Agricultural Land Management for Public Goods Delivery: iCASP Evidence Review on Soil Health

Summary of Report

Healthy soil is essential for the future sustainability of agriculture and underpins the delivery of public goods such as flood protection, protecting water quality and climate change mitigation, but evidence on how some of the most commonly promoted agricultural practices improve soil health is limited.

This report presents the key findings of a rapid systematic review of the academic evidence base concerning the impact of ten land management activities on eight soil health indicators that are related to key soil functions that deliver public goods.

Methodology:

- The land management activities that we reviewed included options popular in the Countryside Stewardship Scheme in Yorkshire and those suggested by a stakeholder steering group.
- We focussed on a set of eight soil health indicators that are important for soil functions and the delivery of public goods, as shown in Figure 1. Changes in these indicators can be linked to key soil functions and the delivery of some public goods, such as improved water quality, flood alleviation and climate change mitigation.
- Our systematic review of peer-reviewed literature used the Population, Intervention, Comparison and Outcome (PICO) framework.
- The effects of the interventions on soil health indicators were reported as either an **increase**, a **decrease** or **no change**. For each land management activity and soil health indicator, the most frequently reported effect was considered to represent the overall effect.
- **Strong evidence** was generally indicated when there were field experiments with well-defined control(s) versus a treatment(s) and/or a meta-analysis of data from such field experiments. However, the number of such studies was often small.

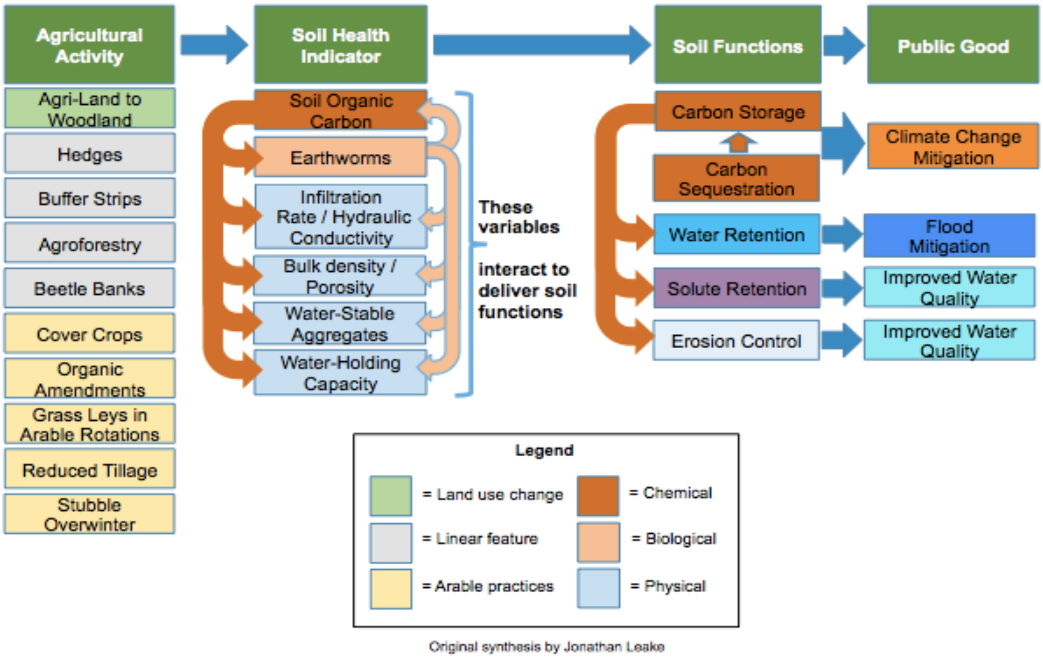

Figure 1: Links between soil health indicators, soil functions and delivery of public goods.

Summary of literature reviewed:

- Results from 240 suitable papers, in the temperate climate zone were included in the review, 17 of which were from the UK.
- The available database on how the target soil health indictors respond to the land management activity is limited; tillage had the most studies (90) followed by cover crops (32), with the other interventions all having less than 30 studies, while none were found for beetle banks.
- The most commonly reported soil health indicators were soil organic carbon and bulk density. Aggregate stability was reported in 56% of papers and earthworms in 34% of papers. Hydrological properties (infiltration and/or hydraulic conductivity) were reported in 34% of papers.
- Only 14 studies reported soil health indicators in soil > 30 cm in depth. A major gap in knowledge is how soil properties and soil functions respond to changes in land management at depth.
- The majority of studies (81%) were carried out at field scale. It is important, therefore, that we identify how public goods delivery at the landscape scale can be measured, e.g. through large scale landscape networks, and/or modelling approaches.
- Very few studies that reported the impact of land management activity on soil health indicators also measured the impact on crop yield; those that did were mainly in relation to tillage practice.

Results by land management activity:
Agroforestry (growing trees in combination with crops or pasture)

Key messages

- **Strong evidence** that agroforestry in arable systems increases the soil's capacity to store organic carbon.
- Agroforestry may improve other soil health indicators; reduced bulk density, increased hydraulic conductivity and increased earthworm population were all reported. **More data is urgently needed** from temperate agroforestry systems to make this a reliable conclusion.

Gaps in evidence

- While long-established in sub-tropical and tropical climates, there is an urgent need for better understanding of how planting trees in temperate agricultural systems impacts on soil health indicators.
- Very few studies have investigated the effects of agroforestry on physical components of soil health such as bulk density, hydraulic conductivity and infiltration, which are important for regulating water flow and quality.

Buffer strips (strips of permanent vegetation either around or within agricultural fields)

Key message

- There is **strong evidence** that soil health (based on the eight indicators reviewed in this study) within buffer strips established around or within an arable field is improved compared to the rest of the field. In particular, soil organic carbon, bulk density and aggregate stability are improved.

Gaps in evidence

- Very few studies (four) have compared soil health indicators of buffer strips within or around grassland fields with the rest of the field.

- Currently there is no evidence that buffer strips will change soil health within the fields they surround.

Cover crops (grown in period between harvest and next main crop)

Key messages

- There is **strong evidence** that single species cover crops do not lead to an improvement in the soil health indicators we reviewed. But they do not lead to a deterioration in these soil health indicators either, and are important in reducing soil erosion and leaching of nutrients.
- There is **some evidence** that cover crops may improve soil health in the long term (> than 10 years). However, the effectiveness of cover crops in improving soil health depends on many interacting factors such as: crop species used, soil texture, climate, crop rotation, fertilizer rate, planting date, and whether and how the cover crop is incorporated into the soil.

Gaps in evidence

- There is limited evidence of the impact of cover crops on soil hydrological properties.
- All of the studies reviewed the impact of single species on soil health indicators. However, UK farmers are now using mixtures of species (e.g. mustards, radishes and grasses) in their cover crop. These may prove more effective than a single species for improving soil health and delivering public goods. No published data on this practice is currently available.

Land use change (conversion of agricultural land to woodland)

Key messages

- There is **strong evidence** that converting grassland to woodland has no significant effect on soil organic carbon stock.
- There is **strong evidence** that converting arable land to woodland significantly increases soil carbon stock.

Gaps in evidence

- There is limited information on the impacts on soil health of converting agricultural lands to deciduous tree cover in temperate climates; most studies have been on coniferous afforestation.
- There is an indication that converting agricultural land (arable and grassland) to woodland increases soil infiltration and hydraulic conductivity; however this is based on four studies only.

Hedges (shrubs and trees of 1-5 m wide around field boundaries)

Key messages

- There is **medium evidence** that soil under hedges stores more carbon than adjacent arable soil.
- In contrast to our understanding of above-ground hedgerow function, **little evidence** exists about how hedgerows affect the target soil health indicators reviewed and thus soil functions.

Gaps in evidence

- Very few studies have investigated the impacts of hedges on soil infiltration and hydraulic conductivity which have implications for water retention and loss.

- Most studies have only compared soils under hedges with soil in arable fields. Only one study compared soil health indicators under hedges with those in grassland soils.
- There are no studies that have investigated the rate of change in soil health indicators after planting new hedges. This is important given that planting hedgerows is a popular option in agri-environment schemes.

Grass leys in arable systems (temporary areas of agricultural grassland sown as part of an arable rotation)

Key message

- There is **strong evidence** that using grass-clover leys in arable rotation increases soil organic carbon stock and the number of earthworms.

Gaps in evidence

- There is limited research on the effects of introducing grass leys into arable rotation on soil structure and hydrological properties, which are important if we want to understand the impact of grass leys on the public goods of flood mitigation and water quality.
- There are no published papers in the academic literature on how herbal leys with deeper rooting mixtures of grasses, legumes and forbs impact upon soil health.

Addition of organic amendments (animal manure/crop residues added to soil)

Key message

- There is **strong evidence** that organic amendments increase soil organic carbon stock, aggregate stability and earthworm population.

Gap in evidence

- No studies included data on the impact of organic amendments on hydrological soil properties.

Leaving cereal crop (not maize) stubble overwinter

Key message

- Stubble retention in arable fields has **no consistent impact** on soil organic carbon storage and earthworm population versus stubble removal, but the evidence for this is based on a **limited number of studies**.

Gap in evidence

- Very few studies compared the soil health of arable fields with and without stubble retention. However, stubble could be considered a type of cover crop as it protects the soil from erosion during the winter.

Tillage practice (conventional vs conservation (non-inversion based tillage) preparation of soil)

Key messages

- There is **strong evidence** that conservation tillage can significantly improve soil health, in particular: SOC, aggregate stability, infiltration, earthworm numbers and porosity.
- The effects of conservation tillage on some soil health parameters such as bulk density and hydraulic conductivity can vary depending on the type of conservation tillage and site characteristics.

Gap in evidence

- There are many types of conservation tillage, and it is not clear from the literature how the effects of the various practices within conservation tillage compare. For example, very few studies compared the effects of direct drilling and minimal tillage on soil health.

Beetle banks (strip of land planted with grasses and/or perennial plants, within an arable field, that provides habitat for beneficial insects, birds, and other fauna that prey on pests)

- **No evidence** found for effects on the eight soil health indicators.

Synthesis of Results

The land management activities reviewed here can be split into (i) land-use change – agricultural land to woodland (ii) arable practices and (iii) linear features. The results from the review are summarised in Table 1 and the main findings synthesised below:

1. Soil health can be improved the most through (not in rank order):

- Conversion of arable land to woodland;
- Conservation tillage;
- Introduction of grass and grass-clover leys into arable rotations;
- Addition of organic amendments.

All these land management options lead to an increase in SOC which is likely to build soil resilience given the important role that soil organic matter plays in soil functioning and improving crop yields. Whether these arable practices contribute to climate change mitigation, depends on how SOC storage changes in the whole soil profile. Unfortunately, 97.5% of the studies reviewed only sampled from the top 30 cm of the soil profile. All these land management options also encourage infiltration due to an improvement in soil structure and thus reduce surface runoff and help to mitigate flooding. Whether increased infiltration leads to an increase in leaching of nutrients is unclear; many studies show that leaching losses from conventional and conservation tillage are similar. The addition of organic amendments may lead to water quality issues if the amendment is surface applied or contains high concentrations of nutrients, heavy metals, pathogens and emerging contaminates.

2. There are important knowledge gaps regarding the **optimal species combinations** to use in arable to woodland planting, hedge planting, cover crops and leys in arable rotations. There is increasing use of deep-rooting species-rich herbal leys in arable rotations in the UK, but no data yet to determine how these compare to traditional grass and grass-clover leys in terms of soil health. There is also increasing use of multiple species rather than one species in cover crops.

3. **Cover crops** and over-winter stubble (which can be considered a type of cover crop) do not appear to lead to an improvement in our focal soil health indicators. However, they do not lead to deterioration in soil health either and so could be promoted to maintain soil health, especially as they are important in reducing soil erosion and leaching of nutrients and thus help protect both soil itself and water quality.

Table 1. Matrix of land management versus soil health indicator. The effect of the intervention on soil health indicator were reported as either an increase, a decrease or no change (NC), the most frequently reported effect was considered to represent the overall effect. Only published papers with experimental control versus treatment and meta-analyses were included in the review. Green shading = overall positive effect, orange = no change and red = overall negative effect on soil health indicator (number of studies). Note a decrease in bulk density represents a positive impact, for all other soil indicators, an increase represents a positive impact.

	SOC stock	Bulk Density	Porosity	Hydraulic Conductivity	Infiltration	Aggregate Stability	Earthworm numbers	Water holding capacity
Agroforestry	Increase (4)	Decrease (2)	Increase (1)	Increase (2)			Increase (1)	
Buffer Strip	Increase(15) NC (6) Decrease(3)	Decrease (11) NC (1) Increase (1)	Increase (2)	Increase (2) NC (2)	Increase (4) NC (3)	Increase (5)	Increase (7) NC (9) Decrease (2)	Increase (1)
Cover Crops	NC (24) Decrease (1)	Decrease (2) NC (20) Increase (1)	Increase (5) NC (6)	NC (1) Decrease (4)		Increase (7) NC (10) Decrease (2)		
Arable to Woodland	Increase (4) NC (2) Decrease (2)	Decrease (2) NC (2)	Increase (2)	Increase (2)				
Grass to Woodland	Increase (2) NC (11) Decrease (9)	Decrease (3) NC (11) Increase (2)		Increase (1)	Increase (1)	NC (1)		
Hedges	Increase (6) NC (1) Decrease (1)	Decrease (3) NC (1)		Increase (1)	NC (1)	Increase (2)	Increase (3) NC (2)	
Leys in arable rotations	Increase (14) NC (4)	Decrease (1) NC (1)				Increase (1)	Increase (3)	NC (1)
Organic Amendments	Increase (20) NC (9)	NC (2)				Increase (10) NC (2)	Increase (7) NC (2) Decrease (1)	
Crop Stubble over Winter	Increase (4) NC (4)	NC (3)				Increase (1) NC (2)	Increase (4) NC (3)	
Conservation Tillage	Increase (83) NC (48)	Decrease (27) NC (80) Increase (43)	Increase (6) NC (5) Decrease (4)	Increase (12) NC (19) Decrease (11)	Increase (17) NC (1)	Increase (60) NC (28) Decrease (3)	Increase (16) NC (10) Decrease (2)	

4. The database for evaluating the introduction of **linear features** into the environment on soil heath is limited and more data is urgently needed given that hedges and buffer strips are both popular options in the current Countryside Stewardship Scheme. In addition, there is a lack of information on which species should be planted and how they should be managed for the delivery of soil-based environmental goods and services.

5. **Soil depth** - the review indicates that there is a lack of data on how soil health indicators and thus soil functions respond to changes in land management at depth (>30 cm) as most studies only sampled the topsoil. This is a major knowledge gap if we want to evaluate which agricultural practices can contribute to climate change mitigation, as some practices may result in a change in the SOC distribution but not the SOC stock in the whole profile.

6. **Spatial scale** - the vast majority of studies were carried out at the field and site scale. Therefore it is important that we identify how public goods delivery at the landscape scale can be measured, e.g. through large scale landscape networks, and/or modelling approaches.

7. **Yield and soil health** - very few studies reported the impact of the land management activity on crop yield as well as soil health indicators, making it difficult to evaluate how best to develop agricultural systems which are able to balance productivity with sustainability and protecting and enhancing the environment. Such studies need to consider full cropping system rotations and long-term effects of multiple rotations.

Conclusions and recommendations:

- Our approach has focussed on a set of soil health indicators that are important for soil functions and the delivery of public goods and services, but is not exhaustive, and has not included components such as biodiversity and soil microbiology which are complex to interpret, but may also be important.
- We have highlighted, from a list of 10, which land management interventions lead to an improvement in some key indicators of **soil health** and the delivery of other public goods, such as climate change mitigation, improved water quality and flood alleviation.
- The gaps in evidence that the report highlights can provide a focus for future/current research, including Defra-funded trials/tests, use of transition period funding, and UKRI-NERC programmes.
- It is critical that this current/future research is done with a range of stakeholders, including farmers, land managers and academics, to enable immediate use in informing the new ELMS.
- There is a need for critical assessment of the ability of different interventions to **deliver multiple public goods**. This information is currently lacking in the literature and urgently needed. The same mitigation option will not result in the same impact everywhere due to variations in soil type, climate, crop rotation, fertilizer application and land management practices. Sometimes, although we may see an improvement in one targeted public good, the same intervention may result in the deterioration of another public good.
- We need to be realistic about time frames, as many soil health indicators take time to respond to changes in land management. For example, benefits of conservation tillage, land-use change to woodlands and agroforestry may take many years to become apparent.

Policy options:

- Given the lack of data, particularly from the UK, on how different interventions lead to an improvement in soil health and delivery of multiple public goods, we recommend including a wide range of options within ELMS and building flexibility into the scheme so that activities can be reviewed/added/removed as more robust evidence becomes available.
- It is important that farmers wishing to trial new combinations of land management to deliver improvements in soil health should be supported. There is an urgent need to develop the evidence-base for on-farm approaches that are feasible for maintaining and improving soil health for the delivery of public goods.
- Codes of good practice could be made part of ELMS, such as the recent Defra Code of Good Agricultural Practice for Reducing Ammonia Emissions, which provide simple, evidence-based ways to reduce ammonia emissions.

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The full report is available from: https://icasp.org.uk/resources/public-goods/

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Integrated Catchment Solutions Programme

The Yorkshire Integrated Catchment Solutions Programme (iCASP) is a five-year (2017-2022) UKRI-Natural Environment Research Council-funded partnership established to support the UK Industrial Strategy. iCASP aims to generate £50 million+ of benefits to Yorkshire's economy by influencing investments, informing policies and strategies, identifying cost savings, and creating new products and jobs. It does this through projects that support the use of environmental science in catchment management. As well as regional impact, iCASP is aspiring for national and international influence through sharing the experience of regional projects at the national level, and by exporting catchment management expertise and products internationally. iCASP has already informed regional policies and national guidance, and provided scientific evidence to >£120 million public-sector investment plans.

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Further information about iCASP can be found at https://icasp.org.uk/