The potential for an agroecological approach in Scotland: policy brief

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1 Executive summary

1.1 Aims

Agroecology is receiving increasing attention for its potential to reconcile environmental, sustainability and food production goals, through restoring the health of agricultural ecosystems and increasing the resilience of farms to future challenges.

This study examined five different agroecological approaches[1] that are currently practised in Scotland to determine their potential to support the delivery of policy targets relating to climate change, biodiversity, and food production.

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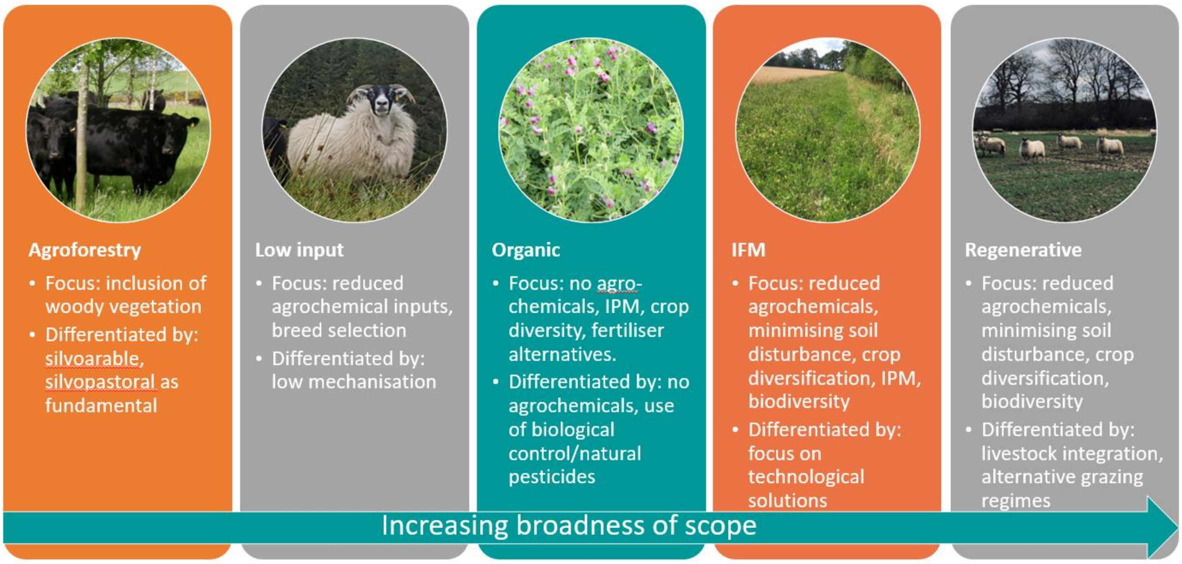
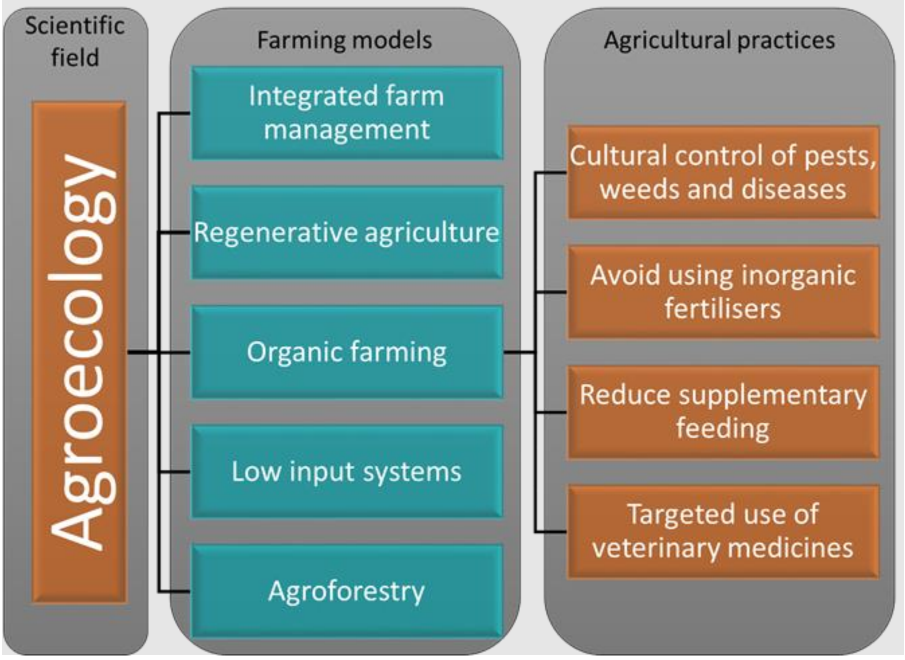
[1] Agroforestry, low-input systems, organic, integrated farm management (IFM) and regenerative agriculture

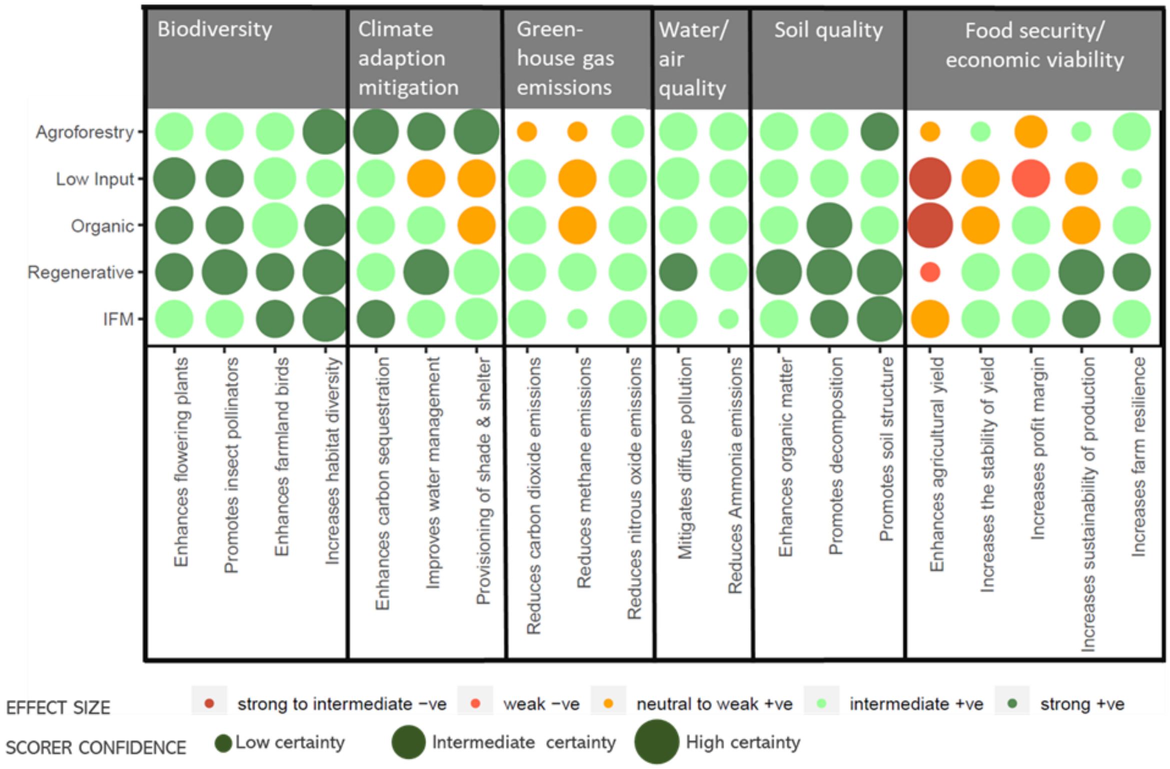


1.2 Findings

- Agroecology is a holistic approach to farming which encompasses food security, environmental and social goals. In this report, we adopt a hierarchical approach where agroecology is the scientific discipline that underpins specific farming models, with each model aligning with a set of agroecological farming practices.
- The five models investigated showed considerable overlap in the farming practices typically adopted and there was no fixed boundary between these models. The models were also not mutually exclusive (e.g. an organic farm may also practise agroforestry).
- Regenerative agriculture, integrated farm management (IFM) and organic farming had the widest range of practices considered as ‘core’ reflecting their broad scope and ‘toolbox’ approach to select practices appropriate to specific locations and circumstances.
- Agroecological approaches are strongly knowledge focused with the farmer as the central decision-maker. A prescriptive set of practices for each model, therefore, goes against the grain. Farming system, geographical location, resource availability, constraints, mindset and priorities of the farmer, all influence the practices adopted under any specific agroecological model.



- A farm-scale shift towards an agroecological model requires expertise, commitment and, in some instances, significant investment. With a typical delay before agronomic benefits are realised, farms need the financial capacity to buffer the economic costs of transitioning.
- Labelling or certification to increase the market value of agroecological produce may incentivise farmers to adopt agroecological approaches. However, ensuring consumer demand and willingness to pay presents a challenge. Fostering farmer choice and flexibility, outcome-based certification schemes may be more appropriate than prescriptive programmes that focus on the inclusion/exclusion of specific practices.
- Outcome-based approaches, whether for certification or agri-environment purposes, require robust, user-friendly metrics, to enable farmers to monitor and benchmark performance and adapt management to optimise outcomes.
  Experts were asked to rate the models against a range of environmental and food security outcomes, with dark green circles representing strong benefits and dark red circles strong dis-benefits. The strongest benefits are shown for biodiversity, while the greatest challenge lies in maintaining yield.



- The five agroecological models have the potential to reduce adverse environmental impacts associated with intensive agricultural production at the farm level.
- While agroforestry and IFM were perceived to match yields attained in conventional systems, organic, regenerative agriculture and low-input systems were perceived to be lower yielding. However, all models were perceived to increase farm resilience and stabilise yields either slightly (low input and organic) or intermediately (agroforestry, regenerative, IFM).
- The potential of agroecological approaches to deliver environmental outcomes depends on efficiently using land and external inputs. Consequently, it is crucial to ensure such systems are efficient and that both yield and environmental benefits are optimised.
- Identifying synergies and trade-offs is vital to help us design agroecological systems that optimise economic, food security and indeed social outcomes. There is a lack of system-based research that concurrently explores evidence for a diversity of outcomes in the Scottish context.
- We found a strong link between agroecology and key environmental and food security outcomes. Agroecological models clearly have the potential to help agriculture meet environmental policy targets and enhance farm resilience to future challenges. However, the impact of a more gradual but widespread adoption of specific agroecological practices (e.g. cover crops, hedgerow restoration) in conventional systems should not be undervalued.

Contents

2 Introduction - agroecology, biodiversity and climate change

With Scotland facing the twin challenges of a climate emergency and biodiversity crisis, agroecology is receiving increasing attention as a farming approach that attempts to reconcile environmental, sustainability and food production goals. Across Scotland, agricultural systems have the potential to draw on agroecological principles and this report aims to help us understand this potential in the Scottish context.

Agriculture is facing unprecedented challenges in producing affordable nutritious food sustainably (IPES Food, 2016), conserving biodiversity (IPBES, 2019), and storing carbon, while coping with increased climate variability (IPCC, 2021). Agricultural emissions will need to fall considerably to meet emissions targets, and this will require changes in how we manage and use our land.

To ensure the future security of food supply, Scotland must rise to the global challenges of mitigating and adapting to climate change, restoring biodiversity, and sustainably meeting future nutritional demands. These goals must be achieved alongside addressing the social and economic challenges of making healthy and nutritious food available to all. While often considered independently, these challenges are inherently linked and consequently an integrated approach is needed to address them (Arneth et al., 2020).

The industrialisation and globalisation of agriculture has resulted in modern farming systems that are efficient and high yielding; however, they have depleted natural resources and are identified as a key driver of biodiversity declines and climate change (Díaz et al., 2019, Shukla et al., 2019). These issues are intimately linked: the resilience of agroecosystems is compromised by environmental degradation (e.g. two-fold reduction in plant biomass and six-fold reduction in the biomass of wild marine and terrestrial mammals (Bar-On et al., 2018)) at a time when weather patterns are increasingly dominated by extreme events (IPCC, 2021).

There is a clear desire to transform our food production systems to consider social, economic and environmental performance under the changing climate. Focussing on enhancing sustainability and promoting wider societal benefits, the role that agroecology has in shaping future farming systems is becoming increasingly recognised (IPES Food, 2016; Wezel et al., 2020). Agroecological approaches are therefore well placed to help Scotland achieve targets such as:

- Protect and restore biodiversity: The Scottish Biodiversity Strategy: 2020
- Net zero emissions by 2045: The Climate Change (Emissions Reduction Targets) (Scotland) Act 2019
- Sustainable land use: Scotland's Third Land Use Strategy 2021-2026 - Getting the best from our land
- The United Nation's Sustainable Development Goals (https://sdgs.un.org/)

2.1 What is agroecology?

Originally stemming from the fusion of two scientific interests - agronomy and ecology - agroecology has evolved and the term is now understood simultaneously as a scientific discipline, an approach to farming and a socio-political movement (Wezel et al., 2009; Padel et al., 2017).

This report concentrates on agroecology as the scientific discipline that underpins specific farming models where environmental, economic, and social goals inform action on the ground. At the heart of it, agroecology draws on knowledge of the ecosystem processes that underpin agricultural production systems (Figure 1) to identify farming practices that work with nature to increase the systems sustainability and resilience.

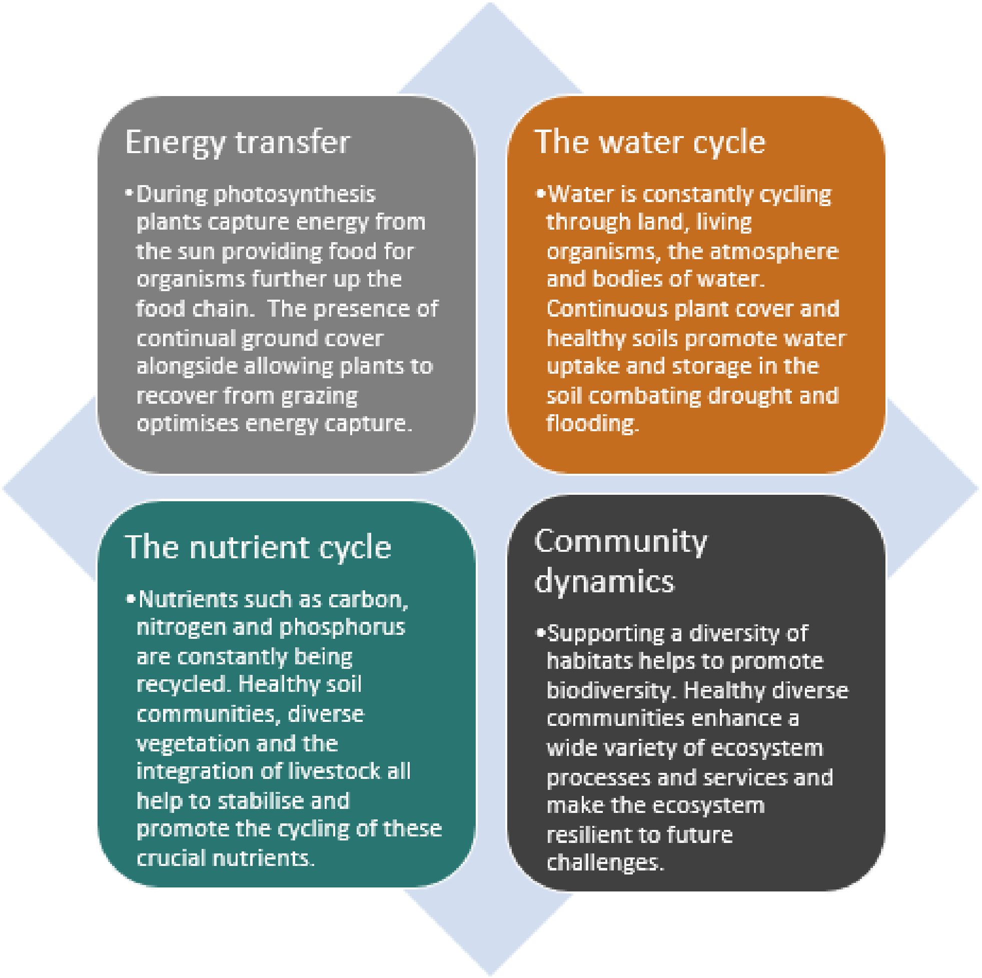


Figure 1: The four ecosystem processes that underpin agricultural production

This report is underpinned by the definition of agroecology set out by Gliessman (2018) as **"research, education, action and change that *brings sustainability to all parts of the food system: ecological, economic and social*".** This definition aligns well with the 13 agroecological principles defined by Wezel et al. (2020) (Figure 2; Appendix 1). These 13 principles highlight how agroecology integrates environmental, economic, and social goals and transcends agronomic practices, for example by linking production into local food systems, promoting fairness and inclusivity, and supporting rural livelihoods and healthy diets.

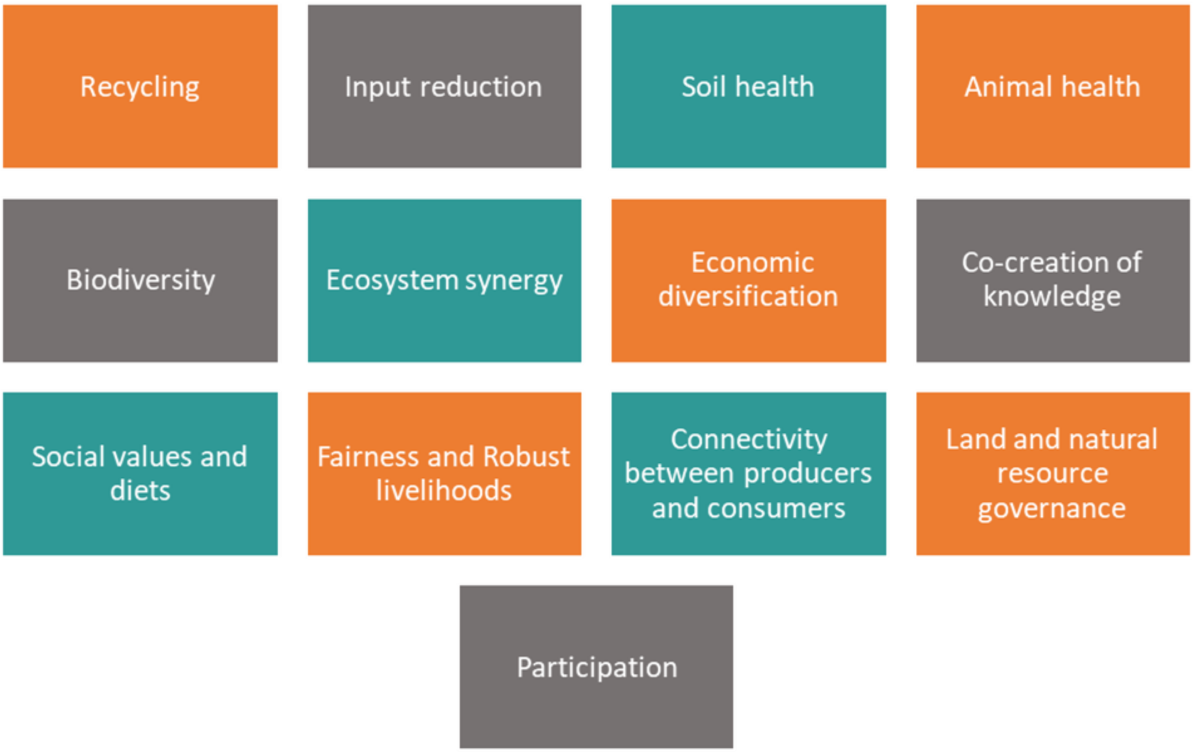


Figure 2: The 13 Consolidated Agroecological Principles (Wezel et al., 2020)

2.2 Report focus

A wide variety of alternative farming approaches (i.e. models) draw on agroecological principles, from agroforestry to organic farming (Lampkin et al., 2015; Rega et al., 2018) (Box 1). While these models have considerable overlap, they vary in their underlying concepts, management practices, potential benefits, legal regulation and indeed suitability to the diversity of farming systems that Scotland supports. This report focusses on five of these agroecological models specifically:

- integrated farm management
- regenerative agriculture
- organic farming
- low input systems
- agroforestry

We identified how these farming models translate to management actions on the ground, allowing us to explore similarities and differences between the five models. Through an expert elicitation process, we determined the potential for each model to deliver a variety of potential outcomes.

While societal benefits of agroecological models are widely recognised (Wezel et al., 2020; Padel, et al., 2018), the primary purpose of this report is to evaluate the potential of these five models to deliver environmental and economic outcomes at the farm level. Finally, we conducted a Strengths, Weaknesses Opportunities and Threats Analysis that takes a more holistic approach considering Political, Economic, Social, Technological, Legal and Environmental factors.

Box 1: AGROECOLOGICAL MODELS

Focus of this report

- Integrated farm management
- Regenerative agriculture
- Organic farming
- Low input systems
- Agroforestry

Other models

- Conservation agriculture
- Biodynamic agriculture
- Permaculture
- Integrated pest management
- Farming with nature
- Renewable farming
- Climate smart agriculture
- High Nature Value Farming

2.3 Agroecological models

Here we adopt a hierarchical framework whereby agroecology is the scientific field that underpins several agroecological farming approaches (i.e. termed in this report as models), with each model aligning with a range of farming practices (Figure 3).

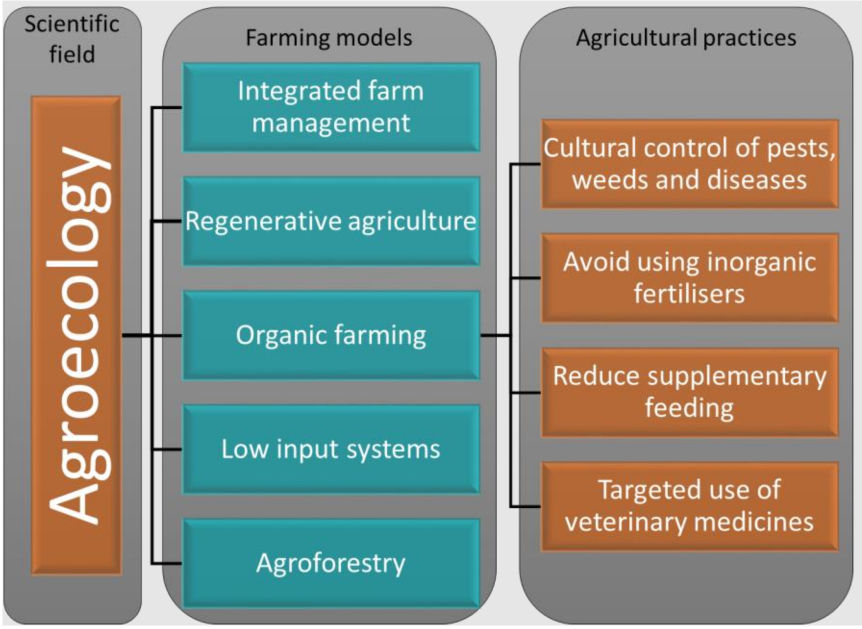


Figure 3: The hierarchy of agroecology – from science to agricultural practice. To ease interpretation only a subset of practices found to be related to organic farming are presented.

The five agroecological models outlined in Figure 3 were selected because they are widely recognised and relevant to Scotland. They range from models that are well-established with certification (e.g. organic agriculture, integrated farm management) to those that are less well defined but gaining momentum within the agricultural sector (e.g. regenerative agriculture and agroforestry).

It is important to note that these five models can be fluid and are not necessarily mutually exclusive. For example, a farm may simultaneously be certified as organic, practicing agroforestry and the farmer may consider themselves a regenerative farmer. Thus, while defining the different models helps us to understand concepts and context, it is important that our thinking is not too constrained since a practitioner's definition of their own approach is inherently subjective. Furthermore, a farmer might choose to implement an agroecological model on only part of their farm (e.g. agroforestry in grassland fields). Many "conventional" farmers also adopt some of the practices attributed to these agroecological models without subscribing to the whole model (i.e. all features shown in Figure 2). In this sense there is no fixed boundary between agroecological and conventional farming.

2.3.1 Defining organic farming

Organic agriculture is probably the world's most familiar alternative farming system (Rega et al., 2018). It has clearly defined legislation, regulations, and certification schemes (Bellon and Hemptinne, 2012). Organic farming is the only legally defined system of farming, and the certification procedure certifies the process of crop and livestock production rather than the product.

It is based on 4 principles: health, ecology, fairness and care. There is a range of definitions used to describe organic farming systems, for example Mannion (1995), defines organic farming as

> *"a holistic view of agriculture that aims to reflect the profound interrelationship that exists between farm biota, its production and the overall environment".*

Another definition is given by the International Federation of Organic Agriculture Movements (IFOAM - Organics International) in 2005 and states

> *"Organic agriculture is a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved".*

In the EU, council regulation 834/2007 defines Organic Farming as

> *"a holistic production management system which promotes and enhances agro-ecosystem health, including biodiversity, biological cycles, and soil biological activity. It emphasizes the use of management practices in preference to the use of off-farm inputs, taking into account that regional conditions require locally adapted systems".*

Several other definitions exist, but these essentially use the same general attributes as those outlined in the three definitions provided above. As such, organic farmers can be labelled as agricultural practitioners that do not use synthetic herbicides or synthetic fertilisers, and instead rely on cultural methods for weed and pest control as well as plant nutrient supply.

Typically, organic farmers have diverse animal and crop enterprises, including the use of crops and livestock bred without using genetic modification (GM) technology, that are adapted to local conditions wherever possible. They utilise diverse crop rotations, with carefully selected sequences of crops (both species and varieties), with nitrogen fixing crops such as clovers or grain legumes as an integral part of the system. Organic farmers aim to utilise home grown livestock feed or locally grown feed. They will apply careful timing to all their field and animal care procedures, and other management practices. The latter include the use of cover crops, green manures, reduced tillage, timeliness and timing of field operations linked to soil and weather conditions, and practices such as composting of animal manure to aid weed control (Stockdale et al., 2001). Table 1, adapted from Seufert et al. (2017), provides a matrix of management practices and how these inter-relate with the key organic principles outlined previously.

	Organic Principles						
Management practices	Natural	Local	Soil	Water	Biodiversity	Animal	Human
Crop rotation			X	X	X		
Species / variety choice	X	X			X		
Tillage			X		X		
Fertilization	X	X	X	X			X
Irrigation			X	X	X		
Pest control	X				X		X
Conservation areas			X	X	X		X
Livestock housing						X	
Livestock feed	X	X				X	
Veterinary treatments	X					X	X
Livestock breeding	X				X	X	
Livestock transport & slaughter						X	
Additives & processing aids	X						X

Table 1: Matrix of organic management practices versus organic principles that could be used to discuss each practice (adapted from Seufert et al., 2017)

2.3.2 Defining integrated farm management

Integrated Farm Management (IFM) is promoted in the UK by organisations such as LEAF (Linking Environment and Farming), who define IFM as

> *'a site-specific farm business approach that uses the best of modern technology and traditional methods'.*

The aim is to increase productivity while preserving resources through appropriate and efficient use of inputs, smarter approaches to business planning, and adoption of innovations and new technologies. The broader goals are to increase climate resilience, improve biodiversity, drive supply chain innovation, and engage consumers in positive change through nine IFM components, captured in the LEAF wheel (Figure 4), which collectively address the entire farm business.

Figure 4: The LEAF 'wheel' of nine interrelated components needed for effective implementation of Integrated Farm Management.

LEAF runs an assurance scheme (LEAF Marque) held by certified farm businesses that meet the LEAF standards of sustainable farming practices and allow consumers to recognise products grown in a more sustainable way.

Alongside minimising inputs and pollutants, whilst maintaining high quantities and standards of food production, IFM practices encourage biodiversity for its contribution to ecosystem services, particularly in pollination, natural enemy control of crop pests, disease and weed suppression, improved soil health and fertility. Similar to organic and regenerative agriculture, integrated farming systems utilise biodiversity to minimise reliance on agrochemicals for regulation of system processes. Where chemical inputs are still required, efficiency gains are made through techniques such as threshold monitoring for crop protection inputs, and precision agriculture for sowing and fertiliser applications.

Key agroecological practices applied in IFM systems at the field and farm-scale are reviewed in Hawes et al. (2021) and include (see Figure 5):

- reduced soil disturbance to maintain soil structure and organic matter retention
- site-specific soil nitrogen calculations and soil mapping to inform variable rate fertiliser applications
- use of alternative nutrient sources (organic or legume-based)
- integrated pest management tools
- increasing the area of natural habitat to support biodiversity.

Soil nitrogen mapping at the Centre for Sustainable Cropping, Barluddery Farm, Angus

Species-rich flowering mixtures in field margins to support biodiversity

Hutton criteria to forecast blight risk and minimise fungicide use in potato crops

Direct drilling of cereal-legume intercrops

Figure 5: Examples of Integrated Farm Management practices applied in Scottish conditions.

2.3.3 Defining regenerative agriculture

Regenerative agriculture is a holistic approach to farm management. It focusses on enhancing ecosystem function through promoting diversity and restoring ecosystem health; this gives greater ecological and economic resilience. First coined in the 1980s by the Rodale Institute, regenerative agriculture has seen a recent surge in popularity amongst farmers, NGOs (e.g. WWF, Friends of the Earth), multi-national companies (e.g.

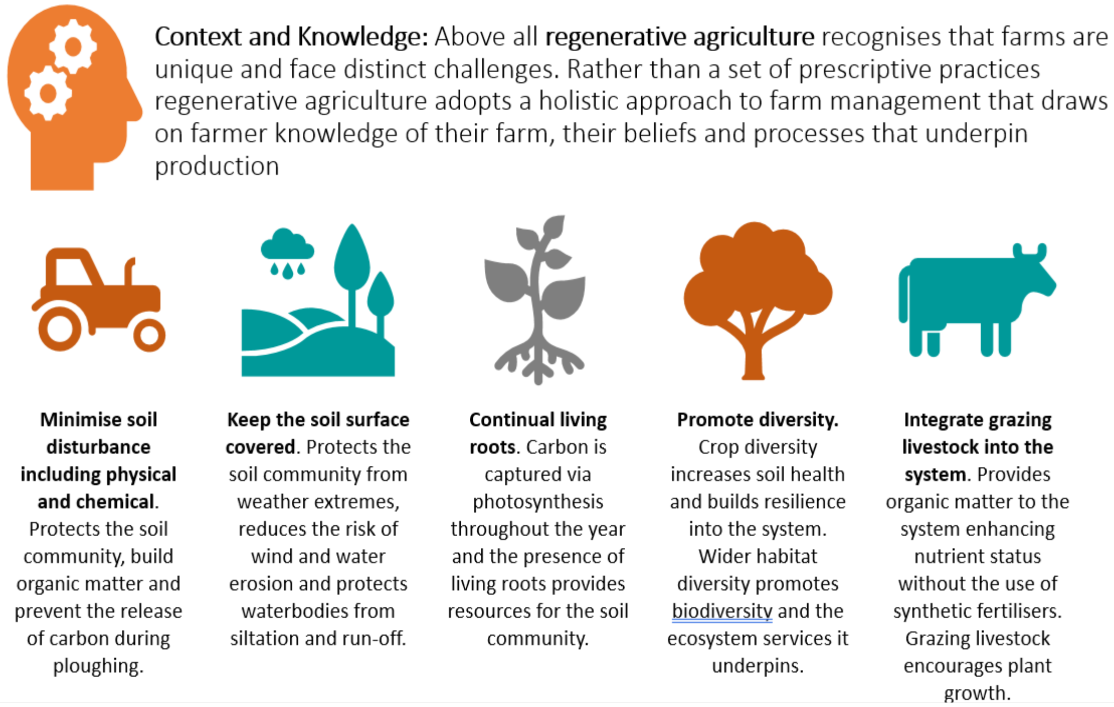
Danone, Kellogg’s), politicians and consumers (Newton et al., 2020; Giller et al., 2021). This gain in traction stems from the fact that through restoring ecosystem processes and enhancing natural assets, regenerative agriculture extends beyond sustainable farming concepts (Kassam and Kassam, 2021).

Despite its growing popularity, regenerative agriculture lacks a uniform scientific definition, posing a challenge when incorporating into political, research or legal frameworks (Newton et al., 2020). In this report, we will adopt the provisional definition by Schreefel et al. (2020) that regenerative agriculture is

> *“an approach to farming that uses soil conservation as the entry point to regenerate and contribute to multiple provisioning, regulating and supporting ecosystem services, with the objective that this will enhance not only the environmental, but also the social and economic dimensions of sustainable food production”*

Despite the lack of a uniform definition, certification schemes exist and, in the US, Regenerative Organic Certified is based on soil health, animal welfare and social fairness.

Regenerative agriculture relies on the principle that healthier ecosystems enhance the delivery of provisioning (e.g. food, fibre), supporting (e.g. water and nutrient cycles, soil formation) and regulating (e.g. natural pest control, pollination) ecosystem services. Rather than a set of prescriptive management practices, regenerative agriculture recognises the uniqueness of farms and the knowledge held by farmers; and believes that the farmer should be central in deciding the best way to restore ecosystem health on their farm. Regenerative principles particularly focus on understanding and restoring four interconnected ecosystem processes that underpin agricultural production, specifically the energy cycle, the water cycle, the nutrient cycles (e.g. nitrogen, phosphorus) and community dynamics (Figure 1).



Context and Knowledge: Above all **regenerative agriculture** recognises that farms are unique and face distinct challenges. Rather than a set of prescriptive practices regenerative agriculture adopts a holistic approach to farm management that draws on farmer knowledge of their farm, their beliefs and processes that underpin production

Minimise soil disturbance including physical and chemical. Protects the soil community, build organic matter and prevent the release of carbon during ploughing.

Keep the soil surface covered. Protects the soil community from weather extremes, reduces the risk of wind and water erosion and protects waterbodies from siltation and run-off.

Continual living roots. Carbon is captured via photosynthesis throughout the year and the presence of living roots provides resources for the soil community.

Promote diversity. Crop diversity increases soil health and builds resilience into the system. Wider habitat diversity promotes biodiversity and the ecosystem services it underpins.

Integrate grazing livestock into the system. Provides organic matter to the system enhancing nutrient status without the use of synthetic fertilisers. Grazing livestock encourages plant growth.

Figure 6: The five key principles of soil health (Brown, 2018) alongside context and knowledge

Central to regenerative agriculture is restoring soil health, with most practitioners drawing on Gabe Brown’s five principles of soil health alongside context and knowledge (Brown,

2018) (Figure 6). Healthier soils and greater crop diversity have a greater ability to (1) sequester and store carbon; (2) reduce the need for inorganic fertilisers through enhancing biological nitrogen fixation and increasing nutrient cycling through supporting more diverse soil microbial communities; (3) optimise photosynthesis through enhancing plant diversity and ensuring year-round growth and plant ground cover.

While the restoration of soil and wider ecosystem health underpins regenerative agriculture, it is widely accepted that it expands beyond this to consider wider environmental (e.g. reducing diffuse pollution) and societal (e.g. peer to peer learning, healthier diets) benefits alongside the ability to alleviate the impacts of climate change (e.g. sequestration and storage of carbon, mitigation of flooding/drought) (Schreefel et al., 2020; Kassam and Kassam, 2021).

2.3.4 Defining agroforestry

Agroforestry can be defined in its simplest form as farming with trees (Figure 7). It can include both the deliberate integration of trees or shrubs within grazed or arable land, or the integration of crops or livestock within woodlands (Raskin and Osborn, 2019). Agroforestry is a multi-functional land-use system that takes advantage of the interactions that occur between trees, crops, and/or livestock. Although not a new idea, the term agroforestry was first coined in the 1970s by John Bene, a forester from Canada’s International Development Research Centre, who highlighted the benefits of this type of multi-functional land-use system. Although classed as a model in this report, the practice of agroforestry is often an integral part of the other model systems, for example it is extensively used in organic and low input systems.

There are several different types of agroforestry system, including:

- Silvopastoral systems (e.g. wood pasture, grazed orchards, parklands, individually protected trees)
- Silvoarable systems (e.g. alley cropping, orchard intercropping, individually protected trees)
- Agrosilvopastoral systems (a combination of silvopastoral and silvoarable systems)
- Silvopoultry systems (e.g. woodland egg production)
  Trees between and around the edges of fields (e.g. hedgerows, shelterbelts, riparian woodland strips, small woodland blocks)

Recently planted silvopastoral agroforestry plot with individually protected broadleaved trees. SRUC Hill & Mountain Research Centre

Established silvopastoral agroforestry with Scots Pine at JHI Glensaugh

Alder wood pasture in Glen Lochay, Perthshire

Figure 7: Examples of agroforestry from across the United Kingdom

2.3.5 Defining low input systems

There is no official definition of Low Input Farming Systems, although a description clearly addressing the concept was proposed by Parr et al. (1990): Low Input Farming (LIF) Systems are those that

> *"seek to optimize the management and use of internal production inputs (i.e. on-farm resources) and to minimize the use of production inputs (i.e. off-farm resources), such as purchased fertilizers and pesticides, wherever and whenever feasible and practicable, to lower production costs, to avoid pollution of surface and groundwater, to reduce pesticide residues in food, to reduce a farmer's overall risk, and to increase both short- and long-term farm profitability."*

Low Input Farming Systems might perhaps be better described as Low "off-farm" Input Farming Systems, as it is the reduced external inputs that are key (Poux, 2008).

There are many different types of LIF systems including extensive livestock and mixed farms, dairy farms and arable farms. What they all have in common is the relatively low use of external inputs such as artificial fertilisers, pesticides, fuel and concentrate feeds (Elbersen and Andersen, 2008). LIF systems are often, but not always, low output systems, but provide high non-monetary values in terms of landscape, biodiversity and other environmental ecosystem services (Elbersen and Andersen, 2008).

There is some overlap with other systems such as organic and High Nature Value (HNV) farming systems; however, there will be some organic and HNV systems that have input use that is too high to qualify them as low input systems (Elbersen and Andersen, 2008). Agroforestry is also sometimes practised within low input systems, for example traditional grazed orchards.

In Scotland the low input approach is widely practised in the crofting regions and in some of the extensive hill sheep farms of the highlands, where it is often driven by environmental and economic constraints rather than by farmer choice.

3 Aligning practices and models

3.1 Identification of agroecological practices

We identified a total of 49 farming practices underpinned by agroecological principles from the literature (Giller et al., 2021, Hawes et al., 2021, Newton et al., 2020, Rega et al., 2018, Wezel et al., 2014). All practices are currently implemented in Scotland, although adoption varies from practices that are widely implemented (e.g. variety selection and breed selection to local conditions, and the monitoring of pests, weeds and diseases) to those that are rarely practised (e.g. machinery cooperatives, intercropping).

We assigned these practices into those targeting resource use efficiency and/or substitution (21 practices), and those involving a system redesign (28 practices). Additionally, the 49 practices were classified into seven broad management categories adapted from Wezel et al. (2014). Figure 8 provides a summarised overview, with the full list of practices and their classification provided in Appendix 2.

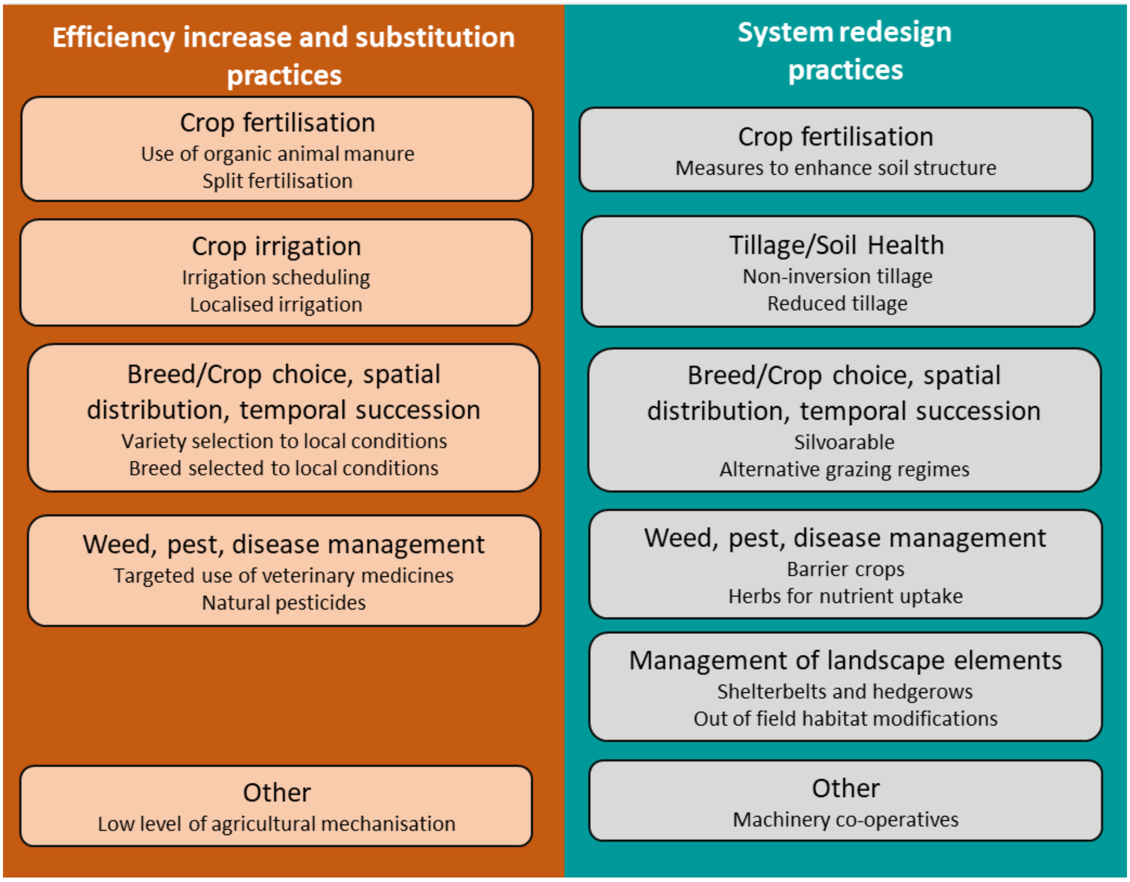
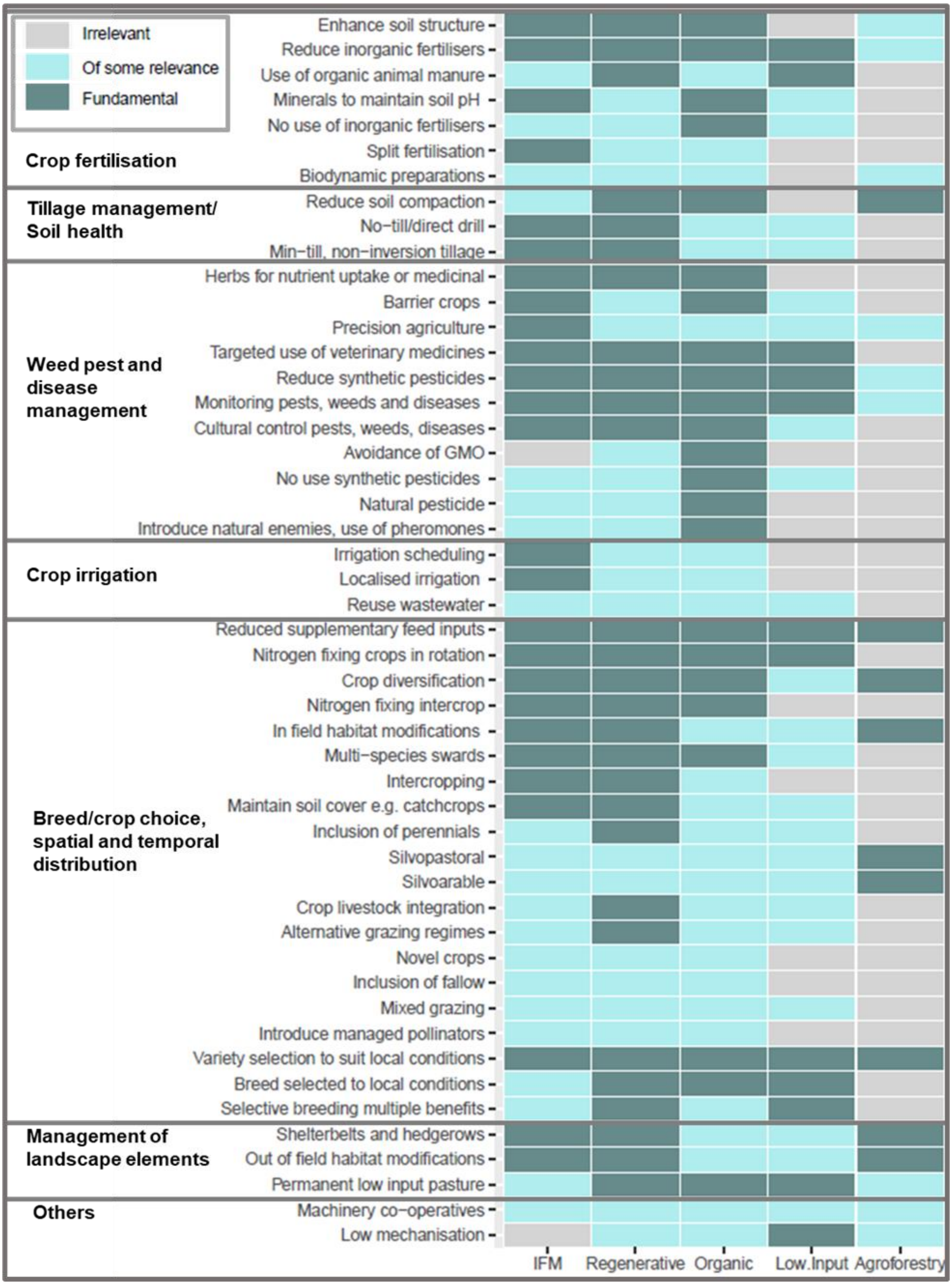


Figure 8: Classification of agroecological management practices adapted from Wezel et al. (2014). See Appendix 2 for comprehensive classification of all 49 practices

3.2 Determining agroecological practices that typify each model

The 49 practices were matched to each of our five agroecological models, and identified as

- irrelevant to the model (i.e. the management practice does not relate to the principles of the model),
- of some relevance (i.e. relates to the principles of the model in question but is not fundamental) or
- fundamental (i.e. management actions that strongly underpin model principles and are typically undertaken by practitioners).



░ Irrelevant
▒ Of some relevance
█ Fundamental

		IFM	Regenerative	Organic	Low.Input	Agroforestry
Crop fertilisation	Enhance soil structure	█	█	█	░	▒
	Reduce inorganic fertilisers	█	█	█	█	▒
	Use of organic animal manure	▒	█	▒	█	░
	Minerals to maintain soil pH	█	▒	█	▒	░
	No use of inorganic fertilisers	▒	▒	█	▒	░
	Split fertilisation	█	▒	▒	░	░
	Biodynamic preparations	▒	▒	▒	░	▒
Tillage management/ Soil health	Reduce soil compaction	▒	█	█	░	█
	No−till/direct drill	█	█	▒	▒	░
	Min−till, non−inversion tillage	█	█	▒	▒	░
Weed pest and disease management	Herbs for nutrient uptake or medicinal	█	█	█	░	░
	Barrier crops	█	▒	█	▒	░
	Precision agriculture	█	▒	▒	▒	▒
	Targeted use of veterinary medicines	█	█	█	█	░
	Reduce synthetic pesticides	█	█	█	█	▒
	Monitoring pests, weeds and diseases	█	█	█	█	▒
	Cultural control pests, weeds, diseases	█	█	█	▒	░
	Avoidance of GMO	░	▒	█	░	░
	No use synthetic pesticides	▒	▒	█	▒	░
	Natural pesticide	▒	▒	█	░	░
	Introduce natural enemies, use of pheromones	▒	▒	█	░	░
Crop irrigation	Irrigation scheduling	█	▒	▒	░	░
	Localised irrigation	█	▒	▒	░	░
	Reuse wastewater	▒	▒	▒	▒	░
Breed/crop choice, spatial and temporal distribution	Reduced supplementary feed inputs	█	█	█	█	█
	Nitrogen fixing crops in rotation	█	█	█	█	░
	Crop diversification	█	█	█	▒	█
	Nitrogen fixing intercrop	█	█	█	░	░
	In field habitat modifications	█	█	▒	▒	█
	Multi−species swards	█	█	█	▒	░
	Intercropping	█	█	▒	░	░
	Maintain soil cover e.g. catchcrops	█	█	▒	▒	░
	Inclusion of perennials	▒	█	▒	▒	░
	Silvopastoral	▒	▒	▒	▒	█
	Silvoarable	▒	▒	▒	▒	█
	Crop livestock integration	▒	█	▒	▒	░
	Alternative grazing regimes	▒	█	▒	▒	░
	Novel crops	▒	▒	▒	░	░
	Inclusion of fallow	▒	▒	▒	░	░
	Mixed grazing	▒	▒	▒	▒	░
	Introduce managed pollinators	▒	▒	▒	░	░
	Variety selection to suit local conditions	█	█	█	█	█
	Breed selected to local conditions	▒	█	█	█	░
	Selective breeding multiple benefits	▒	█	▒	█	░
Management of landscape elements	Shelterbelts and hedgerows	█	█	▒	▒	█
	Out of field habitat modifications	█	█	▒	▒	█
	Permanent low input pasture	▒	█	█	█	▒
Others	Machinery co−operatives	▒	▒	▒	▒	▒
	Low mechanisation	░	▒	▒	█	▒

Figure 9: Aligning management practices for the five agroecological farming models. While Avoidance of GMO's is included for completeness growing genetically modified organisms (GMOs) is currently prohibited in Scotland under the Scottish Statutory Instrument 2019 No.86.

This resulted in a suite of management practices that could be considered as fundamental to each model (Figure 9). Two agroecological practices were identified as fundamental to all five models, specifically *reduce supplementary feed inputs* and the *varietal selection of crop/fodder plants to suit local conditions*. *Breed selection to local conditions* was included as a separate practice and was considered to be fundamental to organic farming, regenerative agriculture and low input systems.

Regenerative agriculture, IFM and organic farming had the widest range of practices considered as fundamental reflecting the broad nature of these models which tend to take a “toolbox” approach to select practices appropriate to specific locations and circumstances. IFM and regenerative agriculture were particularly broad, reflecting their focus on a diversity of outcomes including enhancing ecosystem functioning, crop/livestock diversification, improving resource use efficiency, promoting soil health and enhancing biodiversity. Low input systems and agroforestry were much more constrained in scope with only 12 and 9 practices, respectively, considered as fundamental.

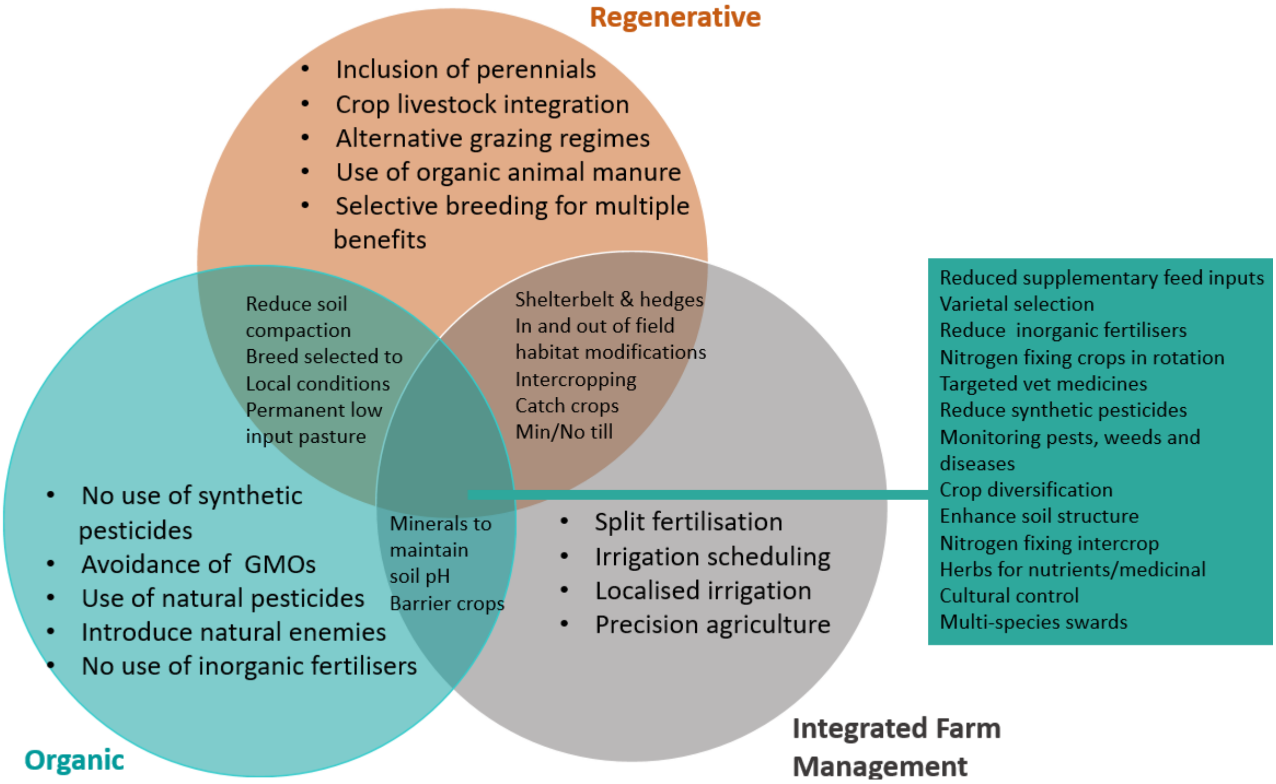


Figure 10: Venn diagram showing overlap between farming practices deemed fundamental to regenerative agriculture, IFM and organic farming.

There was considerable overlap between regenerative agriculture, IFM and organic farming with 13 practices considered fundamental to all three models (Figure 10). This overlap was greatest for regenerative and IFM models where 20 practices were identified as fundamental to both. Differentiation was, however, apparent and practices that were fundamental to IFM but not regenerative agriculture focused on the use of external inputs and technology (e.g. *split fertilization, minerals to maintain soil pH* and *precision agriculture*) whereas those fundamental to regenerative relied on more natural solutions (e.g. *alternative grazing regimes, crop livestock integration,* and *use of organic animal manure*). Organic farming differentiated from IFM and regenerative agriculture primarily with respect to practices that highlight the prescriptive nature of organic farming (e.g. avoidance of synthetic pesticides and fertilisers) alongside the inclusion of alternative measures to control pests, weeds and diseases (e.g. *natural pesticides* and *introduced natural enemies/pheromones*). Additionally, measures to minimise soil disturbance and promote biodiversity were considered fundamental to IFM and regenerative agriculture, but not to organic systems.

Twelve practices were identified as fundamental to low input systems indicating the narrower scope of this model where the focus is on minimising inputs including agrochemical and mechanical interventions. Indeed, this was the only model that classified a low level of mechanisation as fundamental. Except for low mechanisation, practices deemed fundamental to low input systems were also fundamental to regenerative agriculture. As with low input systems, the narrow scope of agroforestry is also highlighted with only nine practices deemed to be fundamental. While silvopasture and silvoarable were considered relevant to all models, they were only considered fundamental to agroforestry.

3.3 The complex link between models and constituent practices

This exercise provides us with a deeper understanding of the farming practices typically undertaken in each agroecological model giving a better sense of where these models overlap and deviate (Figure 11).

Whether a practice is fundamental to a specific model will depend on a wide variety of parameters including farming system, geographical location and land/soil type, resource availability (e.g. machinery, time), constraints, mindset and priorities of the farmer. For example, with pests, weeds and diseases posing a high risk to arable crops, integrated pest management (e.g. barrier crops and monitoring of pests, weeds and diseases) is more applicable to arable systems than grassland systems. It is not just risk that drives uptake, but also the ease and costs of implementation. Additionally, while the integration of livestock was considered fundamental to regenerative agriculture, it was recognised that arable farmers practicing regenerative agriculture may not have access to livestock, or lack fencing and watering points, making livestock integration challenging without significant investment. In this case, other regenerative approaches can be incorporated, to enhance the supporting and regulating services provided by natural biodiversity within arable systems.

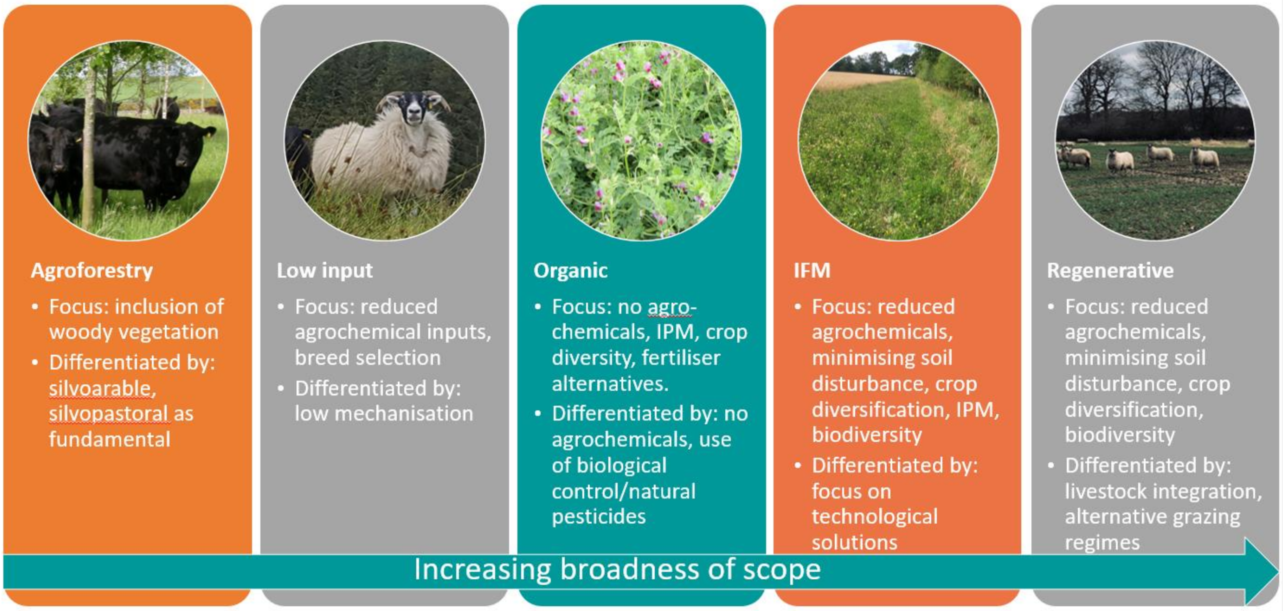


Figure 11: Graphical summary of alignment of practices to models indicating primary focus and where these models deviate from each other

Agroecological systems are strongly knowledge based and, unless constrained by legislation (e.g. use of synthetic insecticides in organic farming), the adoption of practices will be highly context specific. Agroecological approaches typically take a holistic view to farm management, where the farmer is the central decision-maker in determining the best practice to reach the desired outcome (Padel et al., 2017; Mier et al., 2018). A prescriptive set of practices for each model, therefore, goes against the grain of agroecological approaches. Consequently, these approaches rely strongly on the farmer’s understanding of their farm, its ecology and context. For example, while minimising soil disturbance is embedded in regenerative principles, in some instances cultivation may be deemed the most appropriate measure to reach a desired outcome. It is therefore important to recognise that models, and their practices, can be fluid depending on a wide variety of factors including the farming system, the local context (e.g. geographical location, current and historic land use), constraints (e.g. financial, machinery, physical, time) and social factors (e.g. training and mindset of the practitioner, generational attitudes).

4 Applying the models in Scottish farming systems

About 80% of the land area in Scotland is managed for agricultural production through a variety of farming systems. These systems tend to be geographically segregated because of topography, climatic conditions, and soil properties (Figure 12). Most of Scotland’s agricultural land is classified as ‘less favoured area’ where production is constrained by the land type, climate and/or remoteness; the majority of this land is devoted to rough grazing which constitutes 59% of total agricultural land area. Less than 10% of agricultural land is used for arable and horticultural crops, and this is primarily located along the central belt and east coast where land is typically of high quality and the drier, sunnier climatic conditions of the east coast facilitate the growth of high value crops (Figure 12 and Table 2). The wetter, warmer, conditions in the south-west, on the other hand, provide ideal conditions for grass growth and this area supports much of Scotland’s intensive grassland farms typically managed for dairy and beef production.

When it comes to the adoption of agroecological practices, farming systems differ in the constraints they face and the ease of adopting alternative land management strategies.

Land Use	Percentage Agricultural Land	Hectares
Total crops and fallow	9.37%	582,495
Grassland	21.17%	1,316,640
Rough grazing	59.07%	3,673,454
Woodland	8.77%	545,591
Other land	1.62%	100,872
Total agricultural land area		6,219,051

Table 2: Scottish agricultural land use data outlining the area and percentage of agricultural land under each broad land use category (data sourced from the Scottish Agricultural Census June 2020)

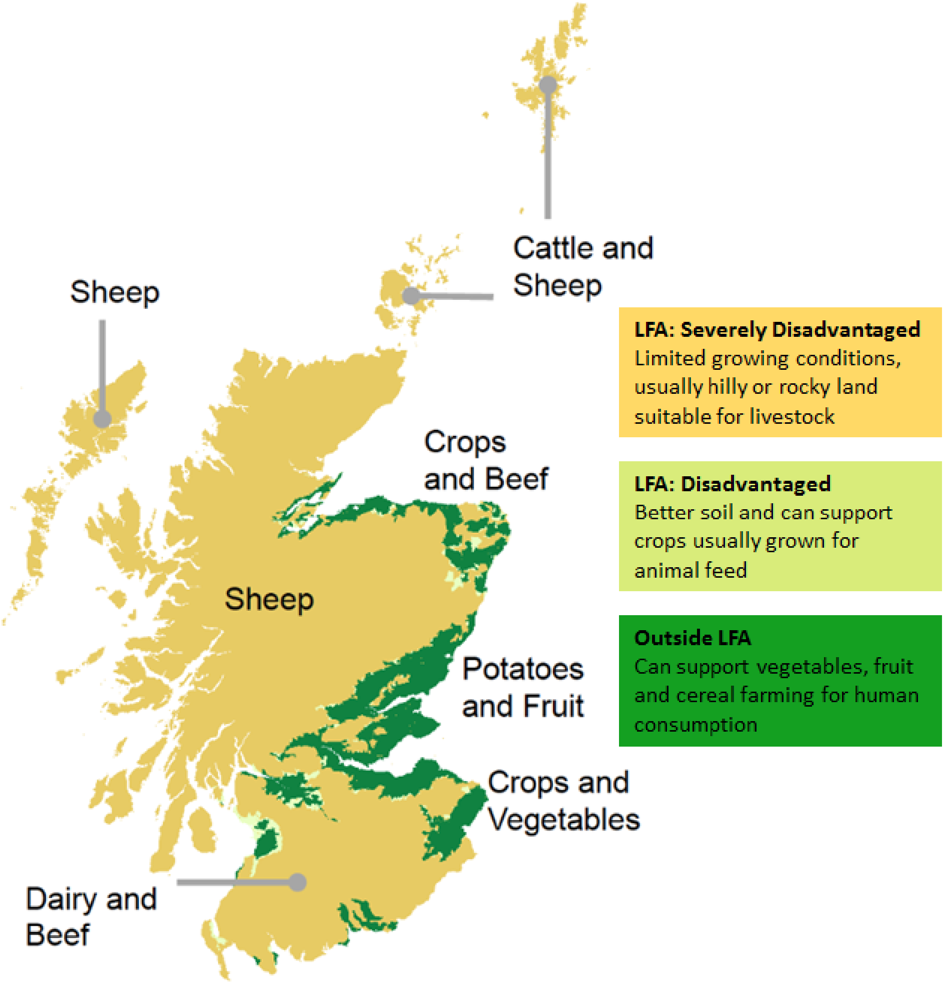


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Figure 12: Geographical configuration of Scotland's agricultural land showing the main types of production in each area alongside the spatial extent of Less Favoured Area land (Scottish Government, 2020)

4.1 Relevance of agroecological management categories to farming system

As outlined above, the 49 agroecological practices were assigned to seven broad management categories (Figure 8; Appendix 2). For each broad category, we determined their relevance to four farming systems dominant in Scotland (Table 3). Breed/crop choice, spatial distribution and temporal succession (e.g. farm scale measures) and management of landscape scale elements were relevant to all four systems.

Taking a more agroecological approach to fertilisation (e.g. use of organic manures, split fertilisation) was relevant to all but extensive livestock systems. Weed, pest and disease management and Tillage/Soil health were particularly relevant to arable and mixed farming systems, with our "other" practices category (particularly low level of agricultural mechanisation) being relevant to extensive livestock farming. Agroecological approaches to crop irrigation (e.g. irrigation scheduling, drip irrigation) are not widely implemented, however, with climate projections indicating warmer, drier summers, with greater extremes in rainfall, irrigation requirements are predicted to increase, particularly on the east coast highlighting future importance in arable situations (Brown et al., 2012).

Broad management category	Extensive livestock	Arable	Mixed	Intensive livestock
Breed/Crop choice, spatial distribution, and temporal succession	🟩	🟩	🟩	🟩
Management of landscape elements	🟩	🟩	🟩	🟩
Crop fertilisation		🟩	🟩	🟩
Tillage/Soil health		🟩	🟩	
Weed, pest and disease management		🟩	🟩	
Other	🟩			
Crop irrigation		🟧		

Table 3: Relevance of our seven broad management categories to four key Scottish farming systems. Green denotes the broad management category is highly relevant to the system in question with amber denoting potential future relevance. Details on the agroecological practices assigned to each of these seven management categories is provided in Appendix 2.

4.2 Extensive livestock systems with rough grazing

Typically receiving low inputs of agrochemicals and reduced mechanisation, these systems align well with both organic and low input models. A substantial proportion of Scotland’s agricultural land is managed as rough grazing, indicating significant benefits could be gained if this sector was to adopt agroecological approaches. Extensive systems, however, struggle to remain viable and measures may be required to enhance their long-term economic and social viability. These extensively managed systems can also provide a diversity of public goods (e.g. carbon sequestration and storage, biodiversity, natural flood management) and outcome-based agri-environment schemes should help to ensure that they are properly valued and financially rewarded (Lampkin et al., 2015).

4.3 Arable cropping systems

With conventional arable farms generally receiving high inputs of agrochemicals and frequent soil disturbance, adopting agroecological approaches such as regenerative agriculture, silvoarable or IFM is likely to have significant benefits. Some agroecological practices take land out of production to improve biodiversity-dependent ecosystem services (e.g. creation of wildflower strips to promote pollination services) and research indicates that this can be agronomically viable, although results are variable (Tscharntke et al., 2021; Albrecht et al., 2020). With arable systems typically lacking livestock, implementing IFM will be easier than regenerative agriculture which has a stronger reliance on the integration of livestock and the use of organic manures. Similarly, with agroforestry there is a time delay before production benefits are achieved, resulting in a financial shortfall in the short-term. Implementing agroforestry and regenerative farming models in arable systems is likely to require significant investment, training and restructuring of the farm business. Financially supporting arable farmers to achieve this transition would help overcome these barriers.

4.4. Mixed farming systems

Many agroecological models rely on integrating livestock and/or replacing some, or all, inorganic fertiliser with organic manures and slurries. In already incorporating both livestock and crops, the adoption of agroecological approaches is likely to be easier to implement in mixed farming systems when compared to arable systems. For example, the farmer has the knowledge of both production systems, existing supply chains and known routes to market. Within mixed systems, the degree of integration of crops and livestock varies (Watson et al., 2019), and significant investment may still be required with respect to farm infrastructure (e.g. stock proofing and establishing water points in arable fields). Mixed farming systems are very suitable for conversion to organic farming as most depend on ley/arable rotations which are advantageous for nitrogen supply and weed control without agrochemicals.

4.5 Intensive livestock systems

In intensive livestock systems the adoption of agroecological models can be achieved without diversifying into arable crops, making implementation potentially easier. However, intensive livestock systems typically have very slim profit margins making system wide changes challenging. Furthermore, with a typical time lag before rewards of adopting agroecological approaches are reaped (e.g. through improved soil health), farms must have the financial capacity to buffer an initial shortfall in production. Adopting alternative grazing practices such as adaptive multi-paddock grazing will require investment in infrastructure (e.g. electric fencing and additional watering points), while the adoption of silvopastoral systems would require knowledge on how to establish and manage trees. Targeting funding to help farms meet these initial outlay costs and providing training and support during transitioning could help overcome these barriers.

5 Impact on food security and the environment

Our five agroecological models differed slightly in the management practices typically adopted by farmers. This will impact on their potential to deliver food security and environmental outcomes.

For each model, a minimum of nine experts with knowledge of that specific model were identified from our collective networks (e.g. for regenerative farming this included regenerative farmers, and researchers and policy advisors with an interest in regenerative agriculture). Each group of experts was asked to assess the potential of the model in question to deliver across 20 outcomes relating to biodiversity, climate adaptation and mitigation, water and air quality, greenhouse gas emissions, soil quality and food security (Appendix Table 3). They were asked to evaluate effects at the level of an individual farm. This was certainly not to ignore the impacts to the wider supply chain, or global impacts relating to a change in yield or production outputs, but to retain a tight boundary for this project. Some extrapolation is possible through integrating yield and environmental scores (see below), but further work is required to consider the wider systems' impacts.

Experts were also asked to assess their level of confidence in the scores to capture strength – or otherwise – of the underlying research evidence and its application on the ground (further details of confidence scores can be found in Appendix 3).

5.1 Overall trends

Regenerative agriculture had the highest number of outcomes rated as strongly positive, including all biodiversity and soil quality outcomes (Figure 13). While this indicates the potential for regenerative agriculture to deliver a wide range of environmental and food security goals, care should be taken as the outcome-based nature of this model could bias scoring towards positive outcomes. Furthermore, it is important to recognise that agroforestry and low input systems have a narrower scope, and as a result outcomes may be expected to be more restricted. Integrated Farm Management also performed strongly.

5.2 Biodiversity

All models were perceived to positively impact on biodiversity, with regenerative agriculture having strong positive impacts on all four biodiversity outcomes. High scores for regenerative agriculture are in line with its focus to diversify crops and restore ecosystem processes and wildlife habitats (e.g. hedgerows and beetle banks). Low input and organic farming were also considered to have strongly positive impacts on the diversity of flowering plants and insect pollinators, with impacts on farmland birds being intermediate - possibly reflecting the fact that birds are influenced at a wider spatial scale. IFM was perceived to provide strong positive impacts on farmland birds and habitat diversity reflecting the importance of creating and maintaining wildlife habitats. Agroforestry was perceived to particularly benefit the creation of habitat diversity/ features and ecological connectivity indicating the importance of woody landscape features (e.g. hedgerows, shelterbelts and individual trees).

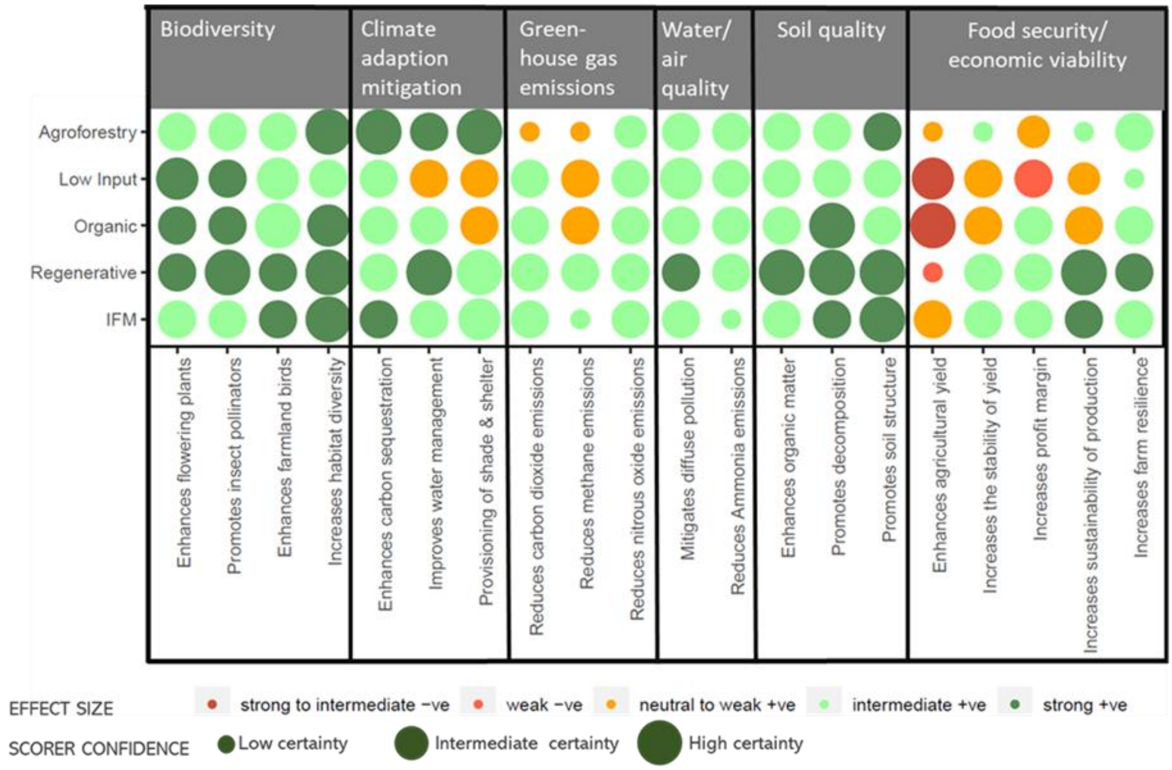

Figure 13: Summary of expert scores. Scores represent the change expected when converting from a conventional system to each of our five agroecological models. Bubble colour indicates the impact strength (from negative to positive) and bubble size the level of confidence experts had in their score (from low to high certainty).

5.3 Mitigation and adaptation to climate change

Agroforestry, IFM and regenerative agriculture were perceived to have intermediate to strong benefits for outcomes relating to climate change adaptation and mitigation. Agroforestry, in particular, received strong positive scores for all three mitigation/ adaptation outcomes. The value of woody vegetation in sequestering and storing carbon and natural flood management is widely acknowledged (Cole et al., 2020; Lorenz and Lal, 2014; Upson et al., 2016; Torralba et al., 2016). Agroforestry was the only model that scored strongly on provisioning of shade and shelter (He et al., 2017) highlighting its potential to enhance animal welfare standards in a changing climate.

5.4 Greenhouse gas emissions

To provide greater detail, experts were asked to score sequestration/storage of carbon and the emissions of three key greenhouse gases separately. However, it is important to note that the actual carbon footprint of a farm will depend on the balance between GHG emissions (and their relative global warming potential/atmospheric lifetime) alongside carbon sequestration/storage (considered above). All models were perceived to decrease nitrous oxide (N_2O) emissions. This reflects the focus of agroecological approaches to reduce synthetic nitrogen fertilisers, a primary source of nitrous oxide (N_2O) emissions (Rees et al., 2013; Kim et al., 2014).

No model was perceived to strongly decrease methane (CH_4) emissions although intermediate impacts were found for IFM and regenerative agriculture. Agroforestry and low input systems typically involve livestock foraging in more natural vegetation which may increase livestock methane emissions due to the higher roughage content (Boer, 2003).

All models were perceived to decrease carbon dioxide (CO_2) emissions reflecting both the reduction in soil disturbance (e.g. minimum tillage, permanent pasture) and lower agrochemical and energy inputs that commonly accompany these models. Agroforestry was only perceived to have a slight positive impact on carbon dioxide emissions. However, agroforestry scorers indicated a low confidence for this outcome, and research has found both an increase (i.e. as a result of tree root and microbial respiration: Wotherspoon et al., 2014), and decrease in soil carbon dioxide emissions (i.e. as a result of lower soil temperatures and water content: Franzluebbers, et al., 2017). As noted above, agroforestry has considerable potential to sequester and store carbon in the vegetation and soil, which is likely to offset any increase in greenhouse gas emissions (Wotherspoon et al., 2014; Resende et al., 2020).

5.5 Water/air quality

All models were perceived to have positive effects on both water quality (i.e. through reducing diffuse pollution/leaching) and ammonia emissions. The use of cover crops, reduced tillage and a reduction in agrochemicals would help reduce diffuse pollution risk. Furthermore, the presence of riparian woodlands, buffer strips, and hedgerows also help to prevent pollutants and sediments entering watercourses (Cole et al., 2020).

5.6 Soil health

Scorers indicated that all five models benefitted soil health, with intermediate to strong positive impacts for all three measures of soil health. Regenerative agriculture scored highly for all measures of soil health and scorers gave high certainty to their scores. This reflects the outcome-based focus of regenerative agriculture to restore soil health with practices that reduce soil disturbance and enhance organic matter being fundamental. Promotion of soil structure and microbial activity/decomposition also scored strongly for IFM, again indicating a focus on reduced tillage.

5.7 Food security

Low input, organic systems and regenerative agriculture were perceived to negatively impact on yield. Regenerative experts, however, indicated a low certainty in their scores, and while yield losses may initially be experienced (LaCanne and Lundgren, 2018), these are likely to lessen overtime as soil organic matter increases (Oldfield et al., 2019). Negative impacts on yield were not detected across the board, with agroforestry and IFM perceived to have neutral and slightly positive impacts, respectively. Agroforestry experts indicated low confidence in their scores, and impacts on yield depend on geographical location, production system, age, type and density of trees and crops grown (including agroforestry products). In temperate regions, mature trees can adversely impact arable yields (Pardon et al., 2018) and pasture production (Nworji, 2020) - most likely driven by increased competition for light and water. This loss in yield may, however, be offset if trees have a productive nature (e.g. fruit, short rotational coppice) and positive impacts on yield have been observed in Spain, France and the Netherlands (Graves et al., 2007). Furthermore, under changing weather patterns, the value of agroforestry in providing shade and shelter and enhancing the uptake and storage of water is likely to become increasingly important.

Yield, however, only provides one measure of food security. Profit margin, stability of yield, sustainability of production and resilience of the farming system are also crucial. Except for low input systems, all models were perceived to increase profit margin, highlighting that in organic and regenerative models reduced inputs and/or increased market value can offset yield losses.

All models were perceived to stabilise yield either slightly (low input and organic) or intermediately (agroforestry, regenerative, IFM). More diverse agroecological systems are likely to have a greater capacity to buffer environmental extremes (e.g. due to healthier soils, greater diversity of crops), resulting in more stable yields. With climate predictions indicating more extreme weather patterns (e.g. periods of drought and flooding), the ability to buffer such extremes is likely to become increasingly important. Furthermore, experts indicated that all models had the potential to increase farm resilience (ability to absorb disturbance and reorganise under external pressures - economic, social, or climatic). Greater diversity of production alongside reduced reliance on external inputs are key to helping recover from the impacts of sudden change.

5.8 System based approaches

The scoring process assessed each outcome independently; however, it is recognised that these different outcomes interact. For example, improvements to soil quality will positively impact on soil fertility and plant health and thereby reduce the need for synthetic pesticides, fungicides and fertilisers. This in turn is likely to have positive implications for greenhouse gas emissions, water quality and biodiversity. The evidence base is however variable and further work is required to assess interactions. Even for organic farming – the only legally defined model – system-based research that explores a wide range of economic and environmental outcomes is lacking. Such research is needed to help us identify where synergies and trade-offs occur. Furthermore, with a time lag before production benefits are realised, for example through improved soil health, long-term monitoring is recommended.

While our five agroecological models were explored independently, it is important to note that these models are not mutually exclusive. Integrating different models, or components of these models, could result in a wider range of positive outcomes. For example, integrating components of agroforestry may increase climate adaptation/mitigation outcomes in IFM systems.

5.9 Global verses farm-scale impacts

It is important to note that scores were generated at the level of the farm (including inputs to that farm and direct outputs). Wider impacts were therefore not considered.

If conversion to an agroecological model indicates a yield loss (e.g. organic, low input and regenerative models), consideration should be given to both emissions per unit area and emissions per unit product. The conversion to organic farming, can reduce yield per hectare and consequently, positive environmental impacts at the farm level (i.e. per unit area) may not necessarily reflect positive impacts per unit of product (Tuomisto et al., 2012, Clark and Tilman, 2017). Impacts, however, strongly depend on the geographical location, system in question (crops, livestock), time since transitioning and the environmental outcomes under investigation. For example, while organic farms tend to have higher nitrous oxide and ammonia emissions per unit of product, their energy requirements tend to be lower (Tuomisto et al., 2012; Clark and Tilman, 2017).

Determining environmental outcomes at the global level is complex, depending on both the outcome/s considered, and the potential requirement of additional land to compensate for a shortfall in food production (e.g. offshoring) (Smith et al., 2019). This highlights that even in agroecological systems it is important to optimise efficiency.

6 The potential for agroecology in Scotland

We found considerable potential for the application of agroecological approaches in Scotland. We also identified challenges, as well as evidence gaps.

Using a workshop format, we asked stakeholders to assess the strengths, weaknesses, opportunities, and threats presented by a transition from a conventional farming model to a more agroecological model (see Appendix 3 for details on methodology). Over 200 comments were generated, with headlines summarised in Figure 14. Detailed results are shown in Appendix 4.

6.1 SWOT analysis: key findings

Stakeholders agreed that converting from a conventional farming system to a more agroecological model can deliver positively across the three pillars of sustainability (economic, social, and environmental). Agroecological approaches can reduce adverse environmental impacts (e.g. soil erosion and GHG emissions) and improve ecosystem health whilst helping to stabilise agricultural yield and increase resilience to change (e.g. through healthier ecosystems and diversification). Such approaches could result in greater job satisfaction with farmers playing a central role in decision-making and feeling they are proactively tackling climate change and biodiversity loss (Padel et al., 2017).

However, agroecological approaches often require an overhaul of the entire farming system which can be risky as farmers learn and adapt to the new system. Farmers may also have to change their vision of what a good farm looks like, whilst facing criticism from their neighbours (over the hedge judgement) (Padel et al., 2017). The ease of transition will depend on the farming system in question, and in some instances, this involves significant changes to farm infrastructure (e.g. stock proofing arable fields), equipment (e.g. direct drilling, combines for mixed crops), supply chains and identifying new routes to market. Furthermore, there is often a time-lag before the economic benefits are reaped - for example, improved yield through enhanced soil fertility, or harvesting of timber in agroforestry. Financial support may therefore be required to support farmers during transitioning along with investment in the physical, social and economic infrastructures needed for agroecological food systems (Lozada et al., 2022).

Strengths	Weaknesses
Healthier ecosystems Increase in farm resilience and yield stability Reduced reliance on inputs Localised food systems in local economy/niche market Being part of the solution to climate and biodiversity emergencies Low-tech and market ready Reduced soil erosion and nutrient loss Application of extensive data on farm Societal benefits (e.g. peer-to-peer networks)	Time-lag to rewards Risk of new approaches (costly to learn from mistakes) Need for mindset change on what is good farming practice (both farmer and peers) Lack of expertise and knowledge in emerging science Transitioning costs alongside time lag before benefits to yield Cost of capital investment for new equipment Lack of permanency – rewards after tenancy agreement finished? Lack of accurate monitoring to inform success Impacts beyond farm scale – results dependent on cooperation across local units
Opportunities	**Threats**
Good timing – Brexit policy window is open Growing evidence base to support agroecological approach Outcome based approach Food sovereignty and connecting consumers with local production Precision agriculture to support sustainability Peer-to-peer learning and online support Potential for certification / labelling Scope for integrated approach to multi-functioning landscapes Redefine food production in context of natural systems Building resilience	Historical short-term approach to policy schemes (need long term stability) Need for a clear agroecological strategy Lack of ambition in policy design to support transformation Supply chain silos - need whole systems approach Wider global impacts of yield declines/offshoring Focus on organic farming excludes alternative approaches Low yield/high quality products vulnerable to changes in purchasing power Lack of workforce – can be labour intensive Lack of training, education, impartial advice Certification is double edged sword – reduced flexibility

Figure 14: Headline results from our Stakeholder Strengths, Weaknesses, Opportunities and Threats workshops.

While it was recognised that agroecological approaches are often low-tech and therefore, relatively accessible, they are typically knowledge intensive. The lack of fundamental training in agroecology, alongside the scarcity of unbiased advice, can make this transition difficult for farmers. Peer-to-peer support networks, and increasing accessibility of online knowledge (e.g. social media and webinars) provide an opportunity to support farmers. Additionally, agroecology could be more thoroughly embedded in agricultural courses (Lampkin et al., 2015), along with life-long learning opportunities, demonstration farms and upskilling farm advisors.

Stakeholders recognised the potential to market *'environmentally friendly*' products to increase the financial viability of agroecological approaches. However, certification and labelling require alternative routes to market and strict regulation to prevent abuse, and this can go against the grain of agroecological approaches which focus on farmer knowledge and choice to adapt to challenges faced. Furthermore, concerns were raised that without consumer demand and willingness to pay premiums for such produce we run the risk of simply flooding the market with expensive *'environmentally friendly'* products. Raising awareness of the issues around food sovereignty (and different farming approaches) and reconnecting consumers with producers provides a key vehicle for increased market demand and alternative food system models. Premiums can restrict accessibility of such produce such that they remain a niche market only accessible to affluent consumers. This not only creates a barrier to widespread uptake, but also goes against the principles of agroecology (e.g. fairness, social values and diet: Figure 2). Premium products may also be more vulnerable to economic and social crises that reduce consumer purchasing power.

The need to adopt more sustainable farming systems is widely recognised and the body of research into the multiple benefits derived from agroecological approaches is growing (Pimbert, 2015; Tscharntke et al., 2021; Viguier et al., 2021). Stakeholders highlighted the need for greater political direction and the development of an agroecology strategy for Scotland (Atkins et al., 2021). The UK's exit from the EU was deemed to provide Scotland with a window of opportunity to overhaul its agricultural policy to support more sustainable agroecological approaches (Mottershead and Maréchal, 2017). Findings from France and Germany have highlighted the importance of a clear strategy with explicit environmental targets integrated with economic objectives (Mottershead and Maréchal, 2017). Concerns were, however, raised regarding the lack of robust, user-friendly, metrics that enable farmers to monitor environmental outcomes. A variety of user-friendly monitoring tools and metrics are being trialled including Nature Scot's Piloting an Outcomes Based Approach in Scotland, The Sustainable Food Trust's Global Farm Metric, and the Food and Agriculture Organization's Tool for Agroecology Performance Evaluation.

There is a lack of research exploring the impact of agroecological systems on a broad range of economic, social and environmental outcomes, both at the farm and global scale. Increasing our understanding would help determine the wider global impacts that may result from a change in yield and/or goods produced and help us detect pollution swapping - whereby management changes to reduce one pollution result in an increase in another. For example, integrating livestock in arable systems while reducing the requirement for inorganic fertilisers may result in an increase in methane production.

7 Conclusions

Agroecological approaches to farm management have significant potential to help Scotland tackle the twin crises of climate change and biodiversity decline whilst building resilience into our food production systems. Additionally, through improving ecosystem health and economic/crop diversification, agroecology can help to ensure that agricultural production systems are resilient to future challenges.

We explored five agroecological models, specifically regenerative agriculture, IFM, organic farming, low-input systems and agroforestry. These models differed slightly in the suite of management practices that are typically adopted by practitioners. Regenerative agriculture, IFM and organic farming drew on the widest range of management practices reflecting their “toolbox” approach to implementation. The five models, however, showed considerable overlap and were by no means mutually exclusive. Furthermore, defining models through a prescriptive set of practices goes against the grain of agroecological approaches which take a holistic view that strongly relies on farmer knowledge to select bespoke solutions to achieve specific outcomes. We identified that lack of agroecological knowledge, training, education and advice was a potential barrier to uptake. Embedding agroecology in agricultural courses, the provision of lifelong learning opportunities and upskilling farm advisors would help to overcome this barrier (Mottershead and Maréchal, 2017).

Our expert review process highlighted that agroecological farming approaches can benefit a wide range of environmental outcomes including biodiversity (Pimbert, 2015; Tscharntke et al., 2021), carbon sequestration and storage (Hathaway, 2016) and GHG emissions (Pimbert, 2015). While low input, organic and regenerative models were perceived to adversely impact yield, their lower input costs means that this deficit only translated into a reduced profit margin in low input systems. Furthermore, all agroecological models were perceived to stabilise yields and increase the resilience of farms to future challenges (Altieri et al., 2015; Saj et al., 2017; Altieri and Nicholls, 2020).Agroecological models differed in their potential to deliver environmental and economic benefits with some models scoring highly for biodiversity outcomes while others scored highly for climate adaption/mitigation outcomes. System-based research that explores multiple outcomes would help to identify where synergies and trade-offs could occur, thus enabling us to optimise the benefits derived from agroecological models. Furthermore, it is important to recognise that agroecological approaches rely on the restoration of agricultural ecosystems and thus change is not immediate. Identifying how different outcomes change over time, alongside their potential to help us mitigate and adapt to change (climate, political, social and environmental), remains a strong area for future research.

To monitor and benchmark farm performance across multiple outcomes, farmers require robust, user-friendly metrics. A wide range of metrics exist including those that monitor agricultural yield, biodiversity, soil and water quality, and carbon sequestration and storage (Appendix 4). Not all metrics are applicable at the farm level (e.g. SEPA’s river water quality indicator), and many require a degree of specialism limiting their potential use to practitioners (e.g. diversity of pollinating insects). There is a knowledge gap, however, regarding appropriate metrics for assessing socio-economic performance of agroecological systems (Lozada et al., 2022). The value of participatory monitoring in providing immediate feedback on performance, which allows farmers to adapt their management to improve outcomes, is becoming increasingly recognised (Runhaar and Polman, 2018; Garratt, et al., 2019). As a result, a variety of user-friendly monitoring tools and metrics are being trialled and participatory monitoring is likely to become more prevalent (e.g. adoption of outcome-based payment schemes).

Transitioning towards agroecological approaches at the farm scale involves significant risk with farmers needing to learn and adapt to the new system. Furthermore, there is often a delay before economic benefits are realised (e.g. harvesting of timber in agroforestry, organic certification). This means that farms must have the financial capacity to buffer initial shortfalls in production (Padel et al., 2017). The ease of transitioning will depend on the farming system in question, and in some instances transitioning may require an overhaul of the entire system with costly changes to equipment/infrastructure alongside finding new routes to market (Padel et al., 2017). Some form of economic support may help meet initial outlay costs and sustain the farm enterprise during transitioning and consideration should be given to the wider infrastructure to ensure they support agroecological production systems.

There is the potential for agroecological produce to reach niche markets and attain a higher market value (e.g. for '*environmentally friendly*" produce). Establishing a trusted and widely recognised labelling or certification scheme could make agroecological approaches more economically viable. However, stakeholders raised concerns that without consumer demand, and willingness to pay, we run the risk of flooding the market with '*environmentally friendly*' products. Quantifying and raising awareness of the environmental and societal benefits of agroecological farming practices and increasing food sovereignty could help increase market demand. Food certification and labelling could provide a double-edged sword: on one hand certification/labelling requires strict regulation to prevent abuse (Newton et al., 2020), yet on the other hand over prescriptive certification removes flexibility in management limiting farmer choice. Certification schemes that focus on the achievement of specific outcomes would provide greater flexibility and are likely to be more appropriate than process-based schemes that focus on the inclusion, or exclusion, of specific practices (Newton et al., 2020).

Agroecological farming systems clearly have the potential to deliver a wide range of economic, environmental, and societal benefits. Through restoring and diversifying farming systems they can build resilience into Scottish agricultural production systems. In addition, significant opportunities exist for conventional systems to implement agroecological management practices (e.g. wildflower margins, cover crops, soil carbon amendments) without overhauling the entire systems. The impact of widespread implementation of such practices within conventional systems should therefore not be undervalued.

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Appendix 1: Key Principles of Agroecology

The thirteen key principles of agroecology as identified by Wezel et al. (2020)

1. Recycling. Preferentially use local renewable resources and close as far as possible resource cycles of nutrients and biomass.
2. Input reduction. Reduce or eliminate dependency on purchased inputs.
3. Soil heath. Secure and enhance soil health and functioning for improved plant growth (e.g. manage organic matter and enhance soil biological activity).
4. Animal health. Promote animal health and ensure welfare.
5. Biodiversity. Maintain and enhance diversity of species, functional diversity and genetic resources. Maintain biodiversity over time and space at field, farm and landscape scales.
6. Synergy. Enhance positive ecological interaction, synergy, integration, and complementarity amongst the elements of agroecosystems (plants, animals, trees, soil, water).
7. Economic diversification. Diversify on-farm incomes by ensuring small-scale farmers have greater financial independence and value addition opportunities while enabling them to respond to demand from consumers.
8. Co-creation of knowledge. Enhance co-creation and sharing of knowledge including local and scientific innovation, especially through farmer-to-farmer exchange.
9. Social values and diets. Build food systems based on the culture, identity, tradition, social and gender equity of local communities that provide healthy, diversified, seasonally and culturally appropriate diets.
10. Fairness. Support dignified and robust livelihoods, especially small-scale food producers, based on fair trade, fair employment and fair treatment of intellectual property rights.
11. Connectivity. Ensure proximity and confidence between producers and consumers through promotion of fair and short distribution networks and by re-embedding food systems into local economies.
12. Land and natural resource governance. Recognise and support the needs and interests of family farmers and smallholders as sustainable managers and guardians of natural and genetic resources.
13. Participation. Encourage social organization and greater participation in decision-making by food producers and consumers to support decentralised

Appendix 2: farming practices underpinned by agroecological principles

Appendix Table 1: Overview of our 21 agroecological practices targeted towards resource use efficiency and/or substitution. Details of their broad management category are also provided.

Efficiency increase and substitution practices	
Broad management	*Agroecological practice*
Crop fertilisation	
	Use of organic animal manure to enhance soil fertility and replace inorganic fertilisers
	Use of minerals to maintain soil pH (e.g. lime) and allow for better nutrient uptake/availability
	Split fertilisation - fertilisers applied with several operations to increase uptake efficiency and diffuse pollution risk
	Biodynamic preparations/Biofertilisers: application of microorganisms and mineral foliar applications to plant/soil to increase nutrient availability and enhance resilience to pests and disease
	Reduction of inorganic fertilisers
	No use of inorganic fertilisers
Crop irrigation	
	Reuse of treated wastewater
	Irrigation scheduling: based on local knowledge of crop requirements, soil properties and rainfall and/or based on plant stress parameters
	Localised irrigation (e.g. drip irrigation where water is slowly dripped onto the crop to maximise uptake by plant)
Weed, pest and disease management	
	Natural pesticides: plant (e.g. pyrethrum) or mineral derived (e.g. Boric Acid)
	Reduction of synthetic pesticides (e.g. herbicides, fungicides, insecticides)
	No usage of synthetic pesticides (e.g. herbicides, fungicides, insecticides)
	Selective/targeted use of veterinary medicines (e.g. anti-helminthics, antibiotics) for example informed by faecal egg counts, weight gain
	Introduction of natural enemies (e.g. parasitoids), microbial pesticides or use of pheromones
	Monitoring pests, weeds and diseases and targeted application of pesticides and/or biocontrol agents
	Cultural control of pest, weeds and diseases
	Avoidance of genetically modified organism (GMO)
Breed/crop choice, spatial and temporal distribution	
	Breed selected to local conditions (e.g. native breeds)
	Selective breeding for multiple benefits (e.g. ease of birth, reduction in GHG emissions)
	Varietal selection/varietal mixing (select varieties based on local conditions/disease risk)
Other	
	Low level of agricultural mechanisation

Appendix Table 2: Overview of our 28 agroecological practices that focus on redesigning the system. Details of their broad management category are also provided.

Redesign practices	
Broad management	*Agroecological practice*
Crop fertilisation	
	Measures to improve soil organic matter, water holding capacity (e.g. through incorporation of green cover, cover crops, or other organic waste products)
Tillage management/Soil health	
	Measures to reduce soil compaction to improve water holding capacity and soil health (e.g. controlled farm traffic)
	No-till/direct drill into crop residue or cover crop
	Non-inversion tillage, reduced tillage
Weed, pest and disease management	
	Barrier crops to deter pests or inclusion sacrificial plants to attract pests (push-pull system, trap crops, companion planting)
	Inclusion of herbs with anti-helminthic properties or for micronutrient uptake
	Precision agriculture (e.g. use of technology to improve ecosystem processes, resource use)
Breed/crop choice, spatial and temporal distribution	
	Nitrogen fixing crops included in the rotation,
	Nitrogen fixing crops included as an intercrop, cover crop or under-sown
	Intercropping (two crops growing simultaneously), relay intercropping (under-sowing a follow-on crop in an existing crop)
	Multi-species swards
	Mixed grazing (e.g. sheep and cattle grazing together)
	Silvopastoral agroforestry: inclusion of woody vegetation within a livestock system
	Silvoarable agroforestry: intercropping woody vegetation within an arable system
	Alternative grazing management (mob, strip, adaptive multi paddock grazing)
	Integration of cropping and livestock
	Maintain soil cover (e.g. catch crops, green cover)
	Crop diversification
	Integration of novel crops into the rotation (e.g. triticale, hemp, Miscanthus).
	Inclusion of perennials in the system (e.g. grass in a rotation)
	Inclusion of fallow land/set-aside to promote biodiversity and/or provide a break in the crop rotation
	In field habitat modifications to enhance beneficial insects/biodiversity (beetle banks, conservation headlands, targeted weed control to allow a more diverse weed understorey (e.g. 10% weed cover)
	Introduction of managed pollinators (e.g. honeybees, bumblebees) to enhance pollination services/additional production (e.g. honey)
	Reduced supplementary feed inputs/increase homegrown components of the diet (e.g. increase grass content of diet)
Management of landscape elements	
	Shelterbelts and hedgerows
	Habitat modifications external to crop targeted to enhance biodiversity (e.g. flower-rich field margins, farm woodlands, farm ponds)
	Permanent pasture with reduced inputs
Other	
	Machinery co-operatives

Appendix 3: Methodology

A3.1 Literature review

A review of the published and unpublished literature was carried out in order to define what is meant by the term agroecology, determine, and describe the main farming approaches that utilise agroecological principles, and identify the farming practices that are underpinned by agroecological principles. The review was neither a systematic nor comprehensive review of the literature.

A3.2 Aligning practices with agroecological models

From the literature review, five agroecological models and forty-nine farming practices were identified that were thought to be the most relevant to Scotland. For each of the five agroecological models a panel comprising of two or more of the report authors together with another expert and/or practitioner, were asked to identify which of the practices were fundamental to the model, which were of some relevance, and which were irrelevant to the model. A consensus was reached for each model and the practices identified were used in the expert elicitation scoring process.

A3.3 Expert elicitation scoring process

A list of desirable farming outcomes relating to biodiversity conservation, climate change mitigation and adaptation, water and air quality, greenhouse gas emissions, soil quality and food security were drawn-up from the literature (Appendix Table 3). For each agroecological approach, a group of experts and stakeholders, including researchers, farmers, advisors and policy makers (Appendix Table 4), were invited to score each outcome at the farm level based on the expected change on a five-point scale (ranging from a strong adverse impact -2 to a strong positive impact +2) they would expect to see if the farming system were to convert from a conventional system to the particular agroecological system as the main approach.

The farm level approach required the respondents to focus on effects on the farm, ignoring potential impacts in the wider production system from achieving lower yields or a change in the production mix. A conventional farming system was defined as a system that is managed in a typical way which is often intensive, for example relatively high stocking densities, use of agro-chemicals such as inorganic fertilisers and pesticides. To assist with the scoring, and to ensure robustness between scorers, the fundamental management practices that had been identified were provided. The scorers were asked to select how confident they were with respect to their given score (low, medium or high degree of certainty) depending on their knowledge, the strength of evidence and the variability of outcomes (e.g. geographical location, context and farming system). The scorers were also asked where possible to provide comments/sources (e.g. personal experience, scientific papers, websites, podcasts) to support their score. Score averages were calculated (Appendix Table 5) alongside median certainty for each outcome.

A3.4 Score confidence

The experts typically indicated an intermediate to high level of confidence in their scores. Although the body of research into organic systems outweighs that for our other agroecological models, organic scores largely received a similar degree of certainty. Accompanying comments highlighted variability between research findings, with outcomes depending on management intensity, geographical location, landscape context, and crops grown. With a lack of system-based research into our other agroecological models (particularly in the Scottish context), scores for these models are more likely driven by personal experience and research on the impact of individual agroecological practices that are typically implemented by practitioners.

Appendix Table 3: Desirable farming outcomes relating to biodiversity conservation, efficient resource use, climate mitigation and adaptation, and economic and environmental sustainability.

Category	Outcome
Biodiversity	Enhances flowering plants
	Promotes insect pollinators
	Enhances farmland birds
	Increases habitat diversity, supports habitat features and/or enhances ecological connectivity
Climate change adaption/ mitigation	Enhances carbon sequestration and storage
	Improves water management (e.g. resilience to flood/drought)
	Provisioning of shade/shelter
Water/air quality	Mitigates diffuse pollution/Reduces leaching of phosphorus and nitrogen
	Reduction of Ammonia emissions
Greenhouse gas emissions	Reduction of carbon dioxide emissions
	Reduction of methane emissions
	Reduction of nitrous oxide emissions
Soil quality	Enhances soil organic matter
	Promotes decomposition rate/microbial activity
	Promotes soil structure
Food security	Enhances agricultural yield (per annum/crop)
	Increases the stability of agricultural yield over time
	Increases economic viability (profit margin)
	Increases the long-term sustainability of food production
	Increases farm resilience (ability to absorb disturbance and reorganise under external pressures - economic, social, or climatic)

Appendix Table 4: Number of scorers per system per category

	Researcher	Farmer	Farmer/ Advisor	Consultant	Policy advisor	All
Agroforestry	9	2	1	1	0	13
IFM	6	1	0	0	2	9
Low-input	7	1	1	0	0	9
Organic	7	1	1	0	0	9
Regenerative	6	4	1	0	1	12

Appendix Table 5: Mean Scores (-2.0 strong adverse impact to +2.0 strong positive impact)

Environmental and food security outcome	Agroforestry	IFM	Low Input	Organic	Regen-erative
Enhances flowering plants	1.0	1.2	1.5	1.7	1.5
Promotes insect pollinators	1.2	1.4	1.5	1.6	1.5
Enhances farmland birds	1.2	1.6	1.3	1.3	1.5
Increases habitat diversity	1.9	1.6	1.0	1.5	1.6
Enhances carbon sequestration and storage	1.8	1.6	1.0	1.1	1.4
Improves water management	1.5	1.4	0.3	1.1	1.6
Provisioning of shade/shelter	2.0	1.1	0.4	0.4	1.3
Reduces carbon dioxide emissions	0.6	1.3	1.0	0.8	1.4
Reduces methane emissions	0.4	0.8	0.4	0.3	0.8
Reduces nitrous oxide emissions	0.7	1.3	1.2	1.3	1.3
Mitigates diffuse pollution	1.4	1.4	1.3	1.4	1.5
Reduces ammonia emissions	0.9	1.2	1.0	0.9	1.1
Enhances organic matter	1.2	1.4	1.2	1.3	1.5
Promotes decomposition	1.2	1.6	1.4	1.6	1.5
Promotes soil structure	1.5	1.8	1.0	1.1	1.6
Enhances agricultural yield	0.0	0.6	-1.9	-1.6	-0.5
Increases the stability of yield	0.8	1.3	0.4	0.4	1.0
Increases economic viability (profit margin)	0.3	1.1	-0.4	0.7	0.7
Increases the sustainability of food production	0.9	1.8	0.1	0.5	1.6
Increases farm resilience	1.1	1.3	0.7	1.1	1.7

A3.5 Strengths, Weaknesses, Opportunities and Threats

Strengths, weaknesses, opportunities, and threats of converting from a conventional farming model to a more agroecological model were captured via two stakeholder workshops. A multi-actor approach was adopted with workshops attended by policy advisors, farm advisors, farmers and researchers. To ensure a diversity of aspects were considered, stakeholders were requested to explore Political, Economic, Social, Technological, Legal and Environmental aspects that may be faced by a farm enterprise during the process of conversion. To help standardise thoughts on both conventional and agroecological approaches, these different farming models were discussed. Stakeholders were asked to present their ideas anonymously on an online think tank. Following the collation of all ideas, stakeholders were then requested to score ideas (one to five star).

Appendix 4: Examples of metrics and indicators

Outcome	Examples of Metrics/Indicators
Flowering plants	Scorecards Piloting an Outcomes Based Approach in Scotland (Nature Scot) Scorecards developed for the Bride project and the Burren Farming for Conservation Project, Ireland E-Surveyor – habitat monitoring app (UKCEH) National Plant Monitoring Scheme (BSBI, UKCEH, Plantlife, JNCC).
Insect pollinators	UK Pollinator Monitoring Scheme (PoMS) (UKCEH) Beewalk survey scheme (Bumblebee Conservation Trust) UK Butterfly Monitoring Scheme (Butterfly Conservation) Wider Countryside Butterfly Survey (Butterfly Conservation)
Farmland birds	Farmland bird survey (RSPB) Breeding bird survey (British Trust for Ornithology) Scorecards for specific species (e.g. Hen Harrier score cards for a variety of habitats) Farmland Bird Index
Habitat diversity, features, ecological connectivity	Countryside Survey (UKCEH) High Nature Value Farmland Indicator Scorecards to monitor habitat quality (e.g. Hen Harrier score cards for a variety of habitats) Broadscale habitat data from IACS/spatial maps/Remote sensing (e.g. % area of semi-natural habitat, number of crops grown) Great British Hedgerow Survey and Healthy Hedgerows (People's Trust for Endangered Species) Integrated Habitat networks (Nature Scot)
Carbon sequestration and storage	Carbon audit tools (e.g. AgreCalc) Soil organic carbon at various depths Mapping of soil carbon potential Peatland depth 3D structural diversity of landcovers, tree line or hedgerow density Area of relevant habitat/practice, carbon measuring or calculation
Water management	Natural flood risk management interventions monitored at the CSC platform and Balruddery Farm Infiltration rate Measure of soil compaction (e.g. penetrometer) Visual Evaluation of Soil Structure Scorecard (Aarhus University, SRUC, UEM) Moisture sensors/ lysimeter measurements Water flow rates in streams, rivers Water levels in streams and rivers (SEPA)
Shade/ shelter	Spatial mapping of area, height, orientation of hedgerows, trees Behavioural (foraging/resting time)/physiological (skin temperature) response of livestock

Outcome	Examples of Metrics/Indicators
Mitigates diffuse pollution	LCA metrics; N surplus/land area or product (kg, energy or protein kg), N use efficiency Long-term river water quality indicator (SEPA) Temperature, relative humidity, solar radiation (differences between microhabitats) Surface water status (JNCC) EPT Ephemeroptera, Plecoptera, Tricoptera) Richness Index
Ammonia emission	Area exposed to damaging levels of ammonia in the atmosphere UK National Ammonia Monitoring Network (UKCEH) Soil and Vegetation indicators
Carbon dioxide emissions	Carbon auditing tools (e.g. AgRE Calc, Farm Carbon Toolkit, The Cool Farm Tool) Cover boxes to monitor GHG emissions (e.g. Centre for Sustainable Cropping) Net kg CO_2e / kg protein produced (or kg product, or kcal energy); kg CO_2e / ha Monitoring Red diesel sales to Agri Industry Greenhouse gas emission statistics
Methane emissions	Carbon auditing tools (e.g. AgRE Calc, Farm Carbon Toolkit, The Cool Farm Tool) Number, type and breed of livestock Direct measure of emissions (respiration chambers e.g. SRUC's Green Cow Facility) Net kg CO_2e / kg protein produced (or kg product, or kcal energy); kg CO_2e / ha
Nitrous oxide emissions	Carbon auditing tools (e.g. AgRE Calc, Farm Carbon Toolkit, The Cool Farm Tool) Nitrogen fertiliser sales in UK Amount of bagged fertilisers used Farm nutrient balance GHG emissions could be closely related to either the farm N surplus or the farm N efficiency Net kg CO_2e / kg protein produced (or kg product, or kcal energy); kg CO_2e / ha
Soil organic matter	Visual Evaluation of Soil Structure Scorecard (Aarhus University, SRUC, UEM) Soil health scorecard (AHDB) Soil organic carbon at various depths (loss on ignition)
Decomposition rate/ microbial activity	Bait lamina test (decomposition rate) Teabag protocol to monitor microbial decomposition Cotton decomposition rate (e.g. Soil my undies challenge) Soil health scorecard (AHDB) Phospholipid fatty acid test Metabolic quotient (qCO_2) Earthworm count (AHDB) Soilmentor (Soil health app) Slake Test (wet aggregate stability)

Outcome	Examples of Metrics/Indicators
Agricultural yield	Agricultural yield/live weight gain (etc.) Plant growth (Plate meter) Scottish Agricultural Census: national statistics on crop areas and yields Farm Incomes, Subsidies and Borrowing Statistics
Yield stability	Agricultural yield/plant growth metrics over time Farmbench (AHDB) Scottish Agricultural Census: national statistics on crop areas and yields Farm Incomes, Subsidies and Borrowing Statistics
Profit margin	Farm level data on yield and profit margin Scottish Agricultural Census: national statistics on crop areas and yields Farm Incomes, Subsidies and Borrowing Statistics Farmbench (AHDB)
Sustainability of food production	Sustainability tools (e.g. Public Goods Tool, The Farm Sustainability Tool) DEXi analysis (The James Hutton Institute) Scottish Agricultural Census: national statistics on crop areas and yields
Farm resilience	Sustainability tools (e.g. Public Goods Tool, The Farm Sustainability Tool) Farm level data on yield and profit margin over time Scottish Agricultural Census: national statistics on crop areas and yields Farm Incomes, Subsidies and Borrowing Statistics Change in consumers/retailer attitudes (e.g. agroecological market demand)

Appendix 5: Detailed SWOT analysis

The broad categories into which the SWOT statements were grouped, the number of statements in each category and an example statement and its score

A5.1 Strengths

Aspect	Broad category	Number of suggestions in broad category	Example statement	Example statement score
Economic	Ecosystem health, reduced inputs, diversified systems enhance resilience/economic viability	9	In the long-term agroecological approaches should have healthier ecosystems, diversified crops and reduced reliance on inputs. Likely to improve yield stability and farm resilience under environmental change (e.g. drought, etc.).	4.5
	Reduced inputs improve profitability/reduces risk	4	A shift away from intensity to less intensive farming requires lower inputs and therefore reduced exposure to risk.	4
	Localised food systems/niche markets	3	Agroecology promotes localised food systems, which can enable more money to return to the farm and can strengthen local economies.	3.5

Aspect	Broad category	Number of suggestions in broad category	Example statement	Example statement score
Social	Being part of the solution, greater job satisfaction	2	The opportunity to be part of the climate solution and lead with production of food which is better for health and planet is significant.	4.5
	Increased human and social value, positive interactions with others	3	Agroecology recognises the importance of co-creation, knowledge sharing and the role of human and social values (FAO). By its very nature, it is inclusive and enables autonomy and values social interactions.	4.5
Techno-logical	Low-tech approaches increasing accessibility	3	Most farm practices for agroecological approaches are low tech and readily available.	4
	Use of on farm data to direct operations	2	Farmers now have access to a huge amount of data from their farm, current and historic. Potential to further use this data to direct operations.	4
Environ-mental	Reduced emissions, pollution	3	Reduced soil erosion and nutrient loss.	5
	Enhances biodiversity/ ecosystem services	3	Agroecological farms provide increased ecosystem services compared to conventional farms (Garbach et al., 2017; Boeraeve et al., 2020)	5

A5.2 Weaknesses

Aspect	Broad category	Number of suggestions in broad category	Example statement	Example statement score
Political	Guidance needed about the direction of change	2	Mixed messages from policy makers about the direction of change in Scottish agriculture (particularly what that will mean on the ground).	4.5
Economic	Economic costs of transitioning/ time-lag before yield benefits are gained	7	Time-lag before rewards. It can take years before benefits of agroecological approaches (e.g. enhanced soil fertility) positively impact on yield. This can leave landowners facing costs of transitioning (e.g. fencing of arable fields, yield loss due to lack of inorganic fertilisers) to more regenerative practices without yield benefits.	5
	Risk associated with transitioning/lack of experience	3	Risk of trying new approaches and crops. Diversifying the system may require some trial and error. It may be longer-term and more complex (e.g. getting the right rotation) than the farmer has experienced before.	4
	Risk of pests, weeds, diseases	2	Potential for some agroecological practices to increase pest, weed and disease burden. For example, cover crops acting as a green bridge allowing pests to persist from one growing season to another. Greatest impact for arable systems.	3.5

Aspect	Broad category	Number of suggestions in broad category	Example statement	Example statement score
Social	Mindset change in what makes a good farm, negativity of over the hedge judgement	5	There will have to be a social shift (and not just by farmers) in terms of what a good farm or good farming practices look like: it's less likely to be all straight lines, clear paths and tidy patches. For example, people might need to start looking at weeds as biodiversity; there will probably also have to be some allowances for losses to pests to start being seen as supporting multiple species on-farm. It will be a social shift - but it will probably be a slow one - that will also alleviate some over the hedge criticism felt by farmers.	4.5
	Lack of expertise, knowledge	4	There can be a disconnect between farming and the ecological processes that underpin these systems, this was much stronger in the past. Need to reconnect and gain a deeper understanding of the system as a whole, and impact of farming practices.	5
	Requires conviction as rewards may be long-term	1	Complete 180 in terms of approach to farming, need a deep conviction and motivation to keep going, as results might not come quickly.	4.5

Aspect	**Broad category**	**Number of suggestions in broad category**	**Example statement**	**Example statement score**
Social	Variability in crop yield/quality societal change needed alongside financial support	1	Natural systems are variable: agroecological systems may be more prone to peaks and troughs than conventional ones (which we've tamed for greater consistency or maximum yields through large inputs), more prone to shortfall and glut years. It's hard to plan for variability and plan a business around it. With climate change and ecosystem services shortfalls, conventional farming will become more vulnerable to than agroecological farming, but probably not at the rate to convince farmers to move to agroecology without incentives or support institutions or infrastructures. How can we, as a modern society, cope better with agricultural variability in yields, quality, products, etc.? How can we support farmers in this?	5
Techno-logical	Investment required to upgrade equipment/ processes	2	Existing farm equipment and processes might not be readily adapted to agroecological approaches, and require further capital investment (e.g. direct drill, combines/grain separators for mixed crops).	4

Aspect	Broad category	Number of suggestions in broad category	Example statement	Example statement score
Legal	Lack of permanency or flexibility with land tenancy agreements	3	Yield benefits derived from agroecological approaches may take years to come to fruition, short term tenancy agreements make such approaches less viable. Short term tenancy agreements can result in environmental degradation.	5
	New entrants/ accessibility of farming	1	Farmers do not get pushed off their land easily. New entrants to farming who might want to implement agroecological principles might not have access.	4.5
Environ-mental	Difficulty in monitoring outcomes across the three pillars of sustainability/lack of metrics	6	Lack of accurate monitoring to prove success. A multiple, complex number of metrics which are interconnected is expensive and difficult to monitor. A physical yield or margin is easy.	5
	Surrounding landscape may impact on a farms capacity to improve environmental performance	1	Improved environmental performance of agroecological systems might depend on how neighbouring land is managed rather than local changes on-farm	4

A5.3 Opportunities

Aspect	**Broad category**	**Number of suggestions in broad category**	**Example statement**	**Example statement score**
Political	Policy window to adopt agroecological approaches	6	This is a time of political change with BREXIT and moving from the CAP. This puts Scotland in the position to define its future with respect to farming.	5
	Research/strategic documents support transitioning to agroecological approaches	4	Recognition of agroecology/regenerative agriculture as a way forward for Scottish/UK agriculture in many recent key reports.	4.5
	Agroecology transcends policy areas helping to meet multiple objectives	4	Because agroecology delivers on a number of public (non-market) goods and services, it is the domain of policy more than it is of the market to define standards and objectives of the direction of travel. It is justifiable to think of agroecology as an area of public investment for delivery of social goods and services.	4.5
	Movement to outcome-based payment schemes aligns with agroecological approaches	3	Outcome based approaches for incentive schemes may result in better agroecological system performance than more prescriptive approaches.	5

Aspect	Broad category	Number of suggestions in broad category	Example statement	Example statement score
Political	Opportunity to create an agroecological strategy for Scotland	1	Scotland needs to develop an agroecological strategy. There is no legislative framework in Scotland. In France public bodies must promote agroecological systems and seek to make them permanent and that the State will encourage farmers to adopt innovative practices and systems. Such a framework ensures that the government will facilitate and support movement towards agroecology.	5
	Flexibility of farmers to respond to subsidy demands	1	Farmers are very good at changing as a result of subsidy movements. The current business model has derived from previous subsidy regimes. Can we use these thought processes to drive the right change in environment and culture?	4.5
	Learning from other countries re agroecological strategies	1	There are good examples in France and Germany of enabling agroecological transition within CAP - so the work has been done and lessons can be learned from this.	4.5

Aspect	**Broad category**	**Number of suggestions in broad category**	**Example statement**	**Example statement score**
Social	Food sovereignty: opportunity to increase consumer demand via education/ marketing	7	There is a disconnect between food production and the consumer. Many people have no idea about how food is produced and the different approaches to farming. There needs to be stronger education on this throughout.	5
	Promotes collaboration, builds social networks	6	Should promote collaboration at landscape scale and through peer networks, so should have positive impacts on farmers' social capital, community building and maybe sense of pride when sharing achievements/good results? More people growing more food in more environmentally friendly ways will strengthen cultural bonds to the land and to the food that we eat.	4.5
Techno-logical	Precision agriculture to target inputs/increase sustainability	6	Opportunity for agroecological farms to use new technological advances to improve sustainability e.g. precision livestock farming, sensor technology, targeted selective treatment of livestock, renewable energy production etc.	4.5
	Online knowledge transfer, peer-to-peer learning/support	5	Social media, webinars, online workshops etc. provide an opportunity for knowledge transfer.	5
	Opportunity to provide training/ensure agroecology is embedded in all levels of education.	3	Opportunities to re-develop agriculture training and agronomy courses to create new expertise, showcasing the experiences of pioneers in agroecological farming.	4.5

Aspect	Broad category	Number of suggestions in broad category	Example statement	Example statement score
Techno-logical	Farm advisory service non-biased advice/support	1	Farm advisory service provides a uniform platform to provide non-biased advice to farmers. These advisors can help support peer-to-peer learning (French GIEE mechanism). Advisory training in agroecological approach and stronger links between FAS and research within SRUC.	5
Legal	Potential for certification/labelling to increase market value (3)	3	A legal framework like organic can bring benefits. In the case of organic it guarantees the production method not the product. This allows a clear differentiation in the market.	4.5
	Utilise cross compliance rules to proactively support agroecological practices (1)	1	Cross-compliance more proactively to support agroecological practices. For example, in Ireland soil testing is required for land under continuous cultivation followed by compulsory one-to-one advice from an accredited farm advisor where organic matter falls below a threshold.	5

Aspect	**Broad category**	**Number of suggestions in broad category**	**Example statement**	**Example statement score**
Environ-mental	Scope for integrated multifunctional landscapes	1	Scope for integrated land use (potentially at a landscape scale) with multiple outputs - food, fibre, ecosystem services etc.	4.5
	Opportunity to redefine food production to enhance natural systems and build resilience	1	The biggest opportunity is, to borrow from the 'planetary boundaries' framework, get ourselves out of this overshoot situation we've gotten ourselves in. Agroecology is an opportunity to reimagine the way we produce food by mimicking and enhancing natural systems, but it's also a way to ensure those systems are resilient and able to support humankind for many centuries to come.	4
	Recognition of the value to biodiversity that farmland can provide	1	Potential to bring conservation groups into conversations about farming. For instance, RSPB or SNH being able to see beyond a wild landscape as being the only way to achieve biodiverse landscapes	4.5

A5.4 Threats

Aspect	Broad category	Number of suggestions within each broad category	Example statement	Example statement score
Political	Concerns re persistency of schemes/ subsidies by future policies/ governments	7	Short-term thinking, associated with political cycles, is a threat to the long-term change that is needed in the sector for agroecology adoption.	5
	Requirement for political will to drive more ambitious policies to achieve transformation	5	Policy not being as progressive or as ambitious as it needs to be to achieve transformation on the ground.	4.5
	Lack of integration across policy areas	2	Agriculture transcends policy areas - food, health, agriculture, biodiversity, climate change. These policy areas are not well integrated and a more joined up political framework is required.	5
	Focus on organic farming excludes alternative agroecological approaches	1	EU/UK focus on increasing the uptake of organic practices might deter/exclude those using other agroecological approaches.	4

Aspect	**Broad category**	**Number of suggestions within each broad category**	**Example statement**	**Example statement score**
Economic	Change is required in the entire route to market (farmer, processor, retailer, consumer)	5	Agroecology requires a whole systems approach - not just the farm making change, but to the whole supply chain, and also consumer attitudes.	5
	Reduced yields and economic vulnerability under change	3	With the trade deals with Australia, the US, etc (i.e. countries where environmental regulations on farming are less stringent) there is a high risk of strong price competition and farmers producing at lower gross margins (i.e. agroecological) not being able to sell at high enough price.	4
	Low customer demand/subsidising to support agroecological farming could just flood the market	2	The market for more expensive (and sustainable products) is currently small. Subsidising the market to support agroecological farming may just flood the market with products that people are not wanting to buy/pay for.	4.5
	Financial support peer-to-peer networks, training, research	1	Outside of the farming enterprise there is the requirement for financial support re peer-to-peer learning, education, training, support networks and research to identify best way forward.	5

Aspect	Broad category	Number of suggestions within each broad category	Example statement	Example statement score
Economic	Need to move away from solely economic evaluation of performance	1	There is a risk inherent in having an economic system that is built on a narrow set of human values (profit, market value...) dictating to the degree it does where and how you invest your resources. There is a wider conversation to be had on how the economic system works and why it doesn't deliver on socially desirable outcomes, such as the ones that result from agroecology.	4
Social	Lack of workforce	3	Certain agroecological practices can be labour intensive, which might make the farm more susceptible to external factors causing labour shortages	4.5
	Lack of knowledge around different farming systems	2	The many different agroecological systems and organisations makes it confusing for members of the public (and policy makers) to know what they are and what they mean. Most people know what organic means but not what regenerative farming or biodynamic farming or permaculture are.	4.5
	Requirement for change in consumer attitudes	1	The general public are happy with a constant choice of every food stuff. Changing this to the more inevitable choice of more seasonal foods could take some time.	4.5

Aspect	Broad category	Number of suggestions within each broad category	Example statement	Example statement score
Techno-logical	Lack of training/education/ impartial advice in Scotland	5	Poorly informed people looking to work on the land will make poor decisions. Education of all people in the benefits of agroecology is paramount (everything from nursery to adults at home so Clarkson's farm is an integral part of this along with SRUC, RHET and primary schools up and down the country).	4.5
	Investment required to upskill consultants/ advisors	1	Govt's willingness to boost farm advice, particularly relevant to these farming models (which would need a massive training investment for consultants) might be limited, given the severe budget constraints	5

Aspect	Broad category	Number of suggestions within each broad category	Example statement	Example statement score
Legal	With regulation comes lack of flexibility	5	Certification will become a real problem. By its very nature, agroecological farming is a very flexible system, making the box ticking brigade nervous and perhaps resistant to allowing the necessary changes year to year.	4.5
	Abuse of certification/ labelling	4	Labelling standards are a risk to agroecological businesses if other farms are able to greenwash processes undertaken with a deliberately vague label.	4.5
	Lack of permanency or flexibility with land tenancy agreements	2	Yield benefits derived from agroecological approaches may take years to come to fruition, short term tenancy agreements make such approaches less viable. Short term tenancy agreements can result in environmental degradation.	5
	Lack of legal definition	2	Some approaches (e.g. regenerative agriculture) has no legal or regulatory definition. This makes it difficult for certification, policy.	5
	Time delay for regulatory approval of agrochemical alternatives	1	Alternatives to agrochemicals (e.g. biopesticides used for pest and disease control) might take a long time to achieve regulatory approval (as the system is not set up for these types of products).	4

Aspect	Broad category	Number of suggestions within each broad category	Example statement	Example statement score
Environ-mental	Complexity of system-based approaches/ pollutant swapping	4	Not from a business point of view, but from the wider perspective. Farmers doing agroecological farming would need a lot of freedom an autonomy in deciding what practices they use. However, there is a considerable risk for unnoticed pollution swapping or deteriorating some environmental outcomes if these changes are not recorded. But recording them is very difficult in many respects (time required, data/IT structure, impact on farmers' wellbeing, etc) and often does not give a good enough proxy for estimating the various environmental impacts. (Example can be barn type regarding bedding). Unsure/mixed environmental effects on the wider scale, if the yields are lower.	4.5 3.5
	Potential lack of support in outcome-based payment schemes	1	With much talk about payment for ecosystem services style agri support policy (though not much action on it), it might happen that those farming practices will be supported which are easier to quantify, and many of the agroecological ones have very complex system effects which are difficult to measure/estimate. Thus, they might get under supported if PES schemes are rolled out.	4.5
	Historic loss of biodiversity degrading natural processes	1	Reliance on nature to carry out key functions (soil nutrient cycling, pollination, natural pest control) might be compromised by historic losses of key organisms and habitats (e.g. pollinator declines).	4.5

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