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Department for Environment Food & Rural Affairs

Evidence Project Final Report

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Project identification

1. Defra Project code: SCF0321
2. Project title: Evaluating the Productivity, Environmental Sustainability and Wider Impacts of Agroecological compared to Conventional Farming Systems
3. Contractor organisation(s): Cranfield University and UK Centre for Hydrology and Ecology (UKCEH)
4. Total Defra project costs (agreed fixed price): £ 87,082
5. Project: start date .... 1 July 2022
   end date .... 28 February 2023

6. It is Defra's intention to publish this form.
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Executive Summary

7. The executive summary must not exceed 2 sides in total of A4 and should be understandable to the intelligent non-scientist. It should cover the main objectives, methods and findings of the research, together with any other significant events and options for new work.

Context, aim and objectives

Existing agriculture systems in the UK are effective at producing safe and relatively cheap food, but they are a cause of greenhouse gas emissions, biodiversity loss, and soil degradation. It has been proposed that greater use of agroecological and regenerative farming would lead to more positive effects. The aim of this project was to evaluate the productivity, environmental sustainability and wider impacts of agroecological compared to conventional farming, by addressing three objectives:

1. to undertake an evidence review of regenerative/agroecological farming systems,
2. to assess the risks, barriers and opportunities, and identifying gaps in the knowledge, and
3. to characterise agroecological farming research capability in the UK, explore gaps and priorities, and explore the potential role of a new "living lab" trial network.

The research has been presented in three separate reports (Burgess et al. 2023, Hurley et al. 2023, and Staley et al. 2023), which are attached as appendices. The main results are summarised here.

Method

Objective 1 was addressed using a desk-based rapid evidence review, and the level of confidence in the analysis was determined using the IPBES four-box model (IPBES 2017, 2018). Objective 2 was addressed by in-depth semi-structured interviews with 23 respondents including farmers in late 2022. The interviews were used to explore definitions of agroecological and regenerative farming, barriers to the adoption, and views towards the concept of 'living labs'. Objective 3 was addressed through an online survey with 22 respondents from 20 organisations in January and February 2023, an online workshop with 34 participants in January 2023, and informed by the findings of work to address Objectives 1 and 2.

Results and discussion

1.1 Defining and characterising agroecological farming systems

A review of definitions highlighted, in brief, that organic farming places strong restrictions on inputs, agroecological analyses often focus on principles, and regenerative farming typically emphasises the enhancement of soil health and biodiversity at a farm-scale. The stakeholder interviews demonstrated that the terms regenerative agriculture and agroecology are employed interchangeably by some, sequentially by others (with regenerative practices seen as steps towards a bigger whole-farm agroecological system), and viewed by some as discrete (who recognise the social justice, economic and political aspects of agroecology). Within these different interpretations, regenerative practices are often assumed to be those that minimise tillage and bare soil, foster plant diversity, and reduce the use of pesticides and synthetic fertilizers. We noted that the impact of organic, agroecological or regenerative systems on greenhouse gas emissions was implicit rather than explicit. We identified 16 agroecological practices that could be used in the UK: crop rotations, conservation agriculture, cover crops, organic crop production, integrated pest management, the integration of livestock to crop systems, the integration of crops to livestock systems, field margin practices, pasture-fed livestock, multi-paddock grazing, organic livestock systems, tree crops, tree-intercropping, multistrata agroforestry and permaculture, silvopasture, and rewilding.

1.2. Impact of agroecological practices at farm-scale

Our detailed review (see Burgess et al. 2023) highlighted that the 16 agroecological practices tended to increase soil and biomass carbon and biodiversity at a field- or farm-scale relative to a stated baseline. The soil carbon benefits were due to increased crop cover, the introduction of grass into arable systems, reduced cultivation, and/or the addition of soil amendments. The biodiversity benefits were derived from an increased diversity of crops and habitats, introducing plants that attract pollinators, reduced grazing pressure, and/or reduced use of pesticides and herbicides. Gaps in knowledge were highlighted particularly in terms of greenhouse gas emissions and biodiversity. The analysed effect on yields, product values, and input costs varied according to the practice and the baseline comparison. Hence in most cases, a farmer will need to balance trade-offs, perhaps guided by tools such as financial, economic, or life cycle analyses. In some cases, such as organic farming, a reduction in profitability due to a reduction in yield and certification costs may be compensated by an increase in product price.

1.3 Modelling agroecological systems in a UK context

Our review highlighted existing modelling frameworks such as ASSET, ERAMMP IMP, EVAST and NEVO that could be repurposed to model agroecological systems across the UK. However we identified three barriers to their successful use. Firstly, modellers need to quantify the links between agroecological scenarios, spatial contexts and selected parameters within the underlying models. Secondly, the lack of readily available experimental data on the effect of agroecological practices and their change over time means that parameterising models remains challenging, and the alternative use of expert-based scoring or

benefits transfer approaches can result in very large levels of uncertainty. Thirdly, a validated assessment of the aggregated impact of agroecological practices at a national scale will require effective national monitoring approaches that can assess the level of implementation of agroecological practices.

2. Opportunities from and barriers to a transition to agroecological systems
The uptake of agroecological practices by farm businesses depends on the balance between the opportunities offered and the barriers to implementation. As indicated in 1.2, the opportunities include increased biomass carbon, increased soil carbon in surface layers, and increased on-farm biodiversity. Supermarkets could support environmentally-positive practices, but there is also a strong drive for low food prices. The barriers to some agroecological practices will be geographical or incompatibility with management objectives at the farm-level. However, where these are not constraints, the major barriers are often related to uncertainty in the effect of the practices on yields and costs, and the need to finance the initial investment and certification costs. Enablers to overcome those barriers include knowledge exchange (particularly as the promotion of agroecological practices is not driven by organisations wanting to sell a product) and financial incentives (with a focus on market mechanisms that differentiate between desired and undesired societal outcomes). Evidence from other countries, particularly France, show that agroecological transitions can succeed where the right combination of policy instruments (e.g. grants, support for advice and collaboration, cultural support) are sustained by long-term political will.

3.1 Existing agroecological farming research capability and infrastructure in the UK
The online survey results indicate that most agroecological farming research initiatives and networks were funded by charities, NGOs, or funded by themselves, with some receiving UK or EU government funding. The initiatives ranged from single sites to networks of 50-100 sites, and with agroecological practices applied from one to over 20 years. Farmer participation in such research may be biased to those who can afford the time and money. Five case studies are examined in the main report (Staley et al. 2023) including an ongoing living lab network, three research projects, and a long-term demonstration farm. Only about 60% of respondents were collecting data from their network, often focused on biodiversity. About three-quarters of those not collecting data, would collect data given more funding, knowledge, or support. Face-to-face and email communication was most frequently used between farms in a network. Around two-thirds of respondents held farm demonstration days as a means of knowledge exchange, and further knowledge exchange was a common future aspiration.

3.2 Research gaps and priorities
The survey and workshop supported the observation from 1.2 that many of the impacts of agroecology practices, especially in relation to greenhouse gas emissions and biodiversity, remain poorly understood. Although 1.2 focused on farm-level effects, the consequential effects of, for example, reduced yields with agroecological practices remains a pertinent area for research. The variation in responses between soil types or regions would also be useful to improve the understanding of scaling-up opportunities. The need to support research over a sustained time period was also highlighted as several years are often needed for effects to become apparent. The transition to agroecological farming across different types of business requires the need for farmer support and changes in agricultural education. The role of economic drivers and supply chain structures in supporting agroecological practices also requires more research. Standardisation of data quality and formats, in particular for regulatory data, could help reduce some barriers, but it could also constrain innovation. National assessments of agroecological practices are also constrained by a lack of uptake data.

3.3 Informing a potential UK living labs trial network
Living labs have been defined as "user-centred, open innovation ecosystems based on a systematic user co-creation approach, integrating research and innovation processes in real life communities and settings" (Malmberg et al. 2017). Important roles for a living labs network include providing robust locally-relevant evidence of the productivity and financial viability of agroecological farming, improving data standardisation, and encouraging collaboration between farmers, organisations, and researchers for data collection, sharing, and use. The role of Defra in a living labs network should be negotiated carefully with existing stakeholders involved in agroecological/regenerative transitions. Such a network should be sufficiently resourced in order to fund research and knowledge exchange and in order to build capacity among farmers and organisational stakeholders. Building on the response of the survey, case studies, and workshops, the benefits and disadvantages of four options were examined:

1) Develop a standardised methodology or protocol to support consistency of farm measurements. Soil carbon and farm carbon accounting were particularly highlighted.
2) To maximise synergies within existing agroecological farm networks with standardised data collection.
3) A new research network set up to apply agroecological practices on commercial farms, co-designed between farmers and researchers, with standardised data collection on impacts and trade-offs.
4) A long-term living lab UK network set up, with funded facilitation roles and research projects.

Some of the above options could be applied in combination. The optimal option will depend on the ambition of Defra and the available funding and timescales.

8. As a guide this report should be no longer than 20 sides of A4. This report is to provide Defra with details of the outputs of the research project for internal purposes; to meet the terms of the contract; and to allow Defra to publish details of the outputs to meet Environmental Information Regulation or Freedom of Information obligations. This short report to Defra does not preclude contractors from also seeking to publish a full, formal scientific report/paper in an appropriate scientific or other journal/publication. Indeed, Defra actively encourages such publications as part of the contract terms. The report to Defra should include:

- the objectives as set out in the contract;
- the extent to which the objectives set out in the contract have been met;
- details of methods used and the results obtained, including statistical analysis (if appropriate);
- a discussion of the results and their reliability;
- the main implications of the findings;
- possible future work; and
- any action resulting from the research (e.g. IP, Knowledge Exchange).

Context and objectives

Existing agriculture systems in the UK are effective at producing safe and relatively cheap food, but they are a major source of greenhouse gas emissions and biodiversity loss. It has been proposed that greater use of agroecological and regenerative farming could lead to more positive effects at farm- and landscape-scales. The aim of this project was to evaluate the productivity, environmental sustainability, and wider impacts of agroecological compared to conventional farming. This document summarises that work.

The project comprised three objectives, with each associated with a work-package. Objective 1 was to undertake an evidence review of agroecological farming systems. The report that we produced (Burgess et al. 2023) addressed four sub-objectives. An assessment of sustainability metrics (which was a separate objective in the research call) was merged into sub-objective 1.1.

1.1. To review definitions of agroecological farming, the metrics associated with sustainable agriculture, and identify UK-relevant agroecological farming practices.
1.2. To review the impacts of UK-relevant agroecological practices with a focus on soil health (primarily through their effect on soil carbon), on-farm biodiversity, food production, costs, and other ecosystem services including socio-economic and animal welfare impacts where available.
1.3. To initiate a review of published evidence on the major opportunities for, barriers to, and enablers of agroecological innovations, technology and actions to improve productivity and sustainability.
1.4. To review and appraise the key tools to model agroecological vs non-agroecological systems including the use of spatial modelling and mapping and consideration of land-use availability and suitability.

Objective 2 was to assess the risks, barriers and opportunities arising from a transition to regenerative/agroecological systems, and identifying gaps in the knowledge. The research is described by Hurley et al. (2023). The first part of work (sub-objective 2.1) included an extension of objective 1.3, which was to review evidence on the opportunities for, barriers to, and enablers of agroecological innovation.

2.1. To complete a review of published evidence on the major opportunities for, barriers to, and enablers of agroecological innovations, technology and actions to improve productivity and sustainability.

The next two sub-objectives were based on stakeholder feedback looking at farmer and stakeholder definitions, barriers, and stakeholder understanding of “living lab”.

2.2. To explore farmer and stakeholder definitions of agroecological and regenerative farming, and to understand the barriers to the adoption of agroecological and regenerative farming.
2.3. To investigate farmer and stakeholder views towards the concept of ‘living labs’ as a way to share research and learnings about agroecological/regenerative farming.

Objective 3 was to map existing agroecological/regenerative farming research capability, explore gaps and priorities, and explore the potential role of a new living lab network. In order to provide context for the third report (Staley et al. 2023), the concept of living labs was first examined. The three sub-objectives were:

3.1 To characterise the existing agroecological and regenerative farming research capability and infrastructure in the UK.
3.2. To explore lessons from recent research initiatives and identify key research gaps, to inform a potential UK living labs trials network in agroecology/regenerative farming.
3.3. To develop recommendations for a new living lab trial or research network in agroecology/regenerative farming.

Extent to which the objectives have been met

All objectives set out in the contract have been met. The initial project meeting was held on 13 July 2022 and monthly management meetings involving staff from Defra, Cranfield and UKCEH continued until February 2023. Three reports were delivered to Defra detailing the findings below (Burgess et al. 2023, Hurley et al. 2023, Staley et al. 2023). The method, results and implications of each piece of work is discussed in turn.

Work-package 1. Evaluating agroecological farming practices

1.1. To review definitions of agroecological farming, the metrics associated with sustainable agriculture, and identify UK-relevant agroecological farming practices

Method

The review examined definitions of organic, agroecological and regenerative farming, and placed them in the context of other terms such as sustainable intensification and climate-smart farming. It then examined the argument that the desirability or not of selected practices depends on their impact, which can be assessed using sustainability metrics. To complete this section of the review, 16 agroecological practices were identified.

Results

Burgess et al. (2023) reviews the terms organic farming, agroecology, and regenerative agriculture. Although there is overlap, there are also differences of emphasis. In brief, organic farming is regulated and places strong restrictions on inputs, agroecological analyses often focus on principles, and regenerative farming typically emphasises the enhancement of soil health and biodiversity at a farm-scale. These aspects alongside sustainable intensification and climate smart agriculture are briefly illustrated below:

Organic farming: the Organic Products Regulations (UK Government 2009) specifies that UK growers, processors and importers who sell feed and food as “organic” need to be registered with one of six approved organisations (UK Government 2020b). These regulations have strong rules on inputs.

Agroecology: the meaning of this term varies between countries and contexts (FAO 2020). The FAO (2018) notes that “agroecology is an integrated approach that simultaneously applies ecological and social concepts and principles to the design and management of food and agricultural systems”. The HLPE (2019) identified 13 agroecological principles, building on the FAO 10 elements, which in turn has similarities to the 10 principles described by the Landworkers Alliance (2019) (Table 1.1). Soil health, agricultural biodiversity, input reduction, and economic diversification are common technical and environmental features. Perhaps surprisingly, the FAO and HLPE definitions of agroecological systems do not make any specific mention of the role of the system in mitigating or adapting to climate change. By contrast, the Landworkers Alliance highlights climate change mitigation as an objective (Table 1.1).

Regenerative agriculture: in a recent review, Burgess et al. (2019) identified three aspects of regenerative agriculture as i) a set of practices, ii) which may or may not avoid synthetic fertilizer and pesticides, and iii) a focus on going beyond the reduction of negative impacts to ensure that agriculture has a positive environmental effect (Figure 1.1). In the study by Burgess et al. (2019), regenerative agriculture was defined as “a system of principles and practices that generates agricultural products, sequesters carbon, and enhances biodiversity at the farm scale”. Hence this form of analysis does not consider the offsite effects. The focus on soil health, carbon sequestration, and reversal of biodiversity loss were also the three main attributes identified in a study of the use of the term “regenerative agriculture” in the North of England (Magistrali et al. 2022).

Sustainable intensification and climate smart agriculture: agroecological or nature-based farming practices are often contrasted with technology-based farming practices. For example, a UKRI and Defra supported MACSUR meeting at the Royal Society on 7 November 2022 posed the question as to whether “sustainable intensification” or “regenerative agriculture” offered the most promising pathway for agricultural sustainability? However, despite the title of the workshop most of the speakers indicated that this was a false binary choice. Instead they indicated that it was more useful to **focus on the outcomes of specific practices** rather than definitions. For example, sustainable intensification (that can encompass agroecological practices) can be defined as “maintaining or enhancing agricultural production while enhancing or maintaining the delivery of other ecosystem services”. This focus on ecosystem services, rather than just environmental services allows the inclusion of societal aspects of sustainability (Diogo et al. 2022).

Table 1.1. The 13 agroecological principles described by HLPE (Modified from HLPE 2019; page 41) categorised as environmental and technical or social and governance, and the relationship with the ten elements described by FAO, and 10 principles by the Landworkers Alliance (2019)

HLPE (2019) agroecological principles	FAO element	Landworkers Alliance (2019)
Environmental and technical		
Soil health: secure and enhance soil health for improved plant growth, by managing organic matter and soil biological activity.	Soil health	Building soil health
Biodiversity: maintain and enhance genetic, species, and functional diversity and overall agroecosystem biodiversity at range of scales.	Agricultural biodiversity	Encourage biodiversity
Input reduction: reduce or eliminate dependency on purchased inputs and increase self-sufficiency.	Exposure to pesticides	Replace agrochemicals
Economic diversification: diversify on-farm incomes thereby supporting greater financial independence for farmers.	Added value	Enhance economic resilience
		Climate change mitigation and adaption
Recycling: preferentially use local renewable resources and help close resource cycles of nutrients and biomass.		Promoting close loop systems
Animal health: ensure animal health and welfare.		
Synergy: enhance positive ecological interactions amongst the elements of agroecosystems (animals, crops, trees, soil and water).		
Social and governance		
Participation: encourage greater participation in decision-making and decentralised governance of agriculture and food systems.	Women empowerment	Integrating the community
Social values and diets: food systems based on the culture, social and gender equity of local communities that provide healthy, diversified, seasonally and culturally appropriate diets	Dietary diversity	Supporting culture and tradition
Fairness: support dignified and robust livelihoods for all actors based on fair trade, employment and intellectual property rights.	Income Productivity Youth employment	Affordability of food Quantity and quality of jobs
Land and natural resource governance: strengthen institutional arrangements to support of family farmers and smallholders.	Security of land tenure	
Co-creation of knowledge: including horizontal sharing of knowledge and farmer-to-farmer exchange.		Encourage innovation and education
Connectivity: ensure confidence between producers and consumers through fair and short distribution networks.		

Figure 1.1. Regenerative agriculture aims to go beyond the "do no harm" principles of sustainable agriculture

Implications and future research

One observation, as previously mentioned in relation to Table 1.1, is that the focus on agroecology does not specifically address the global climate emergency. It could be argued that promoted farming approaches should have a stronger focus on climate-smart agriculture. Climate-smart agriculture has been defined as "agriculture that sustainably increases productivity, resilience (adaptation), reduces/removes greenhouse gases (mitigation), and enhances the achievement of national food security and development goals" (FAO 2013). Hence in a similar way to sustainable intensification, there is an emphasis on increased production, but emphasis is also placed on reducing greenhouse gas emissions (Lipper et al. 2014). A recent review of the impact on agroecological practices on greenhouse gas emissions is provided by Albanito et al. (2022).

Although there is substantial literature focused on definitions, many authors seem to emphasise that the important question is the extent to which these farming approaches can maintain or enhance food production whilst maintaining or enhancing environmental value, and improved social outcomes.

The environmental values of agroecological systems can be reviewed in terms of their effects on greenhouse gas emissions, enhancing biodiversity, and improving soil health. The Global Farm Metric (2022a) seeks to provide a common language and framework for the assessment of the sustainability of agricultural systems, and thereby inform practice and policy (Sustainable Food Trust 2022). At the end of 2022, it was updated to include 12, rather than 11 major categories (Global Farm Metric 2022b) (Figure 1.2). The 12 categories can be grouped into four groups: i) inputs such as farmers and workers, nutrients, and resources, ii) outputs such as crops and pasture, animals, production, and economics, iii) environmental impacts such as nature, soil, water, and climate, and iv) community impacts. Most of these categories, with the possible exception of economics are also covered by Linking Environment And Farming (LEAF) Marque certification (Table 1.2). The Soil Association's organic certification covers each topic except economics and community issues. The Red Tractor mark focuses on health and safety issues, and Pasture for Life and RSPCA Assured primarily focus on animal husbandry issues (Table 1.2).

Figure 1.2. The Global Farm Metric comprises of 12 segments (Global Farm Metric 2022b)

Table 1.2. The 12 categories covered by the "Global Farm Metric" (Global Farm Metric 2022b) and the extent to which the components are covered by other sustainability metrics (after Sustainable Food Trust 2021), and TAPE (FAO 2019). Items indicated with a "✓" and shaded green are included in the metric.

Global Farm Metric	Global Farm Metric	LEAF	TAPE	Soil Association	Red Tractor	Pasture for Life	RSPCA Assured
Farmers and workers	✓	✓	✓		✓		✓
Nutrients	✓	✓		✓	✓		
Resources	✓	✓		✓			
Crops and pasture	✓	✓		✓	✓		
Animals	✓	✓		✓	✓	✓	✓
Production	✓	✓	✓	✓	✓	✓	
Economics	✓		✓				
Nature	✓	✓	✓	✓		✓	
Soil	✓	✓	✓	✓	✓	✓	
Water	✓	✓		✓	✓		
Climate	✓	✓		✓			
Community	✓	✓	✓				

The last section of objective 1.1 was to identify farming practices associated with agroecology. The 16 farming practices identified were conservation agriculture, cover crops, organic crop production, crop rotations, integrated pest management, integration of livestock into arable systems, integration of crops into livestock systems, field-margin management, pasture-fed livestock, multi-paddock grazing, tree crops, tree-intercropping, multistrata agroforestry, silvopasture, and rewilding.

1.2. To review the impacts of UK-relevant agroecological practices

Method

For each agroecological practice, we built on spreadsheets of evidence used in literature review reported by Burgess et al. (2019). When reviewing the practices, focus was placed on their impact in terms of quantifiable impacts on soil carbon (alongside biomass carbon and greenhouse gas emissions), biodiversity, and food production because of their direct link to government targets in relation to net zero greenhouse gas emissions, biodiversity, and proportional food imports. In general, the review did not focus on social and animal health impacts which are often assessed in qualitative rather than quantitative terms. The number of references used was greatest for conservation agriculture (n = 21) and organic agriculture (n = 33) and least for tree crops (n = 6). The level of confidence of impacts was based on the IPBES "four-box" model for qualitative communication of evidence (IPBES 2017, 2018).

Results

The general effect of each of the practices, relative to a stated control, on soil carbon, biodiversity, yield, and other impacts on each of the 16 practices are described by Burgess et al. (2023). An example of the description for crop rotations (the shortest review) and the associated text is provided in Box 1. The report by Burgess et al. (2023) also includes an appendix of the data used for each analysis.

Box 1. Example of the review of one agroecological practice from Burgess et al. (2023)

Crop rotations

The use of crop rotations is a well-established agroecological practice where different crops are grown in sequence on the same arable land. We reviewed seven papers. The main impacts are described in table below with the quality of evidence indicated in brackets. The use of "break crops" can disrupt the build-up of weeds and soil-borne diseases and there can be nutritional benefits if the break crop is a legume (Angus et al. 2015). The type of break crop is important, for example there is little rotational benefit of growing wheat after wheat compared to wheat to barley (Angus et al. 2015). An important assumption is that the yield of the break crop is of similar economic importance to the main annual crop.

Soil carbon: in a global study, Liu et al. (2022) indicated that crop rotations significantly increased soil organic carbon (SOC) in the uppermost 20 cm. They related this to a greater diversity in the form of organic matter added to the soil and greater quantities of biomass production. The use of crop rotations also reduced weed density.
Biodiversity: crop rotation increased soil microbial diversity (Venter et al. 2016), and biodiversity in general (Beillouin et al. 2021).
Yield: a global meta-analysis indicated that the effect of planting different crops in succession on crop yields is positive, and this was attributed to reduced pest, weed and disease pressures (Angus et al. 2015). However there is no yield benefit of growing wheat after another non-wheat cereal (Angus et al. 2015).
Greenhouse gases: the inclusion of a legume crop into a cereal rotation can reduce greenhouse gas emissions (MacWilliam et al. 2018).
Evidence gaps: the benefits of crop rotations are predicated on the profitability and usefulness of the break crops. Hence research to increase the usability and gross margins of break crops, such as dried peas, can be particularly fruitful.

Impacts of crop rotations relative to continuous arable crops	Confidence	Effect
Soil carbon: Crop rotations increase soil carbon compared to continuous annual monocrops	Well established	Benefit
Biodiversity: Crop rotation increases soil microbial diversity Crop rotation increases biodiversity	Well established Well established	Benefit
Yields: Inclusion of non-cereal break crops increases yield of subsequent wheat	Well established	Benefit
Inclusion of non-wheat cereal species have no effect on yield of subsequent wheat	Well established	Similar
Greenhouse gases: crop rotation with cereal and legume reduces GHG emissions per ha and per tonne yield compared to monoculture cereal	Established but incomplete	Benefit
Other: Crop rotation reduces weed density	Well established	Benefit
References reviewed for rotations: Angus et al. (2015), Beillouin et al., (2021). Bowles et al. (2020), Liu et al. (2022), MacWilliam et al. (2018), Venter et al. (2016), Weisberger et al. (2019)		

For each practice, a reference and value, subjectively selected by the authors as being representative after reviewing a selection of papers, was included in a summary table (Table 1.3). For example the value of 1.06 for the impact of crop rotations, relative to continuous cereal crops, implies that the soil carbon following crop rotations was 6% higher than with a continuous cereal crop.

Table 1.3. Indicative main "on-farm" effects of 16 agroecological practices (expressed as effect of intervention divided by baseline. The colour of shading refers to whether the effect is positive, similar to positive, similar or very variable, similar to negative, or negative. References for each value is provided in Burgess et al. 2023.

Agroecological practice	Counterfactual or baseline	Soil carbon	Biomass carbon	On-farm biodiversity	Mean crop, grass or livestock yield	Input costs
Crop rotations	Continuous cereal cropping	1.06		1.03-1.15	1.05-1.37	Inconclusive
Conservation agriculture	Crop production with intensive tillage	Variable		~1.00	0.86-1.01	Lower
Cover crops	Bare fallow	1.07-1.19	Higher	1.38	0.96-1.13	Higher
Organic crop production with organic production with organic amendments	Crop production with fertilizers and/or agrochemicals	1.07-1.09		1.30-1.50	0.48-0.92	Lower to higher
	Crop production with no amendments or fertilizers	1.07-1.09		Inconclusive	1.01-1.07	Higher
Integrated pest management	"Baseline" pest management practice	Inconclusive		Higher or similar	Higher or similar	Reduced agrochemical costs
Integrated livestock/arable	Specialist arable	Similar		Higher or similar	0.93-1.02	Inconclusive
Integrated livestock/arable	Specialist livestock	Decrease		Higher or similar	Higher or similar	Inconclusive
Field margin practices e.g. wild flower strips or hedges	Crop production	1.32	[a]	2.7-7.1	0.85-0.95[b]	Higher
	Grass production	0.91	[a]	Variable	Inconclusive	Inconclusive
Pasture-fed livestock	Grain-fed livestock	Higher or similar		Higher or similar	Lower	Lower
Multi-paddock Grassland	Grassland; continuously grazed	0.99-1.50	Higher	Inconclusive	0.98-1.00[c]	Higher
Organic grass receiving organic Fertilizer	Grassland: receiving synthetic fertilizer	1.20		Higher	0.70-1.50	Inconclusive
	Grassland: receiving no fertilizer	1.30		0.94	1.98	Inconclusive
Tree crops	Annual crop production	1.18	Higher	Higher or similar	0.75-1.60	Inconclusive
Tree intercropping	Annual crop production	1.16)	Higher	1.37	0.42-1.00[d]	Lower to higher
Multistrata agroforestry	Monoculture permanent crops	1.57	Higher	Higher	Variable	Inconclusive
Silvopasture	Grassland	1.00-1.18	Higher	1.21	0.77-1.18[d]	Similar to higher
Rewilding and abandonment of agriculture	Crop and grazing systems	Higher	Higher	Variable	0.11-0.80	Inconclusive

Note that the values are illustrative and their inclusion is based on the subjective assessment of the authors after reviewing a range of papers for each practice. For full details see Burgess et al. (2023).

[a]: Will be higher with inclusion of hedgerows

[b]: For non-pollinated crops

[c]: Whilst grass production may be similar; multi-paddock systems may allow higher stocking rates

[d:]: Crop and grass yield responses in agroforestry are very sensitive to number of trees per unit area;

Positive effect: | Positive or similar: | Similar or very variable: | Similar or negative: | Negative:

Most of the 16 agroecological practices demonstrated **positive impacts in terms of on-farm biodiversity and/or increased soil and biomass carbon** (Table 1.3 and Table 1.4) relative to the stated baseline. The biodiversity benefits were derived from an increased diversity of crops, the introduction of plants that attract pollinators, provision of different habitats, reduced grazing pressure, and/or reduced use of pesticides and herbicides. The benefits in terms of soil carbon are due to increased crop cover, the introduction of grass into arable systems, reduced cultivation, and/or the addition of soil amendments in organic systems. The practices which did not show a well-established increase in biodiversity or soil carbon were conservation relative to conventional tillage, and the integration of crops into grassland systems. Whilst conservation tillage shows increased soil carbon in the surface layers, there is some evidence that this is offset by reductions at a depth of 10 to 60 cm (Cai et al. 2022). In general, an increase in soil and biomass carbon are associated with a decrease in greenhouse gas emissions, except for pasture-fed livestock where reduced growth rates are associated with higher methane emissions per kg of meat.

Table 1.4. Summary of the predicted impact of ten agroecological practices on the growing of continuous wheat and eight agroecological practices on mixed feed continuously-grazed livestock production, based on the results in this report. Positive responses are shaded green and negative responses are shaded red.

Baseline	Implemented practice	Crop yield[ab]	Produce value/kg	Costs	Bio-diversity	Soil carbon	Biomass carbon	GHG emissions
Continuous wheat	Rotations	↑	=	?	↑	↑	=	↓
	Conservation tillage	=	=	↓	=	?	=	?
	Cover crops	=	=	↑	↑	↑	↑	=
	Organic cropping	↓	↑	=	↑	↑	?	=
	IPM	↑	=	?	↑	?	=	?
	Integrate livestock	?	↑	↑	↑	?	=	↑
	Field margins	↓	=	↑	↑	↑	↑	?
	Tree crops	↓	=	?	↑	↑	↑	↓
	Alley cropping	?	=	↑	↑	↑	↑	↓
	Rewilding/abandon	↓	?	?	↑	↑	↑	↓
Mixed-feed continuously-grazed livestock	Integrate crops	↑	=	?	?	↓	?	?
	Field margins	?	=	=	↑	=	↑	?
	Pasture-fed	↓	?	↓	↑	↑	=	↑
	Multi-paddock	=	=	↑	?	↑	?	?
	Organic livestock	?	↑	=	=	↑	=	?
	Tree crops	↓	=	?	↑	?	↑	ê
	Silvopasture	?	=	↑	↑	?	↑	?
	Rewilding/abandon	↓	?	?	↑	?	↑	ê

[a]: Yield refers to the crop yield in the wheat comparison and ignores livestock and tree products.
[b]: Yields refers to livestock production in the livestock comparison and ignores crop and tree products

Note: up arrow demonstrates an increase; down arrow demonstrates a decrease, = signifies a similar response, and ? indicates the response is unresolved or inconclusive. GHG = greenhouse gas.

Implications and future work

It should be noted that the above assessments concern responses **at a field or farm-level.** This is similar to a recent study on the effects of agroecological practices in the UK on greenhouse gas emissions (Albanito et al. 2022). The implications of such practices beyond the farm level, depends in part on the assumptions made. For example, if the assumption is that say reduced yields on an individual farm leads to greater food imports then consequential life cycle assessment generally predicts that the negative effects of the reduced yield on global carbon storage and biodiversity can be substantial. By contrast, if we assume that the lack of production results in less consumption or less waste, then the global effect will be closer to that indicated by the farm-scale analysis.

1.3. To initiate a review of published evidence

Method

An initial review of published evidence on the major opportunities for, barriers to, and enablers of agroecological innovations, technology and actions to improve productivity and sustainability was completed based on seven papers authored by Giller et al. (2021), Sinclair et al. (2019), Mottershead and Maréchal (2017), Jordon et al. (2022), Magistrali et al. (2022), Vermunt et al. (2022), and the Sustainable Food Trust (2022). A more complete review of opportunities, barriers and enabler is presented in the work-package 2 (see below).

Results and discussion

The review demonstrated that the uptake of agroecological practices depends, in part, on the balance between the opportunities that they offer and the barriers to their implementation. The opportunities created by agroecological practices include improvements in soil health and on-farm biodiversity, and in some cases reduced costs (See Table 1.3). The increasing requirements being placed on farm businesses by supermarkets and supply chains to reduce greenhouse gas emissions could be a major driver for regenerative practices, and those requirements could be more durable than UK Government schemes to modify land management. In places the barriers to some agroecological practices will be geographical or incompatibility with management objectives. However where these are not constraints, the barriers are often related to uncertainty or financial considerations.

Implications and future work

Enablers to overcome the above barriers include reducing uncertainty by promoting knowledge exchange (particularly as the promotion of agroecological practices is not driven by a producer wanting to sell a product). and financial enablers (with a focus on market mechanisms that differentiate between desired and undesired societal outcomes, and premium products).

1.4. To review and appraise the key tools to model agroecological vs non-agroecological systems including the use of spatial modelling and mapping and consideration of land-use availability and suitability

Method

A literature review was completed to complete the above sub-objective. The review covered i) the challenges of agroecological modelling, ii) the development of agroecological scenarios, iii) tools for constructing scenarios, iv) the selection of models of agroecological impacts, v) the parameterisation of those models, and vi) approaches for monitoring and evaluation. The analysis used the terms “model”, “modelling frameworks”, and “tool”. A model was defined as a piece of software capable of estimating the impact of change in a set of input predictors on a single or several closely related output responses. By contrast modelling frameworks typically consist of a suite of models applied for a common purpose using common input data. The term ‘tool’ was used generically to encompass our definitions of both models, frameworks, and elements within frameworks.

Results and discussion

Challenges of agroecological modelling

Changes due to agroecological approaches can be considered at spatial scales ranging from field to the farm, landscape, and whole nation (Wezel and Soldat 2009; Bezner Kerr et al. 2021). Changes can also be considered within agricultural systems or across the whole agrifood system (Wezel et al. 2020). The use of models to examine agroecological practices can cover changes in input parameter values (e.g. reduced agrochemicals), changed processes (e.g. novel crop management), or changed target outputs (e.g. higher levels of soil carbon), and can extend to socio-economic issues such as welfare and equitability. All of this complexity means that it will be difficult to model agroecological futures using any single approach. Some of the key steps in modelling the impact of agroecological relative to non-agroecological practices at a UK scale are described in Figure 1.3.

Development of agroecological scenarios

Agroecological scenarios can be normative (also referred to as ‘backcasting”), predictive, or explorative. In practice, predictive and exploratory scenarios can be applied in combination. In the context of agroecology, normative scenarios are likely to be more challenging to develop, as the definitions of agroecology can simultaneously encompass scenario targets and the practices and pathways used to achieve these (Wezel et al. 2020). When establishing scenarios to determine the effect of agroecological practices in the UK, it can be useful to distinguish between “bottom-up” and “top-down” approaches. Bottom-up approaches assume that key decisions are made at the farm level which then drive patterns that scale up to the landscape. By contrast, top-down approaches focus on achieving objectives at higher levels of organisation and distributing the required change across spatial units. In practice, in the context of agroecology which can considered at a range of scales, the construction of a scenario using either top-down or bottom-up approaches should subsequently consider the potential for feedbacks operating in the opposite direction, reflecting the fact that agricultural landscapes are composed of interacting socio-ecological elements at multiple, overlapping levels of organisation (Diogo et al. 2022). Indeed, recent integrated modelling frameworks include both top-down and bottom-up elements and are explicit about the links between them (Harrison et al*.* 2019; 2022).

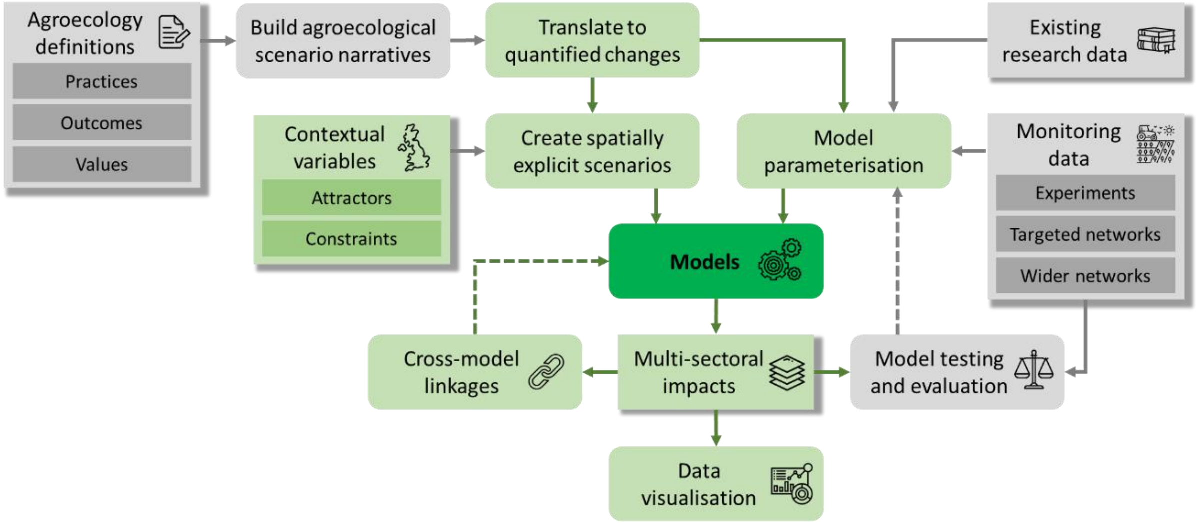

Figure 1.3. Schematic illustration of steps involved in modelling UK-scale impacts of agroecological relative to non-agroecological systems (for full details see Burgess et al. 2023)

Tools to construct agroecological scenarios
Once a broad scenario narrative has been established, the next step is to convert the narrative into quantifiable changes in land use and land cover (LULC) and agricultural practice (Figure 1.3). In the UK context, it is typically useful to create spatially explicit scenarios and to use models that can generate spatially explicit outputs (Finch et al. 2021). This is because the potential impacts of many agroecological practices can depend on parameters and processes that vary strongly with the local context (e.g. Woodcock et al. 2016), and because localised or regionalised inequalities in effects can be important from political and pragmatic perspectives (Reed et al. 2009). Tools that have been used to translate a narrative into quantified changes in land use and land cover in the UK include SFARMMOD (Audsley et al. 2006), CLUE (Britz et al. 2011), and the FABLE Calculator (Mosnier et al. 2020). Within spatial models, the availability, potential, or suitability of a given area for change can be modelled using 'attractors' which increase the likelihood of change in an area, or 'constraints' which reduce or completely preclude the possibility of change (Figure 1.3). Attractors and constraints may be made up of biophysical (e.g. topography, climate, soils, current LULC) or socioeconomic (e.g. proximity to existing LULC or supply chain, potential productivity) factors.

Frameworks that use combinations of attractors and constraints to translate scenario narratives into spatially explicit outcomes within a UK context include:

- the Environment and Rural Affairs Monitoring & Modelling Programme Integrated Modelling Platform (ERAMMP IMP), described by Harrison et al. (2022),
- the Natural Environment Valuation Online tool (NEVO) described by Day et al. (2019a) and
- the ASSIST Scenario Exploration Tool (ASSET) described by Redhead et al. (2020).
- Competition for Resources between Agent Functional Types (CRAFTY-GB, Brown et al. 2022).

An England-focussed equivalent of the ERAMMP IMP called the Environmental Value Assessment Scenario Tool (EVAST) is currently under development. All of these frameworks use a variety of methods to follow pre-set scenario narratives through to spatially explicit realisations and predicted impacts.

Once attractors and constraints have been identified, collated and mapped, the next stage is to produce a realisation of land use and land cover under a given scenario. The full report describes methods by which this can be completed. Whichever approach is used, the spatially explicit outputs are largely based on determining changes in broad land use categories such as arable land, improved grassland or forest, driven by societal (e.g. shared socioeconomic pathways) and/or environmental (e.g. climate) change.

Selecting models of agroecological impacts

Extant modelling frameworks use a wide range of extensively documented component models (e.g. Day et al. 2019a, Finch et al. 2021, Harrison et al. 2022). Whichever exact models are under consideration, the issues and challenges involved in applying them to agroecological scenarios are likely to be governed by the type of model concerned. Individual models can be process-based, statistical, or based on benefits transfer. Process based or mechanistic models are reliant on functions simulating biophysical or socioeconomic process. Statistical models identify statistical relationships between current predictors (e.g. presence of agroecological practices) and the outcome of interest. Benefits transfer models are computationally simpler and identify outcomes associated with particular combinations of input variables (e.g. land cover, soil type, agricultural practice) from existing research, and assume that these outcomes are replicated wherever this combination is encountered. Such models are often described as 'calculators' or 'look-up tables'. Because the impacts of agroecological systems can be social, environmental, and economic, most agroecological modelling frameworks are likely to use a variety of models drawn from all three of the categories above.

The importance of considering cross-sectoral feedbacks was demonstrated by Harrison et al. (2016) who showed that using the CLIMSAVE Integrated Assessment Platform to model cross-sector dependencies and feedbacks predicted substantially different effects on food production, irrigation, proportion of arable land, and carbon storage at a European scale than using single sector models. Given the cross-sectoral and multi-scale nature of agroecology, it is highly likely that potentially misleading results will be generated from single-sector models. One approach to developing integrated models with cross sectoral linkages that can run quickly and efficiently is to develop meta-models, which are "computationally efficient or reduced form models that emulate the performance of more complex models" (Harrison et al. 2015; 2019). They may also reduce the data required for parameterisation by removing factors which remain constant under all scenarios or to which the model is less sensitive. Meta-models need to be tested to ensure they can reproduce the effects of their more complex parent models in terms of responses to the changes of interest. Hence it is likely that the exploration of agroecological scenarios in the UK across a wide range of potential indicators of sustainability is likely to be most effectively derived using models drawn from existing integrated frameworks either by upscaling approaches made for individual countries (e.g. ERAMMP IMP, EVAST) or downscaling pan-European frameworks (e.g. CLIMSAVE). Their successful adaptation to agroecological modelling rests on the ability to parameterise these models with accurate data to ensure that they can accurately simulate the impact of agroecological practices and changes.

Parameterising models of agroecological impacts

Establishing the impact of agroecological practices on sustainability indicators at a field or farm level can be difficult. For practices that are relatively novel or have hitherto only been applied at small spatial scales there is often a limited amount of data on the impacts they are likely to have on the biophysical and ecological properties that models require as input parameters. There are some spreadsheet datasets such as that produced by Jouan et al. (2021a) that describe the effect of several agroecological practices at the farm scale typically using co-efficients connecting practices to indicators. The datasheets produced for this report could also be useful. Nevertheless, a lack of quantitative data on the impacts of agroecological practices has been noted by farmers in the UK (Padel et al. 2020). This problem becomes even more prominent when we wish to consider the parametrisation of inter-model linkages. In the Bezner Kerr et al. (2021) review of agroecological impacts on food security, studies that examined multiple interacting components of agroecological systems were very much in the minority (69% of reviewed studies examined only one or two components), with studies of the impact of the social components (such as social equitability) entirely absent from the dataset.

Even where empirical studies have taken place, the limited sample sizes involved may make it difficult to adequately parametrise process-based models, build robust relationships using statistical approaches or to assess the uncertainties involved in extrapolating their results to wider-scale uptake using benefits transfer approaches. Within the main report (Burgess et al. 2023), the problems of parameterising are illustrated using the example of reduced agrochemical inputs (as an example agroecological practice) on the single output of biodiversity. The analysis concludes that an important first step towards successful modelling of agroecological impacts is likely to involve a comprehensive exercise of collating available data and matching specific agroecological practices to candidate models. Such an exercise should also identify data gaps and deficiencies, which could then be addressed.

Approaches for monitoring and evaluation

The development of sustainable agroecological practices and systems, like any management process, will benefit from effective monitoring and evaluation. This can occur through experiments, targeted networks, or existing national networks (Figures 1.3 and 1.4). Experiments can be useful for enhancing our mechanistic understanding of processes and provide vital quantitative data for model parameterisation. Targeted networks can provide data to evaluate model performance and sensitivities over large spatial scales, and national networks can be used to test model predictions and monitor uptake is having the expected effects.

Ideally a combination of the three approaches can be useful for sense-checking and maximising the usefulness of the available information (Figure 1.4). Some existing farmer-focused networks which could form valuable starting points for evaluating agroecological practices are described in Table 1.5.

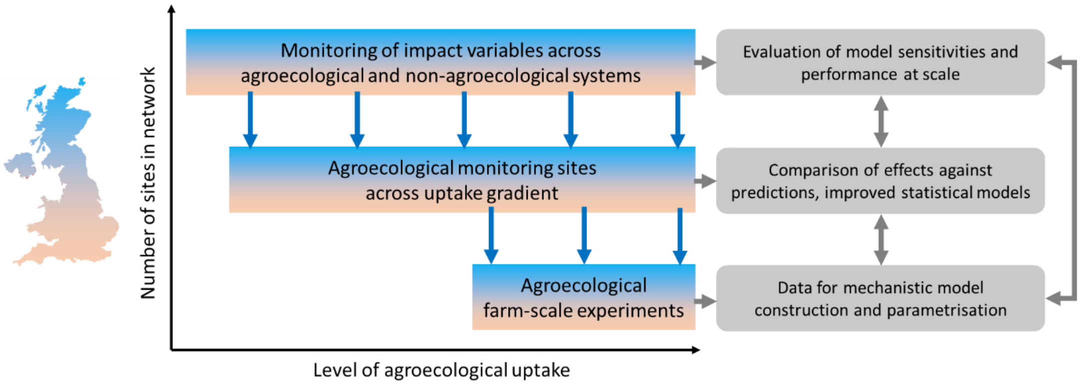

Figure 1.4. Schematic illustration of three levels of monitoring networks for agroecology starting from (lowest level) farm-scale experiments, to the use of monitoring sites across a gradient (middle level), to national monitoring programmes (top level) and their potential use for agroecological modelling (grey boxes)

Table 1.5. Examples of UK networks of farms and farmers with an agroecological or environmental focus

Name of organisation	Website
Farmer clusters	https://www.farmerclusters.com
LEAF Demonstration farms	https://leaf.eco/farming/leaf-network
Nature Friendly Farming Network	https://www.nffn.org.uk/
Agroecology Research Collaboration	https://landworkersalliance.org.uk/agroecology-research-collaboration
Innovative Farmers Project	https://www.innovativefarmers.org/

Implications and future research

Three research gaps were identified in relation to modelling agroecological farming systems.

1. There is a need to ensure that we can construct plausible agroecological scenarios which we can explore with these modelling approaches. Scenarios need to encompass both 'top-down' and 'bottom-up' processes involved in determining the impact of agroecological systems. There are tools to translate scenarios narratives to quantitative descriptors (e.g. SFARMOD, FABLE Calculator) and in understanding where agroecological transitions are likely to take place (e.g. E-Planner) but determining their relationship to specific agroecological practices or systems would require additional development.

2. We need to parametrise models with accurate data on agroecological practices. The lack of experimental data (over larger spatial extents and prolonged periods of time) on agroecological practices means that parameterising mechanistic or statistical models remains challenging. Conversely simply scaling up farm scale expert-based scoring or benefits transfer approaches can result in predicted impacts with unquantified and potentially large levels of uncertainty. Successful selection and parameterisation of models is likely to involve iterative testing of models, using data collated from existing research and from the establishment of multi-scale agroecological monitoring networks.

3. It is vital that we are able to test and improve our ability to model agroecological systems if modelling is to be regarded as a useful tool for decision support, whether at the scale of the individual farmer or the setting of national policy. This relies on effective monitoring of the implementation of agroecological practices. Whilst many existing mechanisms are in place within the agricultural sector that may facilitate agroecological monitoring (including precision farming technologies, decision support tools and farmer networks) these need to be brought together with an explicitly agroecological focus to ensure that they are capable of providing data at the required level of openness, accuracy and spatial resolution for model improvement and validation. Whilst the focus of this study was on bio-economic models, there is also a potential need for improved understanding of the impact of agroecological approaches on social networks.

Work-package 2. Barriers and enablers to uptake of agroecological and regenerative farming practices, and stakeholder views about living labs

2.1. To complete a review of published evidence on the major opportunities for, barriers to, and enablers of agroecological innovations, technology and actions to improve productivity and sustainability

Method

The above sub-objective in work-package 2 built on the initial literature review described in 1.3. A scoping review of the academic literature, supplemented by grey literature, was conducted in November 2022. Search strings were used in Scopus to look for relevant research on farmer adoption of agroecology/regenerative agriculture in similar developed countries to the UK. In total, we analysed 27 written sources of information (academic papers, grey literature, interim project findings/reports).

Results and discussion

Our literature review identified ten major barriers to farmers making an agroecological/regenerative transition (Table 2.1). Key barriers highlighted in most (or all) of the studies were lack of perceived financial benefit, lack of knowledge and support networks, and lack of enabling policies and legislation. Common suggestions to overcome these barriers included building an evidence base to prove benefits (if they exist), support networks of peer-to-peer and advisor-peer learning in farming communities, and providing the right policy instruments to encourage and incentivise uptake. Barriers are often not mutually exclusive and many influence each other. For example, the financial viability of agroecological farming is affected by policies and legislation, as well as societal values to pay more for environmentally-friendly produce and a countering of cheap food narratives.

Table 2.1. Barriers to adoption of agroecological/regenerative farming, from literature review

Barrier	Possible solution
Financial viability/risk/lack of knowledge about benefits	More evidence of viability. Supportive policies/grants. Challenge to cheap food narratives, address inequality.
Lack of advice, knowledge, social capital	Funded, joined-up advisory network. Peer-to-peer learning networks. Good decision support tools.
Lack of supportive policies/ legislation	Political and societal will to develop enabling policies and legislation.
Non-supportive personal values or lack of experience of being in agri-environment schemes	Shift values through social pressure, supportive policies, and helping new entrants with aligned values.
Labour demands/ infrastructure requirements	Potential to use and frame new technology as assisting agroecology/regenerative farming.
Insecure land tenure and succession	Engage landowners, address tenure issues.
Local inflexibility or lack of agency	Evidence-base must support local tailoring of knowledge, advice must enable farmers to make and lead decisions.
Path dependency	Shift values through social pressure, supportive policies, help new entrants with aligned values.
Barriers to entry for young and women	Incentivise new people to enter agriculture, change image of industry, challenge stigma to improve diversity.
Cheap food narratives	Address societal inequality and change values

Implications and future research

The review noted that work led by Wade et al. (University of Leeds), which surveyed 166 UK farmers about barriers and solutions to regenerative farming adoption, as part of the ‘Fix our Food’ project is not yet published. This will be an important project to follow moving forwards. In addition, the Healthy Soil, Healthy Food, Healthy People (H3) project led by the University of Sheffield (https://h3.ac.uk) has also engaged farmers around barriers to agroecology. Results of this project should be sought when available.

2.2. To explore farmer and stakeholder definitions of agroecological and regenerative farming, and to understand the barriers to the adoption of agroecological and regenerative farming

Method

Farmer and stakeholder definitions were examined using in-depth interviews with 23 respondents in November and December 2022. Although not designed to be statistically representative, the respondents included a wide range of stakeholders of varying roles and locations. Full details are provided by Hurley et al. (2023).

Results

All respondents were familiar with the term regenerative agriculture, and slightly fewer were familiar with agroecology. Definitions of 'regenerative agriculture' and 'agroecology' vary, both in how they are understood by different stakeholders and how they are used. The two terms were employed interchangeably by some, sequentially by others (with regenerative practices seen as steps towards a bigger whole-farm agroecological system), and divergently by others (who recognise the social justice, economic and political aspects of agroecology).

The interviews provided a space for respondents to not only speculate on barriers and enablers that they had observed, but - if they were farmers – to reflect on those they had encountered in their own farming practice. The responses were rich and presented experiences that reflected the diversity of farm sizes, types and locations, as well as of expertise from organisational respondents. The reported barriers and enablers were considered in terms of three themes: business and systemic factors, knowledges and networks, and cultures and practice (Figure 2.1).

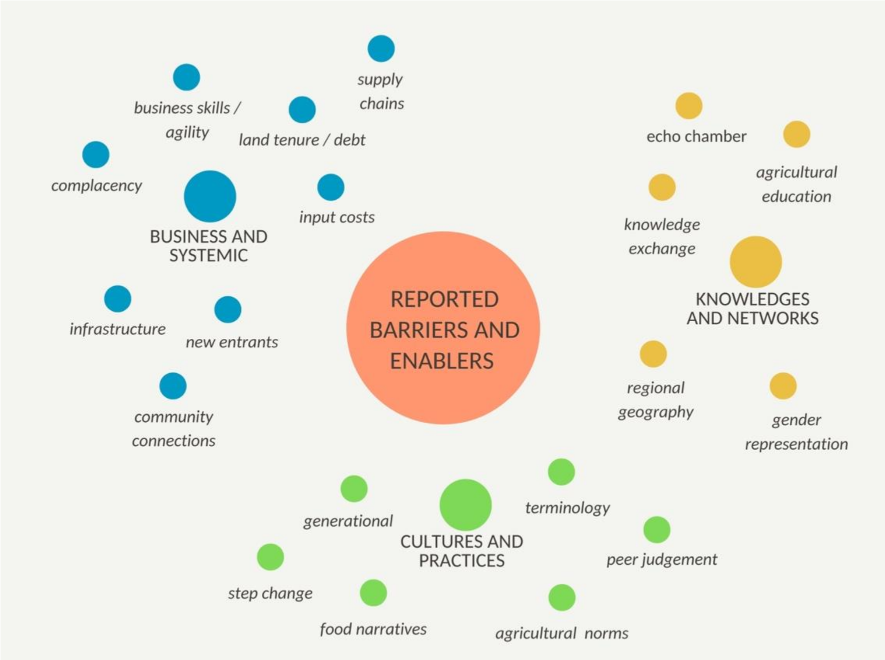

Figure 2.1. Reported barriers and enablers from interviews

Implications and future research

In a similar way to the literature review (see Table 2.1), farmers in the interviews raised concerns about the financial viability of making the transition to agroecological systems. Possible costs of making the transition include buying different machinery and changed labour requirements, whilst the implications for yield and profitability was not clear to all farmers. Financial viability is linked to the policy and industry environment in which farmers operate, which was the second prominent theme. If government policies or corporate retailers support agroecological/regenerative farming, then farmers can be better incentivised for producing food in an environmentally-friendly and socially-just manner. Wide uptake of agroecology/regenerative farming can only exist viably within a supportive wider food system. A range of policy instruments could be useful to incentivise adoption, as shown in countries such as France; these include direct grants to farmers for machinery, free and accessible advisory support to support cultural shifts in attitudes (third major theme), enabling regulations, support for farmer-led innovation and collaboration between farmers, industry, and researchers to share knowledge, and support for new entrants into agriculture (e.g. young, women) who are more likely to practise agroecology/regenerative farming. The security of land tenure and the involvement of the landowners are also vital for enabling long-term agroecological transitions.

2.3. To investigate farmer and stakeholder views towards the concept of living labs as a way to share research and learnings about agroecological/regenerative farming

Method

The same in-depth interviews with the 23 respondents in 2.2 were used to investigate stakeholder views on the concept of living labs.

Results

Regarding living labs, although farmers and organisational stakeholders in our study used different terminology to describe the kind of knowledge creation and sharing under its umbrella, it was clear that the concept itself is vital to enabling agroecological and/or regenerative transitions. Respondents in our study wanted more information on the yield implications and financial viability of agroecology farming and generating and/or sharing this knowledge from a living labs network is crucial.

The responses suggested that the role of Defra in these living labs was open for debate. As with previous literature on engaging 'harder-to-reach' farmers and the co-design of Environmental Land Management scheme (ELMs) (Hurley et al., 2022), Defra may not have to take on a leadership or co-ordinating role. In the ELMs study, it was argued that skilled intermediaries (local trusted advisors) should take the lead in co-designing ELMs with Defra (less trusted amongst some farming communities) taking more of a backseat role, providing financial support and flexibility for local collaboration.

Implications and future research

Recognising that the agroecology and/or regenerative agriculture is largely a bottom-up movement powered by a groundswell of farmer-led innovation and active peer networks, the imposition of Defra in a leadership role for a living labs network may well challenge the grassroots principles that have inspired the movement. However, respondents in our study were keen to point out that many of those engaging most have been prominent in the movement for some time. Whilst peer-to-peer, farmer-led knowledge sharing is important in building social capital, there may be some aspects of living labs which require a co-ordinating role from government. This could include fostering collaboration between farmers and the research community, standardising data collection and sharing, helping the nation make the most of existing demonstration sites belonging to different institutions, and encouraging sharing and use of data. Ultimately, the role of Defra in a living labs network should be negotiated and agreed with the many stakeholders already involved in agroecological/regenerative transitions.

Work-package 3. Characterising current agroecological and regenerative farming research capability and infrastructure, and examining the case for a living lab network

What is a living lab?

Living labs have been used in a range of contexts including for agricultural experimentation and to drive change. The European Network of Living Labs (ENoLL) defines them as user-centred, open innovation ecosystems based on a systematic user co-creation approach, integrating research and innovation processes in real life communities and settings (Malmberg et al. 2017). Living labs are initiatives in which experimentation is conducted in a real context, with managers and other stakeholders involved from the beginning as equal partners in proposing ideas, testing them, improving them and promoting them further. Applied to the agricultural sector, they create opportunities for farmers and other stakeholders to develop solutions together to problems they face in their locality or region, taking into account the specificities of farming systems and their environment (https://ec.europa.eu/eip/agriculture/en/news/eu-mission-soil-deal-europe). One characteristic of a living lab is that anyone can ask a question to be tested. The living lab approach differs from a more typical research approach, where the researchers and/or funders may take a lead on the research focus and questions to be asked (for example on demonstration farms).

Figure 3.1 illustrates five common elements of living labs as defined by ENoLL (Malmberg et al. 2017):

1. Multi-method approaches: there is no single methodology, all living labs combine and customize different methodologies to best fit their purpose.
2. User engagement: the key to success is to involve the users from the beginning of the process.
3. Multi-stakeholder participation: involving all relevant stakeholders is of crucial importance. These include representatives of the public and private sectors, academia and any other stakeholders.
4. Real-life setting: activities take place in real-life settings to gain a thorough overview of the context.
5. Co-creation: mutually valued outcomes that are results of all stakeholders being actively engaged in the process from the beginning.

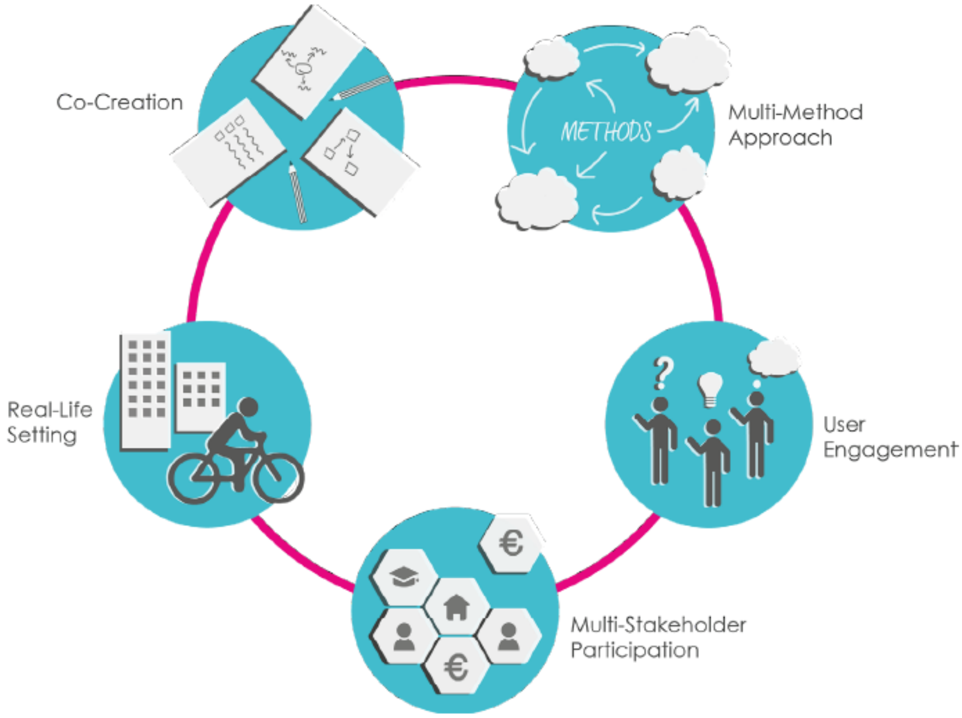

Figure 3.1. Common elements of living labs reproduced from Malmberg et al. (2017)

3.1 To characterise the existing agroecological and regenerative farming research capability and infrastructure in the UK

Method

The project team created a short online survey to gather quantitative and qualitative data on research initiatives to characterise the existing agroecological and regenerative farming research capability and infrastructure in the UK (Staley et al. 2023). The term 'research initiatives' was used in the survey, to include those who do not consider themselves part of a living lab. The survey was submitted to Defra Survey Control for review where it was approved. The survey was structured into seven sections, each with multiple questions, to gather information on: i) Who is responding to this survey, ii) research initiative structure and farming sector, iii) agroecological and regenerative target outcomes and practices, iv) data collection, v) knowledge exchange, vi) funding, and vii) future aspirations. In total, 60 individuals from 34 organisations received the survey directly via email. Further distribution of the survey was facilitated via the Soil Association newsletter (over 6000 recipients), through UKCEH science news Twitter account (seen by over 1100 people) and by LEAF (Linking Environment and Farming) and other organisations working on regenerative farming. The survey was open for responses for four weeks. Further method details are in Staley et al. (2023). The team also reviewed some case-studies.

Results and discussion

There were 22 responses to the online survey. Nine contributors were co-ordinating some form of living lab/farmer cluster or research platform/initiative (Table 3.1). Please note participants could pick multiple answers if their role crossed between two categories. We had a diverse range of contributors across the sector. The full responses are described by Staley et al. (2023).

Table 3.1. Survey participant role in research initiative (participants could pick multiple answers)

Participant role	Count of responses
I am a farmer who implements these practices	6
I am a coordinator of a farm research network/cluster	7
I am a coordinator of a Living Lab/research platform	2
I am a researcher involved with a network/Living Lab/Research platform	6
I am an ecological consultant working for/in a network	2
I am an agronomist working within a network/Living Lab/research platform	1
I am an interested volunteer within a network/Living Lab/research platform	1
Other - NGO promoting Integrated Farm Management	1

The size and the timescales of research initiatives varied substantially from single sites to networks of 50-100 sites, with agroecological/regenerative practices applied from one to over 20 years (Figure 3.2).

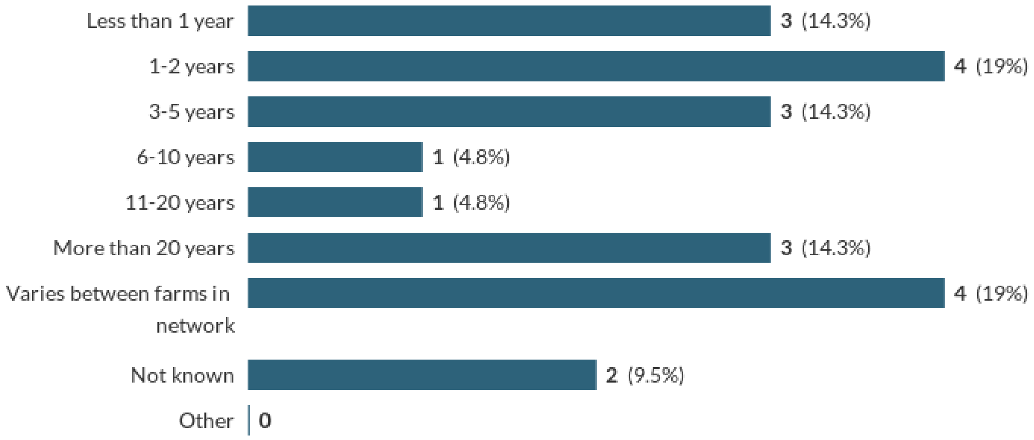

Figure 3.2. The number of responses to the question - How long have agro-ecological or regenerative practices been applied?

The majority of research initiatives included target outcomes of improving ecosystem health increasing biodiversity, improving soil health, carbon sequestration, maintaining or improving farm productivity and increasing profitability (Table 3.2). One of the main principles behind the living lab framework is the collaborative approach to asking questions (see previous section). In our survey, we asked who contributes towards the design of the research initiative. There was a diverse response (Table 3.3), indicating that this collaborative approach is being practiced widely across organisations, farm clusters and networks, with farmers especially prominent in their contributions in co-designing research initiatives.

Table 3.2. Target outcomes for agroecological and regenerative farming practices and the count of the responses from the survey (top nine answers)

Target outcomes for agroecological and regenerative practices	Count of responses
To improve ecosystem health (including ecosystem services)	18
To increase biodiversity	18
To improve soil health (e.g., structure, soil organic matter, fertility)	15
To increase carbon sequestration	14
To maintain or improve farm productivity	13
To increase farm profitability	12
To improve crop resilience to climate change	11
To improve the social and/or economic wellbeing of communities	11
To improve water health (e.g., hydrology, storage, reduce pollution)	11

Table 3.3. The number of responses to the question - Who contributes towards the design of the research initiative?

Who contributes towards the design of the research initiative?	Count of responses
Farmer group / network	12
Individual farmer	10
Researchers	9
Ecological consultants	8
Non-government organisations	7
Agronomists	6
Funder	3
Other	1

One key element of research is the collection of high quality, reproducible data. Almost 40% of those completing the survey were not collecting data on their agroecological or regenerative agricultural practice outcomes. Those that did not collect data said they would, if funding, research support and knowledge were available (75% of those not currently collecting data). One respondent also commented:

> "*Data collection is fine as long as it doesn't impact negatively on the workings of the farm, and compensates for the time and resources it takes us to supply the information.*"

The type of data being collected on research initiative reflect the target outcomes of the network i.e. biodiversity outcomes, soil health and carbon sequestration. Data on yield and/or economic value were also being collected in most of the research initiatives that collect data.

Within the survey we asked what form of communication and knowledge exchange events took place. Face to face meetings and email were the principal forms of communication across networks, with 67% of respondents saying that they held farm demonstration days as a means of knowledge exchange. These events were principally to engage with the farming community, and were aimed at all farmers, including those experienced with agroecological and regenerative techniques but also those that had little or no experience of these methods.

Most respondents (9) received funding from charity or non-governmental organisations for their initiative, with a substantial number funding themselves (6), followed by UK research council and EU funding (8 responses combined).

When asked about future aspirations of the projects, the majority of respondents wanted to continue to develop and grow, incorporating more farms (13 participants) and strengthening knowledge exchange (12 participants).

Survey participants were asked to score various factors and their importance in reaching their aspirations for the project on a Likert scale from very important to not important at all. Targeted funding was cited as *very important* by the majority of respondents. Improving communication with farmers and landowners, and improving skills and knowledge on data collection were thought *fairly important*. Improved infrastructure and monitoring tools were considered *important* for reaching aspirations.

Description of case studies

The online survey results illustrated that the structure of these research initiatives varies substantially from small-scale trials on a few farms to robust repeatable data collection across a large network. To illustrate the range of approaches currently used across this type of research, five UK case studies and the work of the EU network of agroecology living labs in the ALL-Ready project was examined (FiBL 2022).

Case study 1, Innovative Farmers, is a network to facilitate groups of farmers asking applied questions about their farming practices, leading to field trials (Soil Association 2023). This fits in the living lab framework of collaborative research development, with the questions having direct applied relevance to farming practices. Most of the trials are fairly small scale. Hence the results may thus be applicable to the specific conditions (e.g. soil type, region) of that trial with no testing across a range of conditions.

Case study 2 (SEEGSLIP project) worked with a large, established network of 58 farmers who had been applying grazing regenerative practices prior to the start of the research project (UKCEH 2023). Standardised data were collected by researchers on vegetation, soils and other public goods, under a three year project, leading to several journal papers. In ASSIST (Case study 3) researchers worked with 18 commercial farms, with regenerative habitat creation (wildflower margins and in-field strips) practices being introduced using standardised methods at the start of the project (UKCEH 2022). Researchers collected data on biodiversity and related ecosystem services using the same monitoring protocols across all farms. The H3 project (Case study 4) also works with regenerative and conventional farmers to collect data soil health, biodiversity, ecosystem services and food quality (University of Sheffield et al. 2022). SEEGSLIP, ASSIST and H3 were all funded by research councils (BBSRC and NERC) and lasted 3-6 years.

Case study 5 was the Centre for Sustainable Cropping Platform at the James Hutton Institute, which is a single demonstration farm where regenerative and conventional practices have been applied for at least 14 years (James Hutton Institute 2023). This long timescale allows impacts of regenerative practices to be better understood, as they may take several years to become apparent. The wider applicability of these results, in other landscape types and contexts, would need to be investigated separately.

In addition to the UK case studies, the work of the EU network of agroecology living labs in the ALL-Ready project was examined (FiBL 2022). Almost all the living labs in that network had a component of government funding or were run by government research institutes, with the exception of the Innovative Farmers network in the UK (see Case study 1 above). All of the living labs involve a wide range of stakeholders including farmer groups, farmers, NGOs, charities, researchers, agri-technology firms and others. Many of the living labs have an adaptive design approach, whereby research themes or trials are decided periodically through stakeholder workshops or working groups.

3.2. To explore lessons from recent research initiatives and identify key research gaps, to inform a potential UK living labs trials network in agroecology/regenerative farming

Method

To identify the key research gaps and explore lessons from current research, an online workshop was run on 18 January 2023. The workshop was attended by 34 participants (excluding those from Cranfield University and UKCEH). The first part of the workshop present findings of the WP1 evidence review (Burgess et al. 2023) and preliminary results from the WP2 structured interviews (Hurley et al. 2023), and invited discussion to gather feedback. The second part of the workshop focussed on informing a future living labs network for agroecology/regenerative farming through three sets of questions:

1. *Research gaps:* What are the key research gaps in our understanding of agroecological and regenerative farming practices in the UK, and what are the priorities for research?
2. *Infrastructure and skills:* What additional infrastructure/skills are needed to support current and future research into agroecology/regenerative agriculture practices, and who needs to implement those skills/infrastructure developments?
3. *Barriers and solutions to accessing data:* What are the biggest barriers to accessing the agroecological/ regenerative agriculture data you need, and how might these barriers be overcome?

During the second part of the workshop, the participants were split into three smaller groups in breakout rooms, who rotated around discussions of each of the three areas. Within each 25 minute break-out session, the participants had 3-4 minutes to write their ideas on virtual post-it notes. A facilitator roughly grouped the ideas into broad themes, and opened a verbal discussion on the contributions made, their grouping into themes and the second, follow-on question. After the end of the workshop, the facilitator for each area finalised the grouping of notes around common themes or concerns and added subheadings per group. Inevitably there are linkages and cross-overs between these groupings.

Results and discussion

Workshop question 1.1. What are the key research gaps in our understanding of agroecological and regenerative farming practices in the UK?

This question engendered 68 comments (see Appendix C in Staley et al. 2023 for full research gap discussion board). The largest number of comments related to specific impacts (e.g. biodiversity, greenhouse gas emissions, and yield) or outcomes (e.g. mapping nutrient density), and trade-offs between these impacts. Understanding why the effects of practices on these impacts might vary with context (e.g. due to region or soil type) was also highlighted, as was the role of agroecology in adapting to climate change. The range of impacts, outcomes and practices listed as key research gaps indicates a perception that little research has been completed on the impacts of agroecology in the UK. This is summed up by one comment:

> "*All the topics put up so far! Agroecology in the UK has been so underinvested in, that really an entire research agenda is needed. Fundamentally building an evidence base to show different outcomes from agroecology and regen would be so valuable.*"

The importance of research that runs for at least five to ten years given that some impacts take more than five years to become apparent, was raised by various participants. Several participants commented on the existence of barriers to farmers participating in research projects, in particular projects funded by UK Research and Innovation (UKRI) in which farmers are typically not paid for involvement. There was concern that this could be biasing the sample in these projects, towards those farmers who can afford to engage.

The potential for displacement of negative impacts was also raised. In work-package 1, we defined regenerative agriculture as "a system of principles and practices that generates agricultural products, sequesters carbon, and enhances biodiversity at the farm scale" (Burgess et al. 2019; 2023). One argument against agroecological practices is that reductions in yield at the farm scale could consequentially lead to increased production of the same products beyond the farm in different locations where the negative environmental impact is greater (Smith et al. 2018). However, how the consequential effects of reduced yields from increased use of agroecological practices play out in practice (i.e., are the effects absorbed by dietary change, reduced use of crop products for animal feed, and/or land use change elsewhere) remains a pertinent area for research (Benton and Bailey 2019; Feniuk et al. 2019; van der Werf et al. 2020).

The need for research to understand how and why farmers transition to regenerative and agroecological practices was another theme of several comments, including an understanding of how transition pathways may differ across farm businesses, for new entrants and those not yet engaged in these practices. In the verbal discussion, understanding the role of knowledge for agroecological farmers was mentioned as a research area, to compare how much time agroecological farmers invest in knowledge acquisition compared to conventional farmers.

The importance of economic drivers including supply chains, and the role of subsidies, was explored in another large group of comment. The final group of research gap comments was around the need to understand the wider policy context, including how these practices link to agri-environment schemes, such as Countryside Stewardship and Environmental Land Management Schemes, and how they may contribute to progress towards environmental targets. Overall, the range of comments and broad themes showed a large number of gaps in current understanding of agroecology and regenerative farming, suggesting a need for additional research.

Workshop question 1.2. Which of the research gaps should be addressed first?
The comments received for this question included::

- "*To establish practical and cost effective ways of measuring outcomes – need to agree a standard for monitoring responses so data can be compared between studies", and "Sequestering carbon – not much measurement of the greenhouse gas emissions of new practices. There are certain critical measurements that farmers will not have the time or resources to measure, may need some funding or other support".*
- *"Timescale and scaling are coming across as key issues", "Appropriate length of funding is a key take-home message",* and *"Longer term research".*
- *"System level approach, maximise multiple benefits"* and *"Optimising multiple benefits at the system level".*
- *"Lacking an overall direction that enables agroecology to thrive. Moving from a conventional to a regenerative approach, requires you to unlearn lots of what farmers thought they knew".*
- *"Prioritise understanding regional/soil type differences first, prior to scaling up*".

Workshop question 2.1. What additional infrastructure/skills are needed to support current and future research into agroecology and regenerative farming?
The five key themes that emerged from the written comments were i) the need for long term networks, ii) standardised assessments and tools, iii) good communication and credibility, iv) support, and v) Upskilling/education improvements. These are briefly covered in turn.

Need for long term networks: this was the focus of the largest number of comments with emphasis on building stronger links between existing platforms, wider testing of regenerative practices, and funding. Comments included:

> *"Link existing networks – Create better links between universities / organisations and networks that are carrying out research for knowledge transfer and collaboration etc".*

Participants emphasised the need for ongoing funding for existing networks:

> *"The organisation 'Agricology' was funded (not now) by a farm / retail and was an excellent networking org. Core funding for this / similar organisations would help the whole community".*
> *"Agroecology Research Collaboration was formed to co-ordinate agroecology practitioner ideas on research and build relationships with academics to get discussions onto their agendas… support for initiatives like this would be really valuable."*

Testing of experimental results across commercial farms and across a wider range of farm types was also raised, along with the need to scale up results from individual experimental farms. For example:

> *"Hub and spoke model with long-term experimental farm platform linked to satellite farms to test generality of regen farming practices"*
> *"…farm platforms.. need to be linked together, and scaled up to a sample size that allows us to determine statistically robust patterns of landscape scale"*

Standardised assessments and tools: as previously outlined in the research gap priorities, there was a need for a range of tools to enable standardised monitoring approaches and assessments. Specific requirements that were identified include short-term and validated soil assessments including for soil carbon, standardised data formats, apps and other methods for farmer-friendly monitoring, hubs of shared equipment for farmers to borrow for monitoring (including for high tech greenhouse gas measures), yield modelling and farm-scale nutrient mapping.

Good communication and credibility: these needs included better data sharing across organisations and platforms (e.g. for carbon calculators) and links to future climate scenarios. The relationship between researchers and farmer was addressed in several comments, including the need for shared ownership of research, and a partnership relationship with farmers involved from the start as opposed to researchers reaching out once research is complete. One participant commented that communication timescales can differ between researchers and farmers, with farmers keen for rapid communication of outputs from a project to feed into their farming practices, while researchers need time for quality assurance of data, analyses and checking of results. This disparity in communication timescales can erode relationships between researchers and farmers. The WP2 stakeholder interviews (Hurley et al. 2023) also emphasised the differing expectations between researchers and farmers in relation to timescales.

Evidence developed for farmers may need to cover a range of objectives as priorities differ between farmers, e.g. yield vs. biodiversity. If collated evidence summaries are available, farmers can pick out the information helpful to their objectives.

Support: the support highlighted included better guidance, more funding, input from advisors, technical officers or coordinators, and placements for farmers on other farms.

*Upskilling/education improvements: e*ducation for farmers and education for vets and agronomists (who form a trusted source of information), and buyers and processors were highlighted.

Workshop question 2.2. Who needs to implement those skills/infrastructure developments?
The discussion on who should be implementing the advances needed in infrastructure and skills covered several themes:

- Research and development is typically in the hands of industry partners; there is a need to be sure they think about what farmers really want.
- Interesting case study of a farmer going to a university saying I am doing this, on this land, close to the university. Students are now involved in the research/engaged with the practices going on. Connections are being made that were initiated by the farmer.
- National Capability Funding - e.g. ASSIST programme etc. - is scaling up, things are starting to happen.
- Access to information, knowing what is available, funding calls that allow you to use that information would be useful.
- Upskilling agronomists and vets – these are people who farmers already have close relationships with. Through upskilling they could understand agroecological and regenerative practices. There will be a need to keep this up to date. Some farmers who have voiced interest in regenerative farming or agroecology have commented that they were put off by their agronomist.
- Upskilling farmers - a need to upskill the farmers to help themselves, and a concern that agricultural colleges do not put enough focus on agroecology and regenerative farming.
- Worry that a lot of information is tied to big business and there is a need to make it independent.
- Concern around speaking to the converted e.g. Oxford Real Farming conference. Potential for regional conferences to be more accessible to those farmers who are not already engaged with agroecology.

- Innovative farmers scheme – funding needs to be increased.
- Need for small farms / tenant farmers / less profitable businesses to potentially have a subsidy that would allow them to hit Environmental Land Management (ELM) targets.

Workshop question 3.1. What are the biggest barriers to accessing the agroecological/ regenerative agriculture data you need?

In total, 74 comments were made in relation to data access for agroecology and regenerative farming, on the discussion board for this area. Barriers were identified in written comments which were then grouped under six broad themes:

Access to research data, which included comments on '*Knowing where to get the right data'*, '*Is it relevant to me?*', and the time needed to find and identify what data are needed. This theme also covered the need to identify pathways to ensure data were discoverable and accessible to non-academic institutions (or those without an institutional affiliation).

Data sharing, with barriers listed including '*Commercial sensitivity – wanting to be ahead of competitors*', GDPR and the need for consistent data recording and reporting, to be supported by data sharing standards. However, one participant commented verbally that time may be more of a barrier to data sharing by farmers, rather than confidentiality concern, especially where the value of sharing such data was made evident.

Data quality/trust: comments included that '*Lack of consistency in methods of collection – may make it uncomparable*', '*Quality*' and '*Variability and relevance'* including the need to understand/know data context if impacts differ between soil types, regions or other factors.

Balancing data types/sources: several comments emphasised practitioner-led experience, e.g. '*Art vs Science - Ensuring opportunities so practitioner led experience and research led data can meet in middle*'.

Data gaps: these included specific gaps in the availability of data and knowledge such as '*gap in knowledge of soil biology*…' and '*microbial biodiversity especially plant micro symbionts*'.

Data collection: these included a focus on who collects the data, e.g. '*If the onus is on farmers to collect data, we've found it is less likely to be collected even with the best will, due to other priorities and practicalities of collecting it. So it has been better when someone external has collected it*'. There was also a focus on the cost/time needed for data collection, '*Expensive methods and time consuming, e.g. GHG emission measurements, bulk density (very time consuming!), some soil test etc*'.

Workshop question 3.2. How might these barriers be overcome?

On the discussion board, the two principal themes were: i) d*ata integration and training* as a barrier, and ii) data integration and training as a solution. The suggestions to overcome barriers included: '*Training for both farmers, agronomists, ag. colleges etc*', '*Proper documentation*' and '*Guidance/data licensing to enable sharing*'. The wider solutions included *'Long-term monitoring data platforms'*, *'Apps/digital tools'*, and a focus on synthesis of evidence and results-based guidance (e.g. '*Academics making output free access or to produce short summaries for farmers*'). Three knowledge exchange platforms were mentioned: Agricology (https://www.agricology.co.uk), Soil Association Exchange (soilassociationexchange.com), and FarmPEP (https://farmpep.net/). The verbal discussion highlighted that sharing data in understandable formats is needed, trying to avoid proprietary formats that are only associated for example a particular machine format. It was also highlighted that a standardised approach for some data (e.g. soil metrics and biodiversity data) was needed along the supply chain. This would avoid farmers having to collate data in different forms for different uses. However it was also indicated that this should not preclude innovation. An up to date and location-relevant platform of all the current projects and the data from them, collated in one place for the farmers and researchers to use, would also be helpful.

There was a need for a balance between usefulness and being easy enough to collect on-farm. Easy to use apps for data collection or to let farmers know what assessments need to be used would be useful. Knowledge and evidence synthesis in a digestible form for farmers and researchers to collaborate across institutions would also be helpful. Training on the interpretation of data was also highlighted.

Several of the comments above point to a potential tension between trying to make data consistent (in relation to format, standardised protocols for data collection etc) and not constraining farmers from trying out new innovations that may not be part of rigorous, standardised data collection. However, comments also identified existing platforms (e.g. Soil Association Exchange, FarmPEP, and Agricology websites) for data discovery and/or dissemination that participants felt provided good examples of how several of these data barriers might be overcome, whilst allowing for this flexibility in approach and the presentation of practitioner-led experience.

3.3. To develop recommendations for a new living lab trial or research network in agroecology/regenerative farming

Method

Based on the preceding analysis, the final part of the project was to recommend the research, infrastructure and tools needed to address current evidence gaps related to agroecological and regenerative farming and to set out the case for a UK living lab research and development platform or network. There is a strong argument that research and development of agroecological practices should follow the social and governance principles of agroecology described by the High Level Panel of Experts of the Committee on Food Security (HLPE, 2019). These include greater participation, decentralised governance, an appreciation of culture and equity, co-creation of knowledge, and connectivity (Table 3.4).

Table 3.4. The 13 agroecological principles described by HLPE (Modified from HLPE 2019; page 41) categorised as environmental and technical or social and governance

Environmental and technical principles	Social and governance principles
Soil health: secure and enhance soil health for improved plant growth, by managing organic matter and soil biological activity.	Participation: encourage greater participation in decision-making and decentralised governance of agriculture and food systems.
Biodiversity: maintain and enhance genetic, species, and functional diversity and overall agroecosystem biodiversity at range of scales.	Social values and diets: food systems based on the culture, social and gender equity of local communities that provide healthy, diversified, seasonally and culturally appropriate diets
Input reduction: reduce or eliminate dependency on purchased inputs and increase self-sufficiency.	Fairness: support dignified and robust livelihoods for all actors based on fair trade, employment and intellectual property rights.
Economic diversification: diversify on-farm incomes thereby supporting greater financial independence for farmers.	Land and natural resource governance: strengthen institutional arrangements to support of family farmers and smallholders
Recycling: preferentially use local renewable resources and help close resource cycles of nutrients and biomass.	Co-creation of knowledge: including horizontal sharing of knowledge and farmer-to-farmer exchange.
Synergy: enhance positive ecological interactions amongst the elements of agroecosystems (animals, crops, trees, soil and water).	Connectivity: ensure confidence between producers and consumers through fair and short distribution networks
Animal health: ensure animal health and welfare.	

Results

The characterisation of research initiatives and lessons learnt from this current research have demonstrated a wide range of research gaps as well as suggesting priorities, approaches and solutions to barriers (for example to data sharing). The gaps range from specific impacts of individual practices (e.g. GHG emission responses to cover crops), to the need to understand trade-offs across a range of impacts and practices, the drivers of variable responses, a requirement for large-scale and longer-term research, and the suggestion to better integrate existing research initiatives and networks.

Due to the range of gaps and priorities, we developed four potential options for a new research project, research network or living lab network (Table 3.5), each of which has a different structure and focus. The options are not mutually exclusive and could be combined. This current scoping work focusses on the UK, with some lessons learnt from European living labs, due to the aims and objective of the project.

Option 1: the first option focuses on encouraging local decision making, by encouraging farmers and growers to systematically appraise their farm operations from a range of perspectives. The Global Farm Metric (Figure 1.2) identifies 12 attributes for assessment, but does not include standardised methodologies which can be applied by farmers for each attribute. This option would help to meet the infrastructure need to develop standardised assessments and tools, identified in the stakeholder workshop (Section 3.4). There is some ongoing work in this area e.g. by DairyUK and Defra. A similar approach is promoted through the LEAF audit. In some cases, establishing more standardised methods for assessment for some attributes would be helpful. One option might be to extend or build on the LEAF audit, depending on the funding and organisational structures within which Option 1 was implemented. For example, the stakeholder interviews conducted in work-package 2 (Hurley et al. 2023) identified that carbon calculations are still being developed:

"One of the things that's holding all this back is everybody's trying to find the holy grail of calculating carbon and actually, we're still some distance away…"

A range of farm carbon calculators are available, each based on slightly different assumptions. A guide to how they differ, and which may apply in different contexts, could give farmers more confidence in these assessments and potentially result in more standardised data.

Table 3.5. Options for a new living lab network / research network in agroecology and regenerative farming. A more detailed version of this table with pros and cons for each option is given in Staley et al. (2023)

Option	Suggested structure
Baseline: No additional support from Defra	Research in agroecology and regenerative farming continues to develop as it currently is, discrete research projects and limited/no long term funding for research networks.
1. Supporting consistency of farm attribute assessments	Development of a standardised methodology or protocol for UK farms, for each of the 12 attributes within the Global Farm Metric. This could include a portal to collate consistent data, and/or funding for farmers to collect these data.
2. Maximise research synergies with agroecological /regenerative farm networks with standardised data collection	Specific research projects to collect standardised, rigorous data from farms already applying agroecological / regenerative practices, and already linked through a network. Farmers and other stakeholders involved in specifying research focus, co-design. Priorities for data collection could include the impacts identified as research gaps e.g. greenhouse gas emissions and biodiversity.
3. New research network applying agroecological / regenerative practices on commercial farms. Standardised data collection on impacts and trade-offs.	Long-term research project sets up a new network of farms applying agroecological / regenerative practices from a common start date. Standardised, rigorous data collected. Farmers and other stakeholders involved in specifying research focus, co-design. Priorities for data collection could include the impacts identified as research gaps in Section 3 above (greenhouse gas emissions, biodiversity).
4. Living lab UK network set up, facilitation roles and research projects funded.	UK living lab network in agroecological / regenerative farming, bringing together range of stakeholders. Focus on building links and maximising opportunities across current and future research initiatives. Similar structure to some aspects of the European agroecology living labs in ALL-Ready network. For example, research themes and priorities could be set periodically by established stakeholder groups within the living lab, or temporary working groups.

Option 2: this was to maximise research synergies within existing agroecological farm networks with standardised data collection. The scoping of current research initiatives (Section 3.2) identified eight farm networks or clusters applying agroecological or regenerative practices that are not currently collecting data, and an appetite for additional engagement with research. Three-quarters of the participants who are not currently collecting data stated they would like to collect data given more funding, knowledge or support. Option 2 in Table 3.5 involves funding and setting up research initiatives to maximise the synergies between research and existing networks of farms. This approach was used successfully in the SEEGSLIP project, which involved researchers working with members of the Pasture-Fed Livestock Association (an established network) to survey 58 farms on which regenerative grazing practices had been applied over varying timescales prior to the start of SEEGSLIP. Standardised data were collected by researchers on vegetation, soils and other public goods, under a three year project. This approach of standardised data collection by researchers across an existing network of agroecological/regenerative farms used by SEEGSLIP could be applied to other farming systems (e.g. a network of arable regenerative farmers) and to collect data on other impacts (e.g. wider biodiversity beyond plant responses, greenhouse gas emissions).

Option 3: one of the risks around Option 2 is the potential for highly variable data. Hence, Option 3 is to fund a research initiative that creates a new network with similar regenerative practices applied from around the same starting date. This may require long research projects or initiatives, as impacts and trade-offs between impacts have been shown to take time to become apparent and/ or to change over time.

The research initiative possibilities outlined in Options 2 and 3 above include some aspects of living labs, for example the potential to co-design research questions with farmers and other stakeholders. However, neither of them include all five aspects of a living lab, as defined the European Network of Living Labs (Figure 3.1).

Option 4: this includes the establishment of a UK living lab network in agroecology/regenerative farming, drawing on aspects of the European agroecology living labs (Figure 3.1). This would be a longer-term initiative, with a focus on facilitating links between stakeholders and existing research in this area, in addition to potentially setting future research priorities. Such an option could meet the recommendation coming out of the stakeholder interviews in work-package 2, that some aspects of living labs may require a co-ordinating role from government (Hurley et al. 2023). Examples of this coordinating role include fostering collaboration between farmers and the research community, standardising data collection and sharing and helping to make the most of existing demonstration sites belonging to different institutions (Hurley et al. 2023). This form of living lab network would also address some of the recommendations about infrastructure and data from the stakeholder workshop. For example, setting up shared equipment hubs to load scientific equipment to farmers, and helping to facilitate upskilling and improving education on agroecology and regenerative farming.

Combinations of options: combinations of the options in Table 3.5 are possible. For example, Option 4 could be combined with Option 1, where standardised methodologies and toolkits for assessment of Global Farm Metric attributes could be developed within a new living lab network. A living lab could take an adaptive approach, with research priorities and focus changing over time.

Future work and actions

A number of areas of future work and actions can be identified from this research.

1. In the context of global climate change and government targets for net zero emissions, agroecological approaches should explicitly consider the effect of the practices on climate change mitigation and adaptation (Section 1.1; Table 1.1).
2. Whilst some effects of agroecological and regenerative farming practices are well established, the effect of some practices, particularly in terms of net greenhouse gas emissions (per hectare and per unit product), biodiversity, yield, and costs still needs to be resolved (Section 1.2).
3. Research gaps in the modelling of agroecological systems (Section 1.3) include improved understanding of relationship between scenarios and the uptake of agroecological practices, the relationships between practices and impacts (See point 2), and monitoring of the uptake of practices.
4. The focus of this report has been on the effect of agroecological practices at a farm or landscape scale (Section 1.1, Section 3.2). The consequential effects of promoting agroecological farming and the interactions between diet change, reductions or increases in the use of crops for animal feed, waste and land use remain pertinent areas of research for government.
5. Because agroecological systems tend to focus on the reduction of input use, agroecological advice cannot be readily co-financed through the sale and purchase of products such as fertilizers, agrochemicals, and feeds. Hence different models are needed.
6. Important aspects of agroecology include social and governance principles (Table 3.4), and these principles should be followed as far as possible in the development of research and development initiatives to promote agroecological practices. Co-creation of research, user engagement, muti-stakeholder participation, real-life setting, and multi-method approaches are attributes of the living lab approach (Section 3).
7. There are areas of good and existing practice both in the UK and the rest of Europe which can be built on, in terms of European living labs in agroecology and exemplar research projects, and experimental farm platforms in the UK.
8. There is a strong perceived need for research in this area, with many evidence gaps highlighted in Section 3. This is matched by an appetite for additional data collection among existing networks of regenerative farms who are not currently involved in structured research.
9. Various respondents highlighted the need for government and stakeholders along the supply chain to help standardise attribute measurements related to the various sectors of the Global Farm Metric (Section 3.2). The prediction and/or measurement of soil carbon and greenhouse gas emissions in response to regenerative farming practices was particularly highlighted.
10. Predicting and/or measuring public goods such as increased soil carbon or reduced greenhouse gas emissions takes time and money, which many farm businesses do not have. Supply chain and government support in this area, for example through the Environmental Land Management scheme, would be helpful.
11. There is a need for the research completed in this study (e.g. Section 1.2, Box 1 and Table 1.3) to be made publicly available as soon as possible in a digestible format. However, this requires some time and resources. Lack of knowledge and advice concerning agroecological systems is an identified constraint (Table 3.2).

References to published material

9. This section should be used to record links (hypertext links where possible) or references to other published material generated by, or relating to this project.

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Burgess. P.J., Staley, J., Hurley, P.D., Rose, D.C., Redhead, J., McCracken, M.E., Girkin, N., Deeks, L., Harris, J.A. (2023) Evaluating the Productivity, Environmental Sustainability and Wider Impacts of Agroecological compared to Conventional Farming Systems. Evidence Project Final Report of Project SCF3021 for DEFRA.

The following three reports were produced as part of the project.

Burgess. P.J., Redhead, J., Girkin, N., Deeks, L., Harris, J.A., Staley, J. (2023) Evaluating agroecological farming practices. Report from the "Evaluating the productivity, environmental sustainability and wider impacts of agroecological compared to conventional farming systems" project for Defra. 20 February 2023. Cranfield University and UK Centre for Ecology and Hydrology. 102 pp.

Hurley, P.D., Rose, D.C., Burgess. P.J., Staley, J.T. (2023) Barriers and enablers to uptake of agroecological and regenerative practices, and stakeholder views towards 'living labs' Report from the "Evaluating the productivity, environmental sustainability and wider impacts of agroecological compared to conventional farming systems" project for Defra. 6 February 2023. Cranfield University and UK Centre for Ecology and Hydrology. 35 pp.

Staley, J.T., McCracken M.E., Redhead, J.R., Hurley, P.D., Rose, D.C., Burgess. P.J. (2023) Characterising current agroecological and regenerative farming research capability and infrastructure, and examining the case for a Living Lab network. Report from the "Evaluating the productivity, environmental sustainability and wider impacts of agroecological compared to conventional farming systems" project SCF3021 for Defra. Cranfield University and UK Centre for Ecology and Hydrology. 82 pp.

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