<u>Written Evidence submitted by the University of Leeds (SH0087)</u>

<u>Summary</u>

Experts in soil health related research from the University of Leeds have contributed to this soil health Parliamentary Inquiry. Maintaining 'healthy' soils is vitally important to support the production of food and fibre, while continuously delivering critical ecosystem services for society. When measuring progression towards sustainably managed soils, we highlight no single indictor will encompass all aspects of soil health, and that a soil can only be considered 'healthy' when it retains a minimum threshold of soil physical, chemical, and biological properties. It is critically important to consider land use, soil type and, the timing, frequency and scale at which any soil health measurement is taken. A key challenge is to define soil health under different land uses: determining which indicators to measure, when, at what scale and frequency, and the minimum requirements for each indicator. Understanding current soil health is crucial in measuring progression, but soil health measurements are currently costly and time consuming to perform and whoever is responsible for the data collection should be supported financially and adequately trained. Any data collection on soil health should be stored and accessible to all so that there is full transparency, and everyone can benefit from the knowledge gained.

RECOMMENDATIONS:

1. DEFINE SOIL HEALTH STANDARDS FOR DIFFERENT UK LAND USES AND SOIL TYPES.

2. REGULATE SOIL TESTING FOR MULTIPLE SOIL HEALTH INDICATORS.

3. MAKE SOIL TESTING RESULTS AVAILABLE TO ALL.

Current regulations do not support the improvement of soil health and should be improved through expansion of measurements to include all soil health indicators, increased compliance and the sharing of data. There is substantial risk that soil health will be threatened as ELMs is introduced due to a lack of data standardisation, outcome-based measurements and understanding of soil health indicators and the minimum requirements under different land uses. ELMs could go much further in supporting farmers that improve soil health and adopt soil restorative practices, with more options particularly for livestock farmers. This could lead to significant environmental benefits including reduced greenhouse gas emissions, increased biodiversity and improved water quality.

RECOMMENDATIONS:

4. ASSESS SOIL HEALTH CHANGES THROUGH LONG-TERM MONITORING OF SOIL MEASUREMENTS.

5. ADEQUATELY SUPPORT THOSE WHO ARE IMPROVING SOIL HEALTH.

Private sector investment could further support and encourage landowners and farmers to adopt restorative soil health practices, but the government must provide clear standards for the carbon market. The government must also make soil health a key policy priority, ensure balanced and equitable trade and support soil health related research and education. Regulations must be clear, compatible with other schemes and with appropriate incentives. With the drive to reuse resources, adopt circular economy principles, and use regenerative agricultural practices the inadvertent release of contaminants is going to increase. There is a significant lack of data identifying current levels of soil contamination and the government must support this work through data collection and research.

RECOMMENDATIONS:

6. MAKE SOIL HEALTH A KEY POLICY PRIORITY

7. PROVIDE CLEAR STANDARDS FOR THE CARBON MARKET

8. ENSURE THAT EXISTING AND FUTURE REGULATIONS AND SCHEMES ARE COMPLIMENTARY.

Q1: How can the Government measure progress towards its goal of making all soils sustainably managed by 2030? What are the challenges in gathering data to measure soil health how can these barriers be overcome?

Measuring progress towards sustainable soil management

Soil health is a state of a soil meeting its range of ecosystem functions as appropriate to its environment. Measuring progress towards healthier soils requires the measurement of change in multiple soil properties from a baseline over the course of several years. The goal of making all soils sustainably managed by 2030 is unrealistic, as the current baseline for soil health in the country is the 2007 Countryside Survey, which will not necessarily capture today's soil health baseline across the UK. A realistic goal for monitoring soil health status and achieving sustainable soil management is 2050.

A soil is considered healthy when it retains a minimum threshold of soil physical, chemical, and biological properties, and no single indicator will encompass all aspects of soil health. A defining connection between soil properties and soil health is how soil properties influence the role of soil as a natural bioreactor at Earth's surface (Banwart *et al*., 2014 & 2019). Soil receives, transmits and processes flows of energy, water, nutrients and genetic material that influence how ecosystems function and how humans benefit from the functions. Examples of benefits include the supply of food, feed, fibre, clean water, maintaining habitat and biodiversity, filtering pollution from infiltration and runoff, and supplying nutrients to nourish vegetation. A healthy soil benefits from the contribution of each component, as well as from the interactions between them. The optimal range of properties to support healthy soil will differ with time and location, and their observation will depend on several factors

1. Land use
2. Soil type
3. Timing of measurement
4. Frequency of measurement
5. Scale at which the measurement has taken place

Land use and soil type: The definition of soil health, as well as the range of ecosystem functions that a healthy soil can support, changes depending on the intensity of land use and soil type. For example, a semi-natural grassland soil can achieve higher overall soil health than a similar soil under arable management, and a healthy light soil with high sand content will have different properties and characteristics compared to a healthy heavy soil with high clay content.

Timing and frequency: Any soil health indicator must be measured at the appropriate time and frequency. To measure the progress towards achieving sustainable soils, we must monitor changes in soil health indicators over time, recognising that soil properties that underline soil health monitoring can change at different rates. For example, soil organic carbon stocks change over several years, soil pH can change in the span of a few years, while soil fauna can oscillate strongly both intra- and inter-annually. Soil health monitoring on agricultural soils must also account for the timing of farm management practices, as soil analysis results can be strongly affected by, for example, fertiliser application, tillage and addition of organic amendments. These factors have important consequences for the expected amount of time that soils require from transition from a more degraded to a healthier status. Changes in soil properties arising from changes in agricultural management are often small, and it can take several years to measure their impact on soil health. For this reason, 2030 is an unrealistic timeframe to achieve sustainable management of all soils in the UK and should be changed to 2050.

Scale: Soil health indicators depend on the depth and spatial scale at which the indicator is measured. Soil depth has a strong effect on most soil properties, and the sampling depth of soil indicators will affect the comparability of data between sites. For example, issues arise from comparing soil organic carbon content in the top 15 cm depth, and in the top 50 cm depth. This is because in mineral soils most organic carbon is found close to the soil surface. Consistency in the depth of soil sampling is key for the accurate interpretation of soil health status, and soil sampling should occur at a minimum of 0-30 cm depth, as recommended by IPCC guidelines (Ogle *et al.*, 2019). Soil properties are also highly variable spatially, and the interpretation of soil health patterns will depend on the scale at which the underlying soil indicators are measured at. For example, soil properties need to be sampled at specific scales to be used in predictive modelling of soil health status (Biswas & Si, 2011).

The challenges in gathering data and how these can be overcome

The key challenges are

1. Quantifying soil functions
2. Definition of soil health depending on land use: which indicators should be used, at what time, scale, frequency, and what are the minimum requirements for each indicator
3. Lack of standardisation of soil sampling (e.g. to what depth) and method of analysis
4. Data collection: who will gather the data and how reliable are the data
5. Data storage: who will own the data and what will the data be used for

Quantifying soil functions: The rates of energy and material flows and their transformations in soil that support ecosystem function and provide benefits to people are usually not possible to measure. However, these values can be calculated by mathematical models. Most modelling approaches also require substantial data such as meteorological data on rainfall inputs, temperature and soil water evaporation, solar flux to land surface for photosynthesis, as well as input values for soil properties that are used in equations that calculate rates of flows (heat flux, water, carbon, nutrients) and transformations (e.g. plant growth, soil organic carbon sequestration or loss, etc.). Because of the cost to routinely provide such amounts of data and to implement and run models, a usual approach is to use measurements of soil properties as indicators that correlate with ecosystem functions.

Which indicators: An outcome-based approach offers a more robust way of assessing impact and whether soils are being sustainably managed than a practice-based approach. Thus, to be able to measure the progress of soil health, we first need to develop a soil health scoring system based on multiple soil indicators and land uses. This means determining which soil properties will be used as indicators of soil health, when they should be measured, how frequently and at what scale. Minimum thresholds of indicators for different land uses, climates and soil types must also be determined for a soil to be considered in poor, standard, or good health. Such a benchmarking service (e.g. is a soil in poor, standard, or good health) could encourage land managers and landowners to provide data. A good example of a benchmarking system is the Soil Health scorecard, developed with funding by AHDB and BBRO (https://ahdb.org.uk/soil-health-scorecard), which is geared towards agricultural (mineral soil) land. A similar methodology could be developed for other soils and land uses. To determine this, there must be available and accessible data collection from suitable sites, funded by the government wherever necessary.

Standardisation of soil measurement methodology: The short-term changes in soil properties that arise from changes in agricultural management are often small, so reliable and standardised soil measurements are critical. Currently there is a lack of standardisation in soil measurement methodology, which can vary due to costing issues, as well as disunity within the scientific community. As a result, the comparability of soil measurements is limited by spatial variation, sampling strategy, and differences in soil processing methods and laboratory assays (Stanley *et al.*, 2023). This is a substantial issue concerning soil monitoring schemes and should be addressed by developing common standards that can capture soil health status across different land uses.

Data collection: To monitor soil health nationally we will need to collect data on multiple indicators, with challenges arising from the logistical aspects of conducting and interpreting soil testing, as well as from the financial costs of soil testing. Existing models can provide farmers who choose to purchase the service with a comprehensive record of soil health on their land and assists their decision-making across all land management practices. For example, within the Ecological Outcome Verification Programme (https://savory.global/eov/) a regional verifier visits and collects data every 5 years to assess multiple soil health indicators (Xu *et al.*, 2019). Farmers are trained by the verifiers to improve standardisation of soil measurements when collecting data annually for short term monitoring. As a co-benefit, including farmer training in land monitoring reinvigorates systems thinking on the farm, a proven requirement of more sustainable land management (Gosnell, 2021; Gosnell *et al.*, 2019; Sherren *et al.*, 2022). The cost of soil sampling and analysis, however, is often ascribed as the main challenge for farmers conducting soil testing. New technologies which automate soil analysis can dramatically reduce the cost, but they need to be calibrated correctly and used at an appropriate scale to ensure data is comparable and is truly reflective of the soil. Scotland and Northern Ireland have recently developed schemes (National Testing Programme and the Soil Nutrient Health Scheme, respectively) which pay farmers or government contractors to carry out soil sampling and analysis at no cost to the farmer. This is a very different approach to the SFI soil standards in England where farmers need to arrange soil sampling and analysis.

Data storage: Developing and maintaining a soil health database is a fundamental requirement to ensure robust tracking and enable an assessment of progress towards the goal of making all soils sustainably managed. A challenge arising with the large-scale collection of soil health data is concerning the right to privacy and data ownership, which currently differs between the devolved nations. Standardisation for data management across platforms is critical including when capturing input and agronomic data from farms. Data could be hosted by the Office of National Statistics which has many sensitive datasets, but the data must be made easily available.

Q2: Do current regulations ensure that all landowners/land managers maintain and/or improve soil health? If not, how should they be improved?

No. For example, under the 2018 'Farming Rules for Water', farmers are required to undertake soil testing for chemical properties every 5 years (as a minimum). However, there is no enforcement of this regulation and farmers are not required to keep soil test results. The funding for farm inspections has also been reduced. Additionally, between 1990 and 2015 there has been a net increase in urban areas of 3,376 km^2 (majority in England), an area almost the size of Cornwall, and a general trend of further loss of semi-natural habitats and land degradation (Entwistle *et al.*, 2019, Ridding *et al.*, 2020). In the Outcome Indicator Framework for the 25-Year Environment Plan (https://oifdata.defra.gov.uk/), indicator 'E7: Healthy Soils', is still under development. Moreover, the last assessment of soil properties across the UK was in 2007 via the Countryside Survey carried out by UKCEH for DEFRA.

To improve soil health, firstly we must agree on how to monitor it, combining the requirements of existing regulations and make sure that (a) there is compliance with the regulations and (b) that the results of soil testing are shared to determine how soil health is changing over time across the UK.

Improvement of the current regulations

To allow for soil health assessment, regulations need to

1. be expanded to include all soil health indicators to assess soil health status
2. improve compliance
3. require the sharing of soil testing results to monitor soil health

Expand soil health indicator measurements: The 2018 'Farming Rules for Water' require frequent soil nutrient content and pH testing on all agricultural land prior to fertiliser application. This regulation can be considered a suitable starting point for national soil health assessment and monitoring. However, the soil testing should be expanded to include soil physical and biological properties to capture soil health status. Soil analysis needs to be expanded from the focus on chemical to include soil structure and soil organic matter content (which, for example, are already monitored within the Countryside Stewardship soil testing requirements), and any other potential soil health indicators, such as soil fauna (see Q1 on the requirement of establishing clear soil health indicators). Soil health testing should occur every 3-5 years and soil health status could be assessed using a benchmarking system, such as the one developed by the Soil Health Scorecard by the Soil Biology and Soil Health Partnership funded by AHDB and BBRO.

The soil carbon discourse needs to be reframed in the broader context of soil health to make it more inclusive and less daunting and more tangible/easily understood which is key for improving soil health. Initial findings of research by the University of Leeds (not yet published), suggests that there is scope and need for a discourse relating to soil carbon which is inclusive of a wider range of perspectives. It must recognise that not all farmers are interested in generating and selling carbon credits and/or in favour of public and private sector actors being permitted to offset their carbon footprints, particularly in the absence of these actors addressing their own (1) scope and (2) emissions. Broadening the context of soil health recognises that soil organic matter and soil carbon content correlates with many beneficial soil functions. For example, supporting habitat and biodiversity, filtering pollutants from infiltration water, providing plant available nutrients for soil fertility and improving soil structure that increases both the drainage of soil and the storage of plant available water. The benefits of soil carbon go much further than sequestering carbon and nitrogen, and thereby preventing their release as greenhouse gases for climate regulation (Banwart *et al.*, 2014). Reframing the current carbon-centric discourse as a soil health-focused discourse while, conversely, improving farmers' access to reliable information regarding the emerging agricultural soil carbon market and practical actions that can be taken to improve soil carbon stocks, is key to ensuring that farmers in the UK adopt soil health management practices, including those farmers who currently might not perceive an incentive to do so or may be sceptical of the carbon market.

Improving compliance of regulations: The costs related to soil sampling and analysis are arguably the main barrier to the widespread adoption of soil testing and the compliance to existing and future regulations. This issue should be addressed by reducing soil testing costs and/or subsidising soil testing expenses. SFI payment, which ranges between £22-£40 on arable land and £22-£58 on grassland can reasonably be expected to compensate for soil organic matter testing using new technologies. However, SFI payments are available for several changes in management practices (e.g. establishment of cover crop and organic soil amendments) and are not sufficient to compensate for soil testing requirements under the current 'Farming Rules for Water', or of other future requirements to monitor soil health. There is a need for technological development to reduce the cost of soil sampling and analyses necessary to capture soil health status. For example, recent technological advancements enable extensive and accurate measures of soil carbon content for £5/sample, however, standard soil testing of soil pH and nutrient content is £40/sample. Extensive training and communication must be conducted to inform farmers and landowners of soil testing requirements to maximise compliance to existing and future regulations. Despite these regulations being in action, many farmers and landowners may not be aware of specific soil testing requirements (Okumah *et al.*, 2018). Substantial efforts should be made to communicate clearly and, in a context-specific manner the changes in regulations at both national and local level (Okumah *et al*., 2019). For example, it is not clear what regulations exist for construction and forestry sites in terms of maintaining soils (mostly avoiding soil erosion) when building houses, roads and felling trees.

Sharing of data: The 2018 'Farming Rules for Water' specify that failing to comply with the regulation constitutes an offence, but there is currently no requirement for farmers and landowners to render soil testing result available, nor an explicit requirement for record keeping of soil testing results. All soil testing results must be made accessible, as the lack of data availability is a barrier to take up and enforcement of the regulations, as well as a barrier to monitoring current and future soil health status nationally. This requires the development and maintenance of a database for soil health, to track changes in soil health over time, and for comparison across fields, farms and land uses.

Q3: Will the standards under Environmental Land Management schemes have sufficient ambition and flexibility to restore soils across different types of agricultural land? What are the threats and opportunities for soil health as ELMs are introduced?

To a large extent, ELMs payments for public goods have flexibility and ambition to restore soils, but there are several threats and opportunities for soil health as they are introduced.

Threats for soil health with ELMs introduction

Adoption: There is a general and substantial risk that uptake of the soil standards in SFI (part of ELMs) will not be high, as the payments for undergoing prescribed changes in agricultural practices are currently seen insufficient to entice farmers and landowners. Anecdotal evidence suggests that current uptake levels of SFI in England are very low, threatening the goal of improving soil health nationally via this scheme. It is unlikely that the current standards will attract enough participants to reach the DEFRA target of 70% of land managers/landowners signed up to the scheme by 2028. Without reaching this objective, the goal of making all soils sustainably managed by 2030 will be unrealistic. A realistic timeframe for achieving the sustainable management of soils in the UK is 2050. ELMs guidance needs to be easy to read, accessible to all, and supported with simple application systems. It is also critical to ensure that existing and future regulations and schemes work together to streamline soil testing requirements. Moreover, farmer participation in ELMs should not prevent their involvement in other schemes and practices that support ecosystem functioning.

Data standardisation: Current SFI standards require farmers to 'complete a soil assessment and produce a soil management plan' (Action 1) but do not have specifications on the requirements, methodology, and data standardisation resulting from this action. As the final structure and content of this assessment is left up to the individual farmer and landowner, we can expect difficulties with the standardisation and interpretation of resulting data. This will pose a barrier to assessing the current baseline of soil health and monitoring future progresses. This is a significant concern as this data represents the base of the current strategy to monitor soil health. Current SFI standards require 'Action 2: test soil for organic matter' without specifying the soil sampling and analysis methodology. There are different ways to measure soil organic carbon, which are not interchangeable. Importantly, soil organic matter content alone is not enough to capture soil health and other indicators should be included in the requirements.

Practice-based outcomes: Current SFI standards for arable and horticulture require 'Action 3: add organic matter' but not all practices listed should be expected to have the same result, as the ability of a soil to increase organic matter content is influenced by its texture, drainage characteristics and land use. Organic amendments could have direct impacts on soil organic matter (but also on contamination, see Q5), while the diversification of the crop rotation (e.g. use of herbal leys, cover crops, legume mixes) will not necessarily change soil organic matter, especially not within the three years of an agreement. There is no consideration of differences between catch crops (grown between harvest and planting of autumn crops) and cover crops (grown between harvest and planting of spring crops), and while these two can sometimes overlap in species mix, they can be very different from an agronomic point of view. Moreover, the listed option to 'include legume species or legume rich mixes in rotations' is targeting soil nitrogen, not soil organic matter.

Soil health indicators: There is concern that the standards and actions in ELMs will lead to reducing soil degradation rather than actively building soil health, e.g. they might be 'sustainable' but not 'regenerative'. Their potential to increase soil health must be measured and the only way to demonstrate that soil health is improving is to integrate more holistic measurement of outcomes, rather than assuming certain practices will lead to certain outcomes. Therefore, the lack of holistic indicators of soil and ecosystem health (beyond just soil organic matter) could potentially be a threat to the success of the SFI programme.

Opportunities for soil health with ELMs introduction

Through the uptake of ELMs there is opportunity to collect information on the impact of the scheme and practices on soil health across England and consolidate all this information in one place for participants' use. Data could then be available to farmers as a benchmarking service to inform agronomic and land management decision making.

There is an opportunity for ELMs to bring together farmers and the agricultural supply chain, and offer services and training in monitoring, as well as building networks for farmers, so that they transition into more active monitoring with learning networks to ask for assistance (made up of producers, government staff, and academics with knowledge of best practices).

The Countryside Stewardship scheme will likely remain attractive to farmers, as it is well established, and its rules are already clear. The various options within this scheme could have had many beneficial impacts on soil health, but we currently lack a comprehensive overview of their effects on soil. Some of these options have already been assessed, such as planting hedgerows, which can have positive effects on soil health (Biff *et al*., 2002), but all options should be assessed widely. ELMs could go much further in supporting farming that improves soil health, with more options available especially for livestock farmers.

Q4: What changes do we need to see in the wider food and agriculture sector to encourage better soil management and how can the Government support this transition?

What changes do we need to see in the wider sector?

Private sector investment: Private sector-led investment in sustainable land management is likely to play a key role in incentivising farmers' and landowners' adoption of soil health management practices. An example of a private sector-established scheme which recognises the importance of soil health at a landscape level, is the Landscape Enterprise Network scheme (LENs) designed and implemented by 3Keel and Nestlé UK in several locations across the UK. The premise underpinning the LENs is that it is possible to create a marketplace which enables public and private sector actors, who are interested in incentivising nature-based solutions and realising landscape-level outcomes, to establish trading contracts with farmers, farmer cooperatives and landscape managers who can provide aggregated ecosystem services. The University of Leeds is currently undertaking research in the context of two EU-funded projects which explore the scope for LENs to serve as a business model for soil health-related investments by private sector actors who are interested in securing landscape functions and assets (e.g., healthy soils), paving the way for the creation of a network of climate neutral and climate resilient farms across the UK and Europe. Given that private sector actors are increasingly being expected to reach Net Zero or show progress towards Net Zero (or face fines), it is likely that LENs may in the future serve as a platform for the trade and/or direct sale of carbon credits. It is imperative that there is a standard for soil carbon market schemes to be developed, as outlined in the report 'Recommendations on minimum requirements for high-integrity soil carbon markets in the UK'
https://sustainablesoils.org/images/pdf/Framework_Requirements_for_High-Integrity_Soil_Carbon_Markets.pdf

How can government support this transition?

Soil Health as a key policy priority: Soil Health Action Plan for England (SHAPE) provided a roadmap for improving and protecting soil health, driving progress in not only restoring soil health but also meeting biodiversity, water quality and carbon emissions reduction targets. SHAPE has been repackaged into the broader 'Environmental Improvement Plan' announced on the 31st of January 2023. Although aspects of SHAPE have been incorporated into this new plan, there is a risk that the previous strong message in SHAPE that soil health is a key policy priority for the UK government, and that there is an imperative for farmers to protect and invest in soil health management practices, may be lost. If this is not the case, then farmers need clarification on this.

Create sustainable land management approaches: Shift to holistic, systemic, contextual, and grassroots-supported planning and management approaches by all relevant stakeholders that link food security, livelihoods, and market benefits to rising health and resilience in ecosystem function. For example, think about our food systems as systems not just value chains, look at the linkages and shift towards more redundancy in the system, which while creating trade-offs with efficiency, supports greater resilience. Encourage cross-sectoral and multi-stakeholder approaches including those that engage men and women together as agents of change to develop and implement land restoration and drought strategies at local, regional, national and continental scales. Network building is a way to support sustainable behavioural change and there are existing organisations whose networking models could be scaled up e.g. 3LM https://www.3lm.network/

Clear regulations with supportive incentivisation: At a time when the UK agricultural policy landscape is undergoing significant changes, farmers require clear guidance regarding newly introduced ELMs, such as SFI, and the associated opportunities to obtain payments for the provision of public goods. As indicated earlier in this parliamentary submission (see Q3), there is a risk that farmers' willingness to participate in ELMs, including the SFI, will be low. Despite the development of new standards, these schemes may continue to be perceived as offering too little compensation to incentivise farmers' investment in the type of practices and production strategy changes required to realise an improvement in soil health on their farms.

Balanced and equitable trade: Systematically apply true cost accounting (TCA) to food products worldwide, thus ensuring balanced and equitable trade, both domestically and internationally. The Sustainable Food Trust has already involved TCA https://sustainablefoodtrust.org/our-work/true-cost-accounting/ and the TCA Accelerator is bringing together a growing network of interested organisations https://tcaaccelerator.org/ (de Adelhart Toorop *et al.*, 2021)

Standards for carbon market: The emergence of an agricultural soil carbon market, driven by carbon codes and a growing interest among private and public sector actors to offset their carbon footprints - in the long-run, may prove to be a catalyst to incentivise farmers' and landowners' investment in soil health management practices. Research by several of the authors of this parliamentary submission suggests the agricultural soil carbon market is currently perceived by many farmers as a 'wild west' (currently unpublished), with misinformation related to the opportunities to generate carbon credits and participate in the market widespread, and carbon codes and agricultural consultancy providers perceived as operating to serve their own interests in the absence of rules and regulations governing the carbon market. There is a need for the development of a standard for soil carbon market schemes, to improve confidence in the integrity of carbon credits generated. A recent report, 'Recommendations on minimum requirements for high-integrity soil carbon markets in the UK', https://sustainablesoils.org/images/pdf/Framework_Requirements_for_High-Integrity_Soil_Carbon_Markets.pdf proposes minimum requirements for the carbon market and criteria that could be formally adopted and enshrined in a standard to ensure the rigour of carbon codes' and schemes' measurement, reporting and verification of changes in soil carbon stocks, as well as address farmers' concerns in relation to critical principles like permanence, additionality and leakage. Companies should be required to show progress towards Net Zero in their annual reporting to the 'Environmental Reporting' including insetting / offsetting in soil health private schemes which comply with a minimal standard. For example, the British Standards Institute developed a standard on the basis of the proposed 'Minimal Requirements'. Currently only woodland carbon code and peatland carbon code are allowed as offsets, and this need to be extended to other ecosystems with proper minimal standards in place. Consider credits for maintaining soil organic carbon as well as improving it.

Stronger links with policy: Build effective land management approaches into national 'Long Term Low Emission Development Strategies' and the 'Nationally Determined Contributions'. To support and buttress all of this, an effective, ambitious, and professional policy advice and communication effort is needed building upon a grassroots movement of success. Integrate an understanding of regenerative land management into planning, education, health and security policies. Integrating a holistic and systems perspective across multiple spheres influenced by land dynamics.

Research and education: Educate, grow and deploy land management advisors to support the co-design of context specific strategies with local people implementing, linking efforts and learning at wider scales. This could be done through networks like 3LM https://www.3lm.network/ training farmers in holistic management and land monitoring, but also through relationships with agricultural colleges and universities. Boost research and education in both the soil health monitoring space but also in the social science understanding of producer decision making. Collect data and evidence on regenerative agriculture, on farm economics, resilience to climate extremes and support evidence-based practice, demonstrating this evidence and the benefits of soil health to farmers. Support knowledge exchange, social networks and advisory services such as Innovative Farmers https://www.innovativefarmers.org/ The Countryside Stewardship Facilitation Fund for knowledge exchange between farmers is an fantastic scheme that has excellent outcomes but has recently seen a reduction in payments to the facilitator which is extremely disappointing and will lead to reduced uptake. There are important questions to be answered about the role of values in taking up sustainable land management and/or land monitoring, the roles of networks and education in adoption, and the social and economic wellbeing outcomes of such adoption. Project such as https://www.tandfonline.com/doi/abs/10.1080/21683565.2022.2107597 and https://projects.sare.org/sare_project/lnc20-437/ could be repeated in the UK.

Q5: What does UK Government need to do to tackle other stressors on soil health such as soil contamination?

Support regeneration of soils through funding and policy changes: Many of the processes in soil contamination (leaching, carbon loss, metal and organic pesticide contamination) are strongly related to the loss of soil health. Thus, a key factor to tackle soil contamination is ensuring that soils are keeping their buffering effect. Management interventions aiming at soil organic carbon sequestration have long been claimed to enhance soil fertility and productivity, increase soil biodiversity, improve water retention and purification, and reduce erosion, compaction, runoff and water pollution (Lal, 2004; Paustian *et al.*, 1997, 2016; Smith, 2012).

Support research to understand the fate and effects of contaminants in a circular economy: There is currently a lack of understanding of medium- and long-term effects of contaminants in soil and on plant health (and animal health as a consequence). Following a drive to reuse resources, adopt circular economy principles (Banwart *et al.*, 2021), and use regenerative agricultural practices and sustainable approaches to agricultural production, the inadvertent release of contaminants is going to increase. Land application of farmyard manure, slurry and wastewater sludges (biosolids) can provide a pathway by which contaminants can enter and become omnipresent in soils. This can include traditional pollutants such as heavy metals as well as emerging contaminants including veterinary antibiotics, human pharmaceuticals and microplastics. We currently lack comprehensive data regarding the fate and effects of emerging contaminants, but evidence has documented their uptake by plants and potential to elicit toxic responses at environmentally relevant concentrations. Emerging contaminants in particular, pose a risk to soil health due to their conserved biological potency. Pharmaceuticals for example are used to elicit a response in an organism/human and this potency is not lost when they enter the environment. The chemicals can therefore impact processes at a biological level e.g., soil microbial community dynamics which has wider implication for soil health as they control nitrogen, phosphorus and carbon cycling. Key areas of interest are antibiotics (link to antimicrobial resistance) and antifungals used for plant protection are now being linked to the development of antifungal resistance. Use this evidence-based research to support policies.

Produce clear guidance on inputs: Farmers moving away from synthetic fertilisers and towards organic amendments, as well as using biostimulants, want more clarity regarding regulations and direction in terms of soil testing to reduce current uncertainty and future risks. Currently sewage sludge (biosolids) cannot be spread at the same time as crops for human consumption are grown. However, they can be spread on fodder crops consumed by animals, and crops for human consumption can be grown a relatively short amount of time after spreading the biosolids. There is urgent need for research on the long-term effects of these practices, as some chemicals that can be present in biosolids have a long lifespan and are not expected to degrade within the specified timeframe for growing crops for human consumption (Snow *et al*., 2019). This is also relevant to SFI, as Action 3 (‘add organic matter’) the standards for arable and horticulture includes the application of ‘organic manure’ as a practice to increase organic matter in the soil. This term encompasses biosolids and could result in an increase in contaminants in a scheme that aims at improving soil health. Finally, there is a lack of regulation with regard to biostimulants. Biostimulants are generically defined as substances or microorganisms that stimulates natural processes to enhance or benefit crop quality and yield. These products are being increasingly used by farmers, but very little is known on their effect on the broader functioning of the soil system and its related ecosystem services.

Identify current levels of soil contamination: We currently lack crucial baseline data for current levels of soil contamination in the UK following the reuse of resources to land. We also lack an understanding of what would be considered as a permissible level of contamination. This understanding must encompass chemicals other than the traditional metrics currently used, such as heavy metal concentration. We must define for all contaminants, permissible levels of contamination that do not result in any adverse risk to soil health and crop productivity. Compared to controls in industrially contaminated soils employed in land redevelopment, controls on contamination of agricultural soils are minimal. The specific signatures of intensive farming operations are individually visible in both the soil water and groundwater signatures, for example as a result of excessive slurry spreading, used to get rid of the slurry, above and beyond what's needed for fertiliser.

About us: The University of Leeds

The University of Leeds is one of the top 10 UK universities. It is an internationally recognised institute for environmental research that has wide-ranging and positive impacts on our world. With over 285 academic and research staff, 96% of environmental research is classed as 'world-leading' or 'internationally-excellent' (submitted research – REF2021). Our researchers work at the forefront of global agendas, leading the way in finding solutions to major social and environmental challenges. We are world leaders in soil health research, with a current portfolio of cutting-edge research projects valued at around £25M in this area, examining fundamental soil processes related to carbon storage, water, nutrients, contaminants, above and below ground ecology and biodiversity, and plant interactions. We investigate processes at a range of scales from soil pores through to landscape scale. Our aim is to develop enduring solutions that help bring about transformative change to create a food system that is socially-just, climate-smart and goes beyond sustainability; able to adapt vigorously to enhance the future habitability of our planet.

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References

Banwart SA, Black H, Cai Z, Gicheru P, Joosten H, Victoria R, Milne E, Noellemeyer E, Pascual U (2014). The global challenge for soil carbon. In Soil Carbon – science, management and policy for multiple benefits, Banwart SA, Milne E, Noellemeyer E (Eds.), *Scientific Committee on Problems of the Environment (SCOPE)* Series Vol. 71, 1-9. CABI, Wallingford, UK, ISBN-13: 978 1 78064 532 2

Banwart S, Carter L, Daniell T, Zhu Y, Guo H, Guest J, Kirk S, Evans B, Dennis S (2021). Expanding the agricultural - sanitation circular economy: opportunities and benefits. *Policy Leeds,* policy note 3 https://doi.org/10.5518/100/71

Banwart SA, Milne E, Noellemeyer E (Eds.) (2014). Soil Carbon – science, management and policy for multiple benefits. *Scientific Committee on Problems of the Environment* (SCOPE) Series Volume 71(31):0-420. CABI, Wallingford, UK, ISBN: 9781780645322

Banwart SA, Nikolaidis NP, Zhu Y-G, Peacock CL, Sparks DL (2019). Soil functions: connecting Earth's critical zone. *Annual Review of Earth and Planetary Sciences*, 47:333–59 https://doi.org/10.1146/annurev-earth-063016-020544

Biffi S, Chapman PJ, Grayson RP, Ziv G (2022). Soil carbon sequestration potential of planting hedgerows in agricultural landscapes. *Journal of Environmental Management* 307:114484 https://doi.org/10.1016/j.jenvman.2022.114484

Biswas A, Si BC (2011). Scaling of Soil Physical Properties. In: Gliński, J., Horabik, J., Lipiec, J. (eds) Encyclopedia of Agrophysics. *Encyclopedia of Earth Sciences Series.* Springer, Dordrecht. https://doi.org/10.1007/978-90-481-3585-1_243

de Adelhart Toorop R, Yates J, Watkins M, *et al.* (2021). Methodologies for true cost accounting in the food sector. *Nature Food* 2:655–663 https://doi.org/10.1038/s43016-021-00364-z

Entwistle NS, Heritage GL, Schofield LA, Williamson RJ (2019). Recent Changes to Floodplain Character and Functionality in England. *Catena* 174:490–98 https://doi.org/10.1016/j.catena.2018.11.018

Gosnell H (2021). Regenerating soil, regenerating soul: An integral approach to understanding agricultural transformation. *Sustainability Science*. https://doi.org/10.1007/s11625-021-00993-0

Gosnell H, Gill N, Voyer M (2019). Transformational adaptation on the farm: Processes of change and persistence in transitions to 'climate-smart' regenerative agriculture. *Global Environmental Change*, *59:*101965. https://doi.org/10.1016/j.gloenvcha.2019.101965

Lal R (2004). Soil carbon sequestration to mitigate climate change. *Geoderma* 123(1-2):1-22 https://doi.org/10.1016/j.geoderma.2004.01.032

Ogle SM, Kurz WA, Green C, Brandon A, Baldock J, Domke G, Herold M, *et al.* (2019). 'Generic Methodologies Applicable to Multiple Land-Use Categories'. In 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 2. *Intergovernmental Panel on Climate Change* https://cgspace.cgiar.org/handle/10568/107138

Okumah M, Martin-Ortega J, Novo R (2018). Effects of awareness on farmers' compliance with diffuse pollution mitigation measures: A conditional process modelling. *Land Use Policy* 76:36-45 https://doi.org/10.1016/j.landusepol.2018.04.051

Okumah M, Chapman PJ, Martin-Ortega J, Novo P (2019). Mitigating Agricultural Diffuse Pollution: Uncovering the Evidence Base of the Awareness–Behaviour–Water Quality Pathway. *Water* 11(1):29 https://doi.org/10.3390/w11010029

Paustian K, Andren O, Janzen HH, Lal R, Smith P, Tian G, *et al.* (1997). Agricultural soils as a sink to mitigate CO_2 emissions. *Soil Use Management* 13:230–244 doi: 10.1111/j.1475-2743.1997.tb00594.x

Paustian K, Lehmann, J, Ogle S, Reay D, Robertson GP, Smith P (2016). Climate-smart soils. *Nature* 532:49–57 doi: 10.1038/nature17174

Ridding LE, Watson SCL, Newton AC e*t al.* (2020). Ongoing, but slowing, habitat loss in a rural landscape over 85 years. *Landscape Ecology* 35:257–273 https://doi.org/10.1007/s10980-019-00944-2

Sherren K, Hodbod J, MathisonSlee M, Chappell E, King M (2022). Adaptive multi-paddock grazing and wellbeing: Uptake, management practices and mindset among Canadian beef producers. *Agroecology and Sustainable Food Systems*, *46*(9):1304–1329 https://doi.org/10.1080/21683565.2022.2107597

Smith P (2012). Soils and climate change. *Current Opinion in Environmental Sustainability* 4(5):539-544 https://doi.org/10.1016/j.cosust.2012.06.005

Snow DD, Cassada DA, Biswas S, Malakar A, D'Alessio M, Carter LJ, Johnson RD, Sallach JB (2019). Detection, occurrence, and fate of emerging contaminants in agricultural environments. *Water Environment Research* 91(10):1103-1113 doi: 10.2175/106143018X15289915807254

Stanley P, Spertus J, Chiartas J, Stark PB, Bowles T (2023). 'Valid Inferences about Soil Carbon in Heterogeneous Landscapes'. *Geoderma* 430:116323 https://doi.org/10.1016/j.geoderma.2022.116323
Xu S, Rowntree J, Borrelli P, Hodbod J, Raven MR (2019). Ecological health index: A short term monitoring method for land managers to assess grazing lands ecological health. *Environments - MDPI*, *6*(6) https://doi.org/10.3390/environments6060067