; circle is disadvantage; rounded rectangle is a practice].

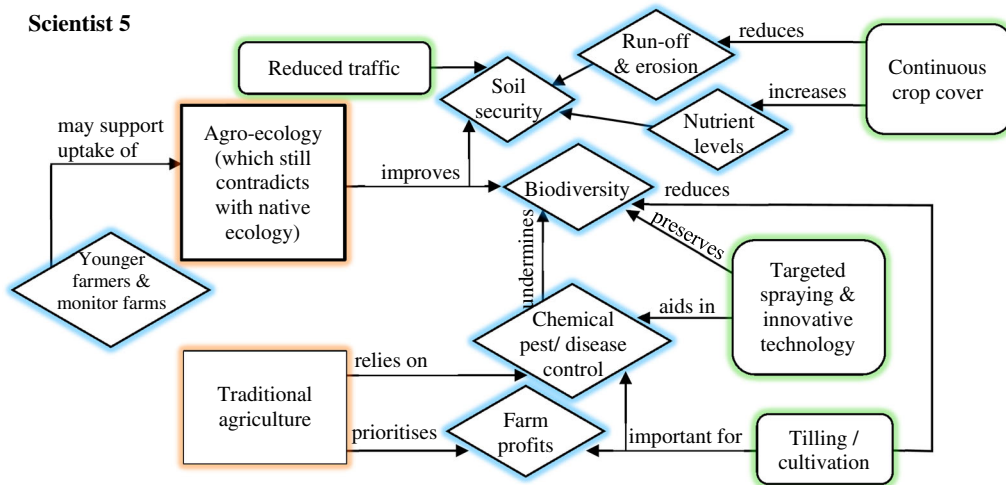


Figure A5. Mental model of Scientist 5, a soil scientist with an interest in soil management in agriculture. [Legend of shapes: rectangle is concept/system; diamond is advantage/mediating factor; circle is disadvantage; rounded rectangle is a practice].

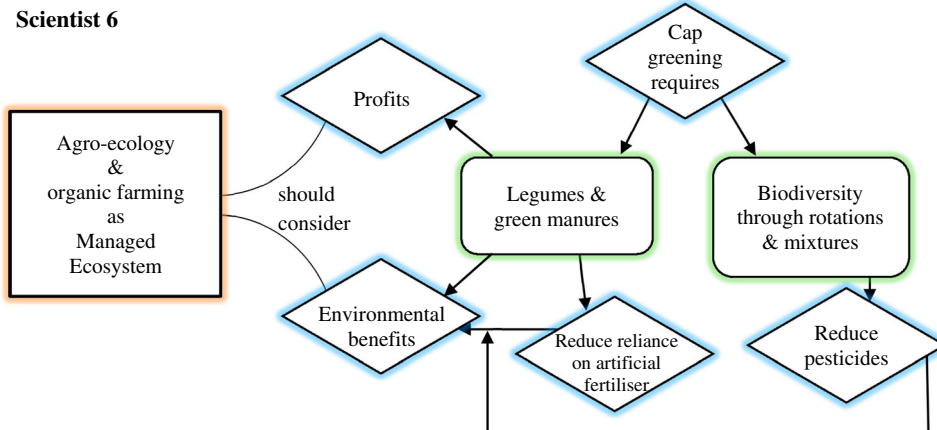


Figure A6. Mental model of Scientist 6, a plant scientist with an interest in organic farming. [Legend of shapes: rectangle is concept/system; diamond is advantage/mediating factor; circle is disadvantage; rounded rectangle is a practice].

Scientist 7

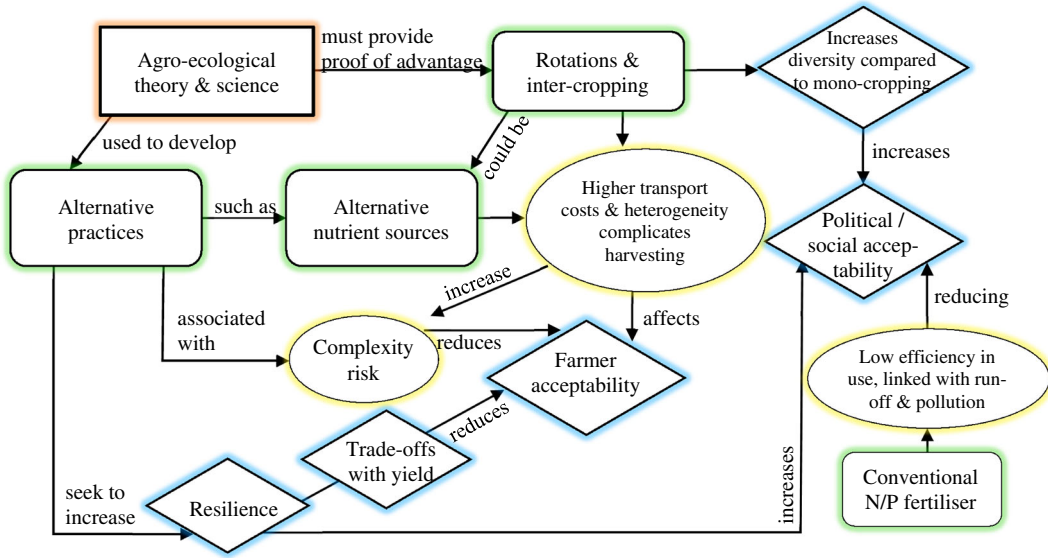


Figure A7. Mental model of Scientist 7, a plant physiologist with an interest in nutrients and rhizosphere dynamics. [Legend of shapes: rectangle is concept/system; diamond is advantage/mediating factor; circle is disadvantage; rounded rectangle is a practice].

Scientist 8

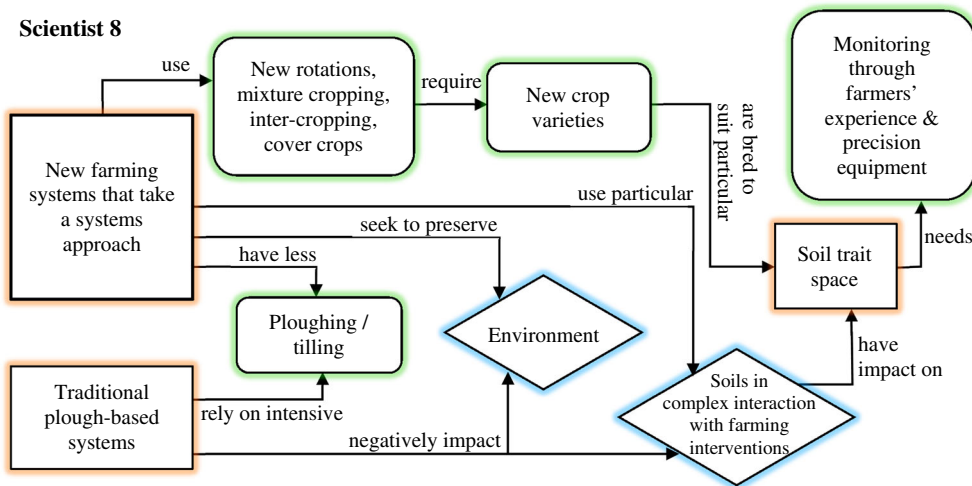


Figure A8. Mental model of Scientist 8, a molecular biologist with an interest in soil-root interactions. [Legend of shapes: rectangle is concept/system; diamond is advantage/mediating factor; circle is disadvantage; rounded rectangle is a practice].

Appendix B. Simplified mental models of farmers

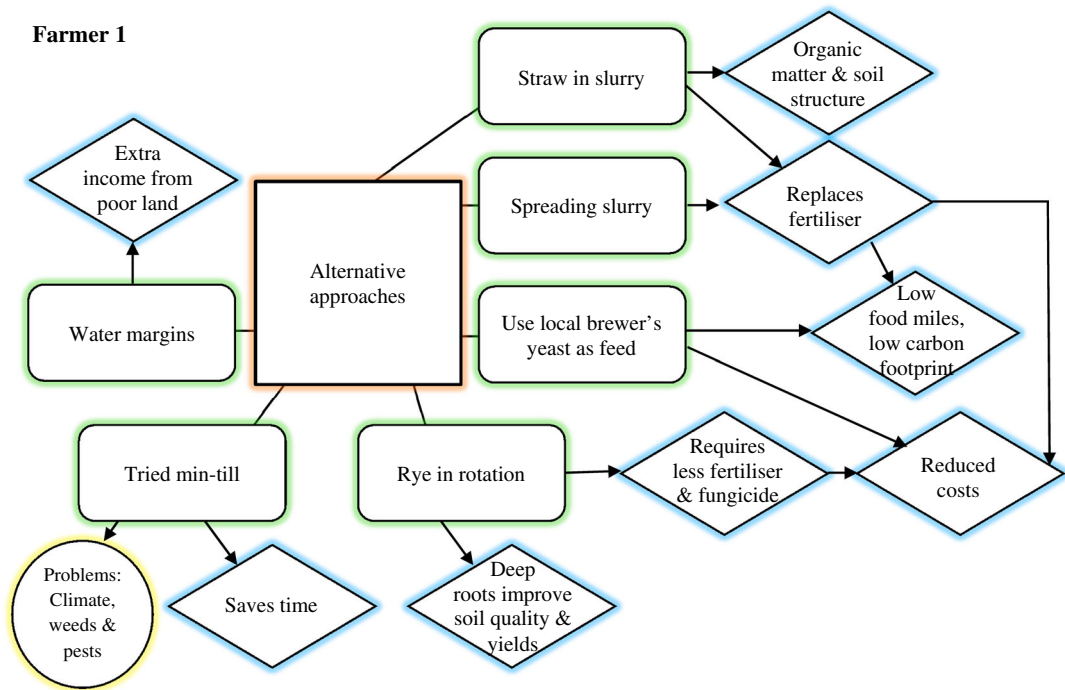


Figure B1. Mental model of Farmer 1, an intensive mixed pig and arable farmer (360 sows and 300 ha arable). [Legend of shapes: rectangle is concept/system; diamond is advantage/mediating factor; circle is disadvantage; rounded rectangle is a practice].

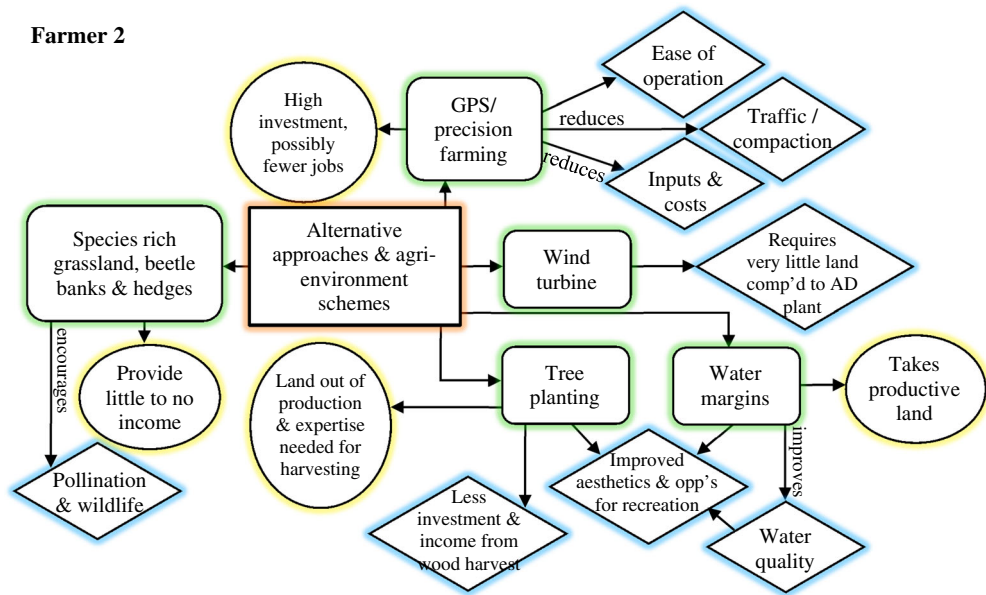


Figure B2. Mental model of Farmer 2, a small arable farmer (150 ha). [Legend of shapes: rectangle is concept/system; diamond is advantage/mediating factor; circle is disadvantage; rounded rectangle is a practice].

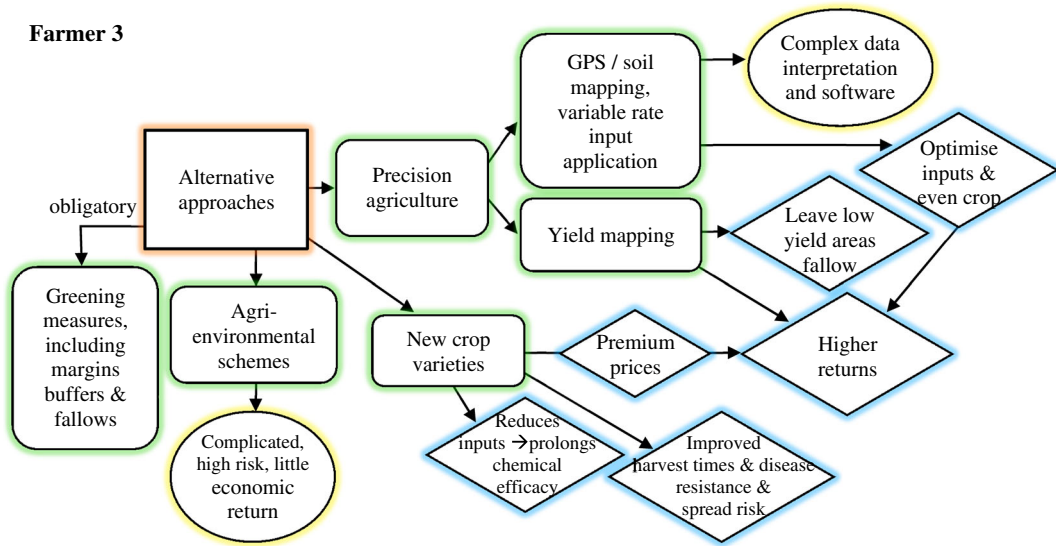


Figure B3. Mental model of Farmer 3, a large arable, contract farmer (1500 ha). [Legend of shapes: rectangle is concept/system; diamond is advantage/mediating factor; circle is disadvantage; rounded rectangle is a practice].

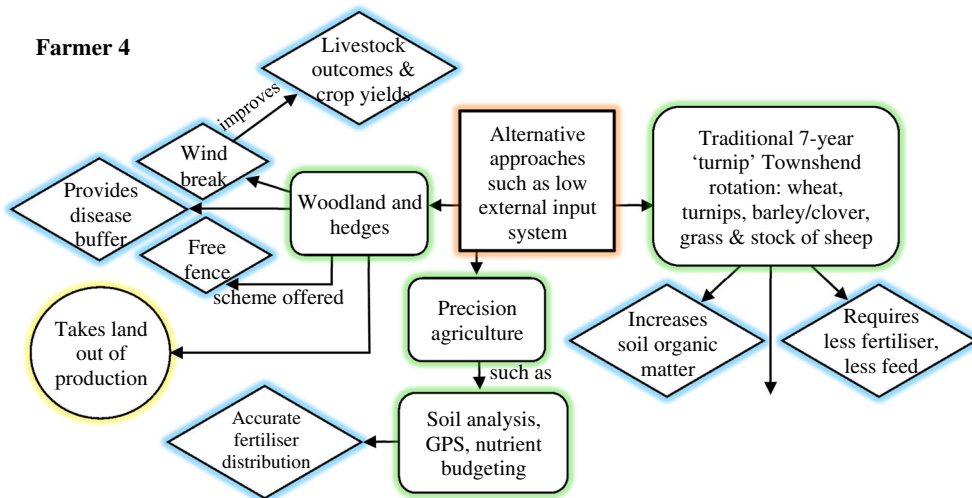


Figure B4. Mental model of Farmer 4, an extensive mixed cattle, sheep and arable farmer (90 ha, 70 cattle, 200 ewes, and 500 lambs for finishing). [Legend of shapes: rectangle is concept/system; diamond is advantage/mediating factor; circle is disadvantage; rounded rectangle is a practice].

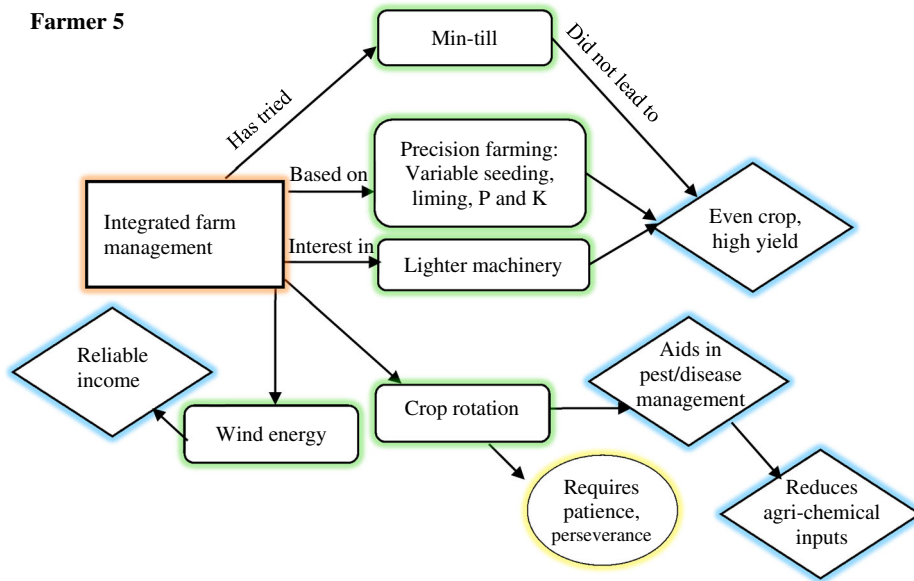


Figure B5. Mental model of Farmer 5, a medium arable farmer (420 ha total, some suckler cows). [Legend of shapes: rectangle is concept/system; diamond is advantage/mediating factor; rounded rectangle is a practice].

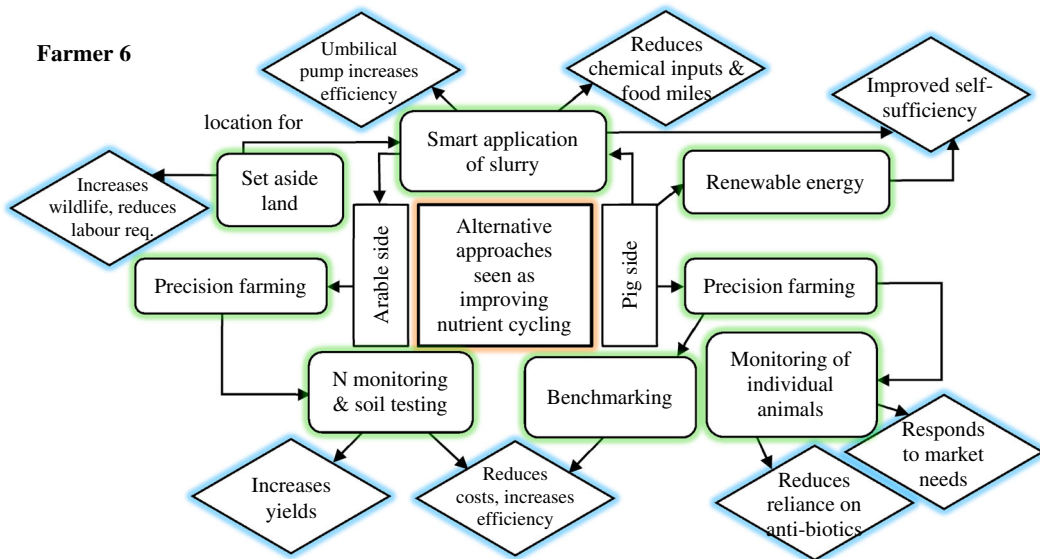


Figure B6. Mental model of Farmer 6, an intensive mixed pig and arable farmer (450 sows and 170 ha arable). [Legend of shapes: rectangle is concept/system; diamond is advantage/mediating factor; circle is disadvantage; rounded rectangle is a practice].

Farmer 7

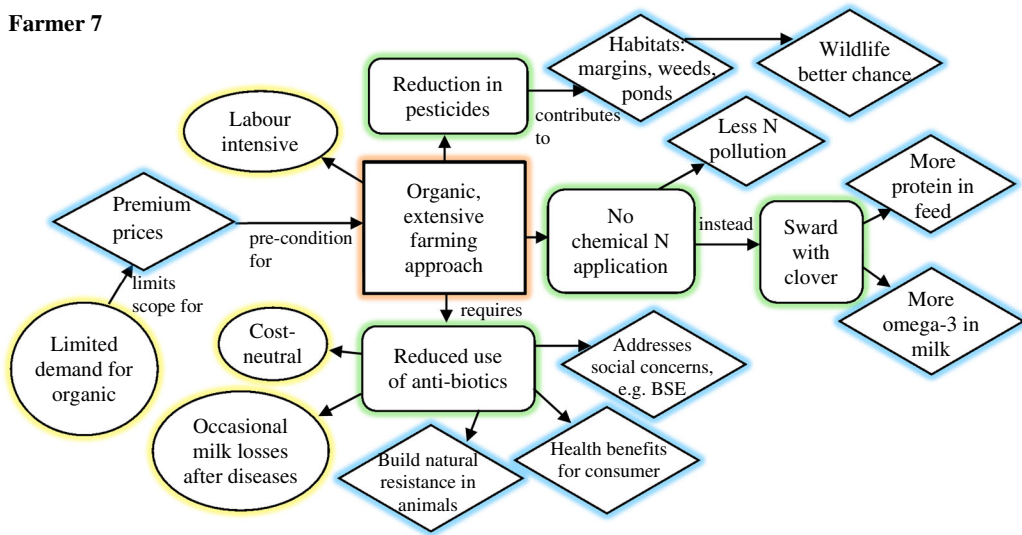


Figure B7. Mental model of farmer 7, an organic dairy farmer (160 ha) with 160 cows. [Legend of shapes: rectangle is concept/system; diamond is advantage/mediating factor; circle is disadvantage; rounded rectangle is a practice].