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Improving soil health in the UK: why a microbial approach is indispensable in attaining sustainable soils

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Abstract

Current agricultural approaches in the UK—and across much of the world—are unsustainable, particularly due to their impacts on soil health. With evidence already showing diminishing returns in productivity, which are only predicted to get worse with the climate crisis, restoring the health of soils and soil-dwelling microbes is an essential prerequisite for a thriving planet. This report proposes taking a new approach to soil health based on the soil microbiome. The complex community of soil microbes and their interactions are known to underpin soil health and consequently food security, resilience to climate change, global health, biodiversity, and more. As such, an approach that holistically takes soil into account is needed, rather than the siloed approaches used to date. This report therefore highlights the opportunity to take a microbiome approach to soil and how such an approach could be implemented in the UK going forward, whilst also recommending microbial solutions that can be deployed to improve the UK's soils now.

Sustainability Statement

World soils and their associated microbiomes underpin many of the UN SDGs. When in a good state of health they not only help to provide food security (relating to UN SDG 2, zero hunger); they also increase resilience to climate change (UN SDG 13), reduce the risk of pathogen and AMR transmission through the environment (UN SDG 3), boost biodiversity (UN SDG 15), regulate water and air quality (UN SDG 6 and 15), and more. As such, the aim of this report is to highlight the essential need to consider soils from a microbiome perspective; not doing so risks managing and treating soils from a siloed point of view. At best, this results in soils functioning at a reduced capacity and at worst, can cause harm through the reverse effects of the beneficial functions described above. We propose that significant progress can be made in achieving the UN SDGs if policymakers adopt the suggested microbiome-based approach outlined here, or at the very least consider some of the microbial solutions that can help to regain healthier soils.

Keywords: soil, soil amendments, soil microbes, soil microbial ecology, soil microbiology

Introduction

Applied Microbiology International (AMI) brings the microbiology community together across international borders and disciplines as it believes global challenges need to be solved by global experts. Centred around six of the UN Sustainable Development Goals (SDGs), AMI has established six advisory groups encompassing international expertise, to ensure a diverse range of voices are identifying how microbiology can contribute towards achieving these goals.

Soil health underpins many of the UN SDGs, including the six that AMI is aligned with. Healthy soils not only help to provide food security; they also increase resilience to climate change, reduce the risk of pathogen and AMR transmission through the environment, boost biodiversity, increase carbon storage and nutrient retention, and more. With the global population ever increasing and demands on our soils simultaneously growing, soil health must be given the attention it deserves due to the complex processes and factors it underpins. Ultimately healthy soils are essential for a thriving planet and future (Evans et al. 2022).

The importance of soils registered with global leaders almost a decade ago (International Union of Soil Sciences 2024), leading to countries such as the USA to pass healthy soils legislation (Delmendo et al. 2021). As such, the UK needs to ensure it is staying aligned with, and at the forefront of, global developments and ambitions concerning soil health. The UK Government has increased attention on soil health, evidenced by the recent publication of a soil health report by the Environment, Food & Rural Affairs Committee, the hosting of a Westminster Conference on improving soil health nationally, and the renewed focus shown towards relevant policies, including the Environmental Land Management schemes (https://www.gov.uk/government/publications/environmental-land-management-update-how-government-will-pay-for-land-based-environment-and-climate-goods-and-services/environmental-land-management-elm-update-how-government-will-pay-for-land-based-environment-and-climate-goods-and-services, accessed 30 July 2024), soil data projects (Environment Agency 2023a, https://www.gov.uk/government/speeches/the-big-soil-stocktake-closing-the-data-gap, accessed on

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24 April 2024), and the upcoming Land Use Framework (Environment Food and Rural Affairs Committee, https://committees.parliament.uk/publications/42415/documents/210844/default/accessed on 29 May 2024). This recent recognition of the importance of healthy soils is reassuring; however, action is needed to ensure the UK's soils are fulfilling their potential. Additionally, recognition of the pivotal role played by microbiology in achieving soil health is lacking, and is of concern to AMI's experts, especially given the need for transdisciplinary efforts, as noted by the UK government, in tackling globally important issues. In response, AMI aims to ensure that the role of microbiology is recognized among decision-makers by showcasing microbial life as the (often untapped) source of potential it is for delivering healthy soils and the benefits such soils would reap.

In 2023, AMI hosted an event at the John Innes Centre in the UK on 'The Power of Microbes in Sustainable Crop Production'. The event focused on the impact of microbes in national agricultural settings and food security. Event discussions identified potential microbial solutions to deploy in support of national scale soil regeneration and emphasized the benefits of promoting a nation-wide microbiome approach to soil health. Although efforts towards taking such an approach are still in their infancy, available evidence shows a microbiome approach holds promise, and as such its potential is explored throughout this report.

The aim of this report is therefore to

- highlight the opportunity of taking a nation-wide microbiome approach to soil health, explaining why this could be beneficial over current approaches and how such an approach could be implemented in the UK; and
- propose microbial solutions that can be deployed now—if supported by UK policymakers and key industry players—to improve the UK's soil health, whilst exploring and building the basis for a microbiome approach.

It is essential that the UK government and industry use the latest scientific evidence to inform their decision-making and actions, recognizing the long-term benefits that would come from a short-term investment into altering current agricultural practices (Evans et al. 2020). However, AMI recognizes that scientific evidence may not always translate perfectly to real-world settings. This report is designed to encourage improved dialogue between evidence generators and potential end-users, to enable the discovery of effective and viable solutions that will positively impact soil health both nationally and internationally.

The current state of the UK's soils

Agricultural land in the UK occupies 70% of the country's land mass but only 36% was considered croppable in 2023 (Department for Environment Food & Rural Affairs 2023d, https://www.gov.uk/government/statistics/agricultural-land-use-in-the-united-kingdom/agricultural-land-use-in-united-kingdom-at-1-june-2023, accessed on 4 April 2024). Cereals—which are known to majorly deplete nutrients in soils—constituted 71% of the crop area (Department for Environment Food & Rural Affairs 2023d, https://www.gov.uk/government/statistics/agricultural-land-use-in-the-united-kingdom/agricultural-land-use-in-united-kingdom-at-1-june-2023, accessed on 4 April 2024). Additionally, despite recent diversification in soil use and agriculture, most farming practices are mechanized and involve large quantities of agrochemical inputs such as artificial fertilizers and pesticides. These practices—which underpin the UK's approach to soil use—are unsustainable, as evidenced by the diminishing returns in productivity observed in some regions of the UK as a result; returns that are predicted to diminish further with climate change (https://www.gov.uk/government/statistics/total-factor-productivity-of-the-agricultural-industry/total-factor-productivity-of-the-united-kingdom-agricultural-industry-in-2023, date last accessed 4 April 2024; Environment Agency 2023b, https://www.gov.uk/government/publications/state-of-the-environment/summary-state-of-the-environment-soil, date last accessed 30 April 2024).

The role of microbes in soil and the soil microbiome

Soil is a combination of minerals, plant, animal and microbial residues (known as soil organic matter), living organisms (including macro- and microorganisms), gas and water (Needelman 2013). The greatest biodiversity within soils comes from the microorganisms (or microbes) that inhabit them; one teaspoon of topsoil is thought to contain ~1 billion cells and ~10 000 different species of microbe (Centre for Ecology and Hydrology, https://www.ceh.ac.uk/why-do-soil-microbes-matter, date last accessed 10 April 2024). The microbes that inhabit soils include bacteria, fungi, protozoa, viruses, and archaea, which as well as comprising a huge part of soils, have essential roles and functions including but not limited to:

- removing contaminants such as pollutants and heavy metals,
- carbon sequestration and storage, helping to mitigate climate change,
- plant protection by helping to improve resilience to stressors and pathogens,
- improving nutrient availability for plants, boosting crop quality and productivity,
- improving soil structure and preventing erosion,
- regulating water and air quality.

This complex community of microbes and their interactions are defined as the soil microbiome (Parliamentary Office of Science and Technology, https://post.parliament.uk/research-briefings/post-pn-0601/, date last accessed 12 May 2024). Soil comprises the planet's most diverse and intricate microbiome, forming a reservoir of beneficial and pathogenic microbes. Since microbes act as a link between different organisms and ecosystems (including humans, animals, plants, and the environment) the soil microbiome plays a crucial role in shaping microbial communities across the One Health spectrum. Consequently, the soil microbiome should be viewed as a cornerstone for taking a holistic view and approach to health across all aspects of life, as healthy soils are invaluable to fostering healthy ecosystems elsewhere (Banerjee and Van Der Heijden 2023).

One of the challenges to do so however, is that despite knowing some of the key roles soil microbes play, very little detail of their diversity, the extent and complexity of their functions, and their interactions with the environment and one another is known (Buckley and Schmidt 2003, Baldrian 2019). This is problematic, as current approaches and initiatives for improving soil health are not factoring in these complexities. Current approaches and initiatives therefore risk affecting the soil microbiome in a negative way, or at the very least are not utilizing soil microbes and their functions to their full potential. To circumvent this, AMI proposes taking a standardized, holistic microbiome approach to soils across the UK, to better capture the complexity of soils and enhance the beneficial functions that their microbial inhabitants offer.

A microbiome approach to soil—a long-term solution

Taking a microbiome approach to soils requires understanding and utilizing the varied groups of microbes that reside within soil ecosystems to enhance soil health and consequently agricultural productivity and environmental sustainability (Dubey et al. 2019, Suman et al. 2022). This approach would acknowledge that soil serves as more than just a platform for plant growth, it would also acknowledge its vital roles in waste removal, climate change mitigation, nutrient cycling, disease suppression, and more; roles that directly relate to national and global goals including achieving net zero, food security, and global health and wellbeing.

To establish a microbiome approach in the UK, a comprehensive strategy encompassing research, education, policy support, and practical implementation would be necessary. Here, we outline a series of recommended actions that would help to establish and maintain such a strategy over a prolonged period:

(1) Study and monitoring: perform extensive studies to define the soil microbiome in different locations throughout the UK and better understand its dynamics.

The initial advances that have been made in soil research, alongside the increased awareness of the soil microbiome's role in global health, highlight the need for further investigation into the potential of soil microbes. The research community stands on the brink of discovering essential information that will determine how the UK's soils can be restored and protected for future generations to come. Resources (including funding) to support continued investigation is critical to ensure the UK's efforts to date are not wasted. A lack of comprehensive knowledge about soil microbiomes and their interactions is the first hurdle to overcome in facilitating a microbiome approach for supporting sustainable soils. Performing regular monitoring of soil microbe populations and their reactions to management approaches will also be essential for making well-informed decisions to ensure the long-term viability of a microbiome approach to underpin sustainable soils.

(1) Educational and outreach initiatives: inform farmers, land managers, legislators, and the public on the significance of soil microbiomes and the possible advantages of utilizing microbiome-based methods. Deliver training and incentives to encourage the adoption of behaviours that are beneficial to the soil microbiome. This will require policy support to overcome concerns and scepticism from farmers and land managers.

(2) Policy support: Establish and modify regulations that provide incentives and assistance for farming methods that promote a healthy soil microbiome. More details on such methods can be found in the second half of this report. Major agricultural policies and projects should be reviewed and amended where possible, to ensure they incorporate any concerns around practices that negatively impact the soil microbiome, to enable a transition towards more sustainable practices.

The need for these reviews is emphasized by AMI's recent review of the Sustainable Farming Incentive (SFI); international microbiology experts flagged concerns around the lack of microbial considerations within the initiative which greatly reduce the potential benefits that could be reaped from the SFI, and which even risk it becoming counterproductive in some circumstances. This highlights the urgent need to start formulating policy decisions and initiatives with better transdisciplinary input, to prevent the risk of future developments needing revision. An adaptive, flexible framework will be necessary to allow new evidence to be incorporated into existing strategies and policies.

(1) Technology and innovation: allocate resources towards the advancement of soil health promoting alternatives to current agricultural practices (such as microbial inoculants, biofertilizers, biopesticides) by protecting funding that supports research and development in this area. Investment will also be needed to explore the scalability and efficacy of a microbiome approach once it is initially established, and regulatory approval of such an approach will need consideration to ensure its implementation.

(2) Collaboration and networking: promote cooperation among scientists, farmers, industry stakeholders, and policymakers to facilitate knowledge exchange and dissemination and a joint approach to developing solutions. Create and foster networks and collaborations focused on promoting the study and implementation of microbiome research in soils across the UK. In particular, through collaboration with researchers, businesses can actively support international legislation, evaluate their soil risks and impacts, and make investments to safeguard and improve soil health (Davies 2017). Encourage a holistic, collaborative, and transdisciplinary approach to the UK's soils, involving all relevant parties from the get-go to avoid future redundancy or revision.

Intermediary solutions to improve soil health

AMI acknowledges that a microbiome approach to support sustainable soils is in its infancy and that sufficient time and effort is required to build and implement this approach nationally. However, that does not mean that action cannot be taken in the meantime to increase the health of UK soils, using the available evidence on soil microbes and their functions. This report outlines some of the solutions that are available to be deployed now, or that can be with minimal investment. With the global market for agricultural biologicals (such as biofertilizers and biocontrol agents) reaching a value of $14.6 billion in 2023 and projected to reach $27.9 billion in 2028, this is an area which the UK can and should capitalize on (Markets and Markets, https://www.marketsandmarkets.com/Market-Reports/agricultural-biological-market-100393324.html, date last accessed 2024).

Alternatives to artificial fertilizers

The term 'biostimulant' refers to 'substances and/or microorganisms that stimulate natural plant processes' (Agriculture and Horticulture Development Board, https://ahdb.org.uk/biostimulants, date last accessed 12 April 2024). These products reduce the need for fertilizers while increasing plant growth and resistance to water and other abiotic stresses. When used in small concentrations, these substances are highly effective in promoting the plant's vital processes and achieving high yields of good-quality produce. If the entire European Union adopted the use of biostimulants, it could potentially reduce nitrogen use by 517 000 tonnes. In addition, when biostimulants are applied, there is a 5%–25% increase in fertilizer use efficacy, a 10%–15% reduction in pesticide use, and a 5%–10% minimum increase in crop yields (Osorio-Reyes et al. 2023).

Biofertilizer

Microbes can be used as alternatives to artificial fertilizers (Bhattacharyya et al. 2020, Milton et al. 2020, Osorio-Reyes et al. 2023). For example, nitrogen-fixing bacteria have been shown to present an effective alternative to artificial fertilizers for legumes (Mahmud et al. 2020). These biofertilizers present an excellent alternative to artificial fertilizers, which are known to adversely impact soil by hardening it and reducing soil fertility (Pahalvi et al. 2021), causing soil compaction and erosion that negatively impacts soil structure. Artificial fertilizers are also known to contribute to climate change through greenhouse gas emissions linked to their direct use and transportation, cause harmful algal blooms in water systems via eutrophication If over applied and even be counterproductive to plant growth due to their impact on soil acidification (Parliamentary Office of Science and Technology, https://post.parliament.uk/research-briefings/post-pn-0710/, date last accessed 10 May 2024). Although biofertilizers alone would not meet food security needs, at a minimum biofertilizers could be used to supplement and therefore reduce artificial fertilizer use.

Using native microbes more effectively is a solution that uses local resources and builds local knowledge and skills regarding soil health management; the latter being an area the Environment, Food, and Rural Affairs Committee has acknowledged the Government should support (Environment Food and Rural Affairs Committee, https://committees.parliament.uk/publications/42 415/documents/210 844/default/, date last accessed 29 May 2024). To increase their attractiveness to UK industry, efforts to enhance biofertilizer reproducibility, shelf-life and storage are needed and care around introducing non-native microbes to soil microbiomes should be considered (Ahmad et al. 2018, Environment Food and Rural Affairs Committee, https://committees.parliament.uk/publications/42415/documents/210844/default/, date last accessed 29 May 2024). The regulation of biofertilizer usage should be carefully applied to ensure environmental safety alongside encouraging ongoing innovation. The issue of cost (for example around transportation and production) also presents one of the largest challenges that needs to be overcome (Kurniawati et al. 2023).

Microbial inoculants

Beneficial native microbes can also be utilized as inoculants to enhance nutrient uptake in soil. For example, by isolating specific species that solubilize desired minerals, these can be amplified in areas of soil where they are lacking. A further benefit of microbial inoculants is the role of some species in bioremediating soils that have been previously polluted by harmful chemicals (such as pesticides) (Raffa and Chiampo 2021), as well as their potential to replete soils left devoid of microbes from artificial fertilizer (and pesticide) use, indicating their multi-pronged utility in improving soil sustainability.

Plant-growth-promoting rhizobacteria (PGPR) and Arbuscular mycorrhizal fungi (AMF) are key classes of beneficial microbial inoculant. AMF form symbioses with plant roots, facilitating nutrient exchange and enhancing resilience to stressors (Ab Rahman et al. 2018). PGPRs include both symbiotic and free-living nitrogen-fixing and phosphorus-solubilizing species, alongside bacteria with diverse plant growth-promotion and bioremediation characteristics (Gouda et al. 2018). Both PGPR and AMF-based products are available commercially to farmers to help boost productivity; however, the market share of both product classes is currently only a small fraction of the conventional agrochemical market. More support is needed to enable the continuation of research efforts to refine this technology and to increase consumer confidence (Malgioglio et al. 2022, Salomon et al. 2022, Watts et al. 2023). Better communication is required between researchers and the regulatory sphere to help translate initial ideas, for example around quality management frameworks (Parliamentary Office of Science and Technology, https://post.parliament.uk/research-briefings/post-pn-0601/, date last accessed 12 May 2024), into implementable structures.

Biochar

Biochar is formed by heating organic matter (known as feedstock) to temperatures of 250°C or above. Heating organic matter to these temperatures produces energy-rich gases and liquids as well as charcoal (or char) (UK Biochar Research Centre, https://www.biochar.ac.uk/what_is_biochar.php, date last accessed 29 March 2024). Applying biochar to soil improves soil structure, increasing nutrient availability and acts as a nutrient source as it contains most of the essential plant nutrients (Bolan et al. 2022). It also decontaminates soil by removing heavy metals and other toxic contaminants, increases carbon fixation, minimizes greenhouse gas emissions and improves water retention, which positively impacts plant growth (Ennis et al. 2012, Verde and Chiaramonti 2020, Yadav et al. 2023). Not only this but applying biochar to soils also increases the activity of soil microbes, enhancing the beneficial functions of the soil microbiome (Orr et al. 2021). Biochars can also be inoculated with specific microbes to provide the desired soil function.

Technically any organic product—including animal and crop waste—can be used as a source for biochar production, thereby biochar production and use has the additional advantage of reducing waste. Although different types of organic matter have different efficiencies that need considering, there is a further advantage that local waste products can be used for biochar production, facilitating waste management by reducing infrastructure demands and transport needs.

Some barriers to widespread biochar implementation include the need to consider the feedstock and conditions used to make biochar, mitigation against the risk of increasing greenhouse gas emissions (Steiner et al. 2016), the need for more long-term assessments of its influence, efficacy in real-world settings and suitability as a sustainable habitat for microbes (Quilliam et al. 2012, Quilliam et al. 2013). However, since biochar reduces the need for artificial fertilizers it should be further explored by policymakers (Parliamentary Office of Science and Technology, https://www.parliament.uk/globalassets/documents/post/postpn358-biochar.pdf, date last accessed 10 May 2024; https://randd.defra.gov.uk/ProjectDetails?ProjectId=18113, date last accessed 3 April 2024) to help farmers move to more sustainable practices.

Biological control agents

Pesticides are used to control agricultural pests. Much like artificial fertilizers, artificial pesticides can have negative impacts on soil health and the environment, in part due to their impact on the soil microbiome (Hussain et al. 2009, Alemayehu and Bitew 2017). Biological control agents (or 'biopesticides') such as bacteria, fungi, viruses, and protozoa offer a sustainable alternative to these harmful products in combatting crop pests (Bonaterra i Carreras et al. 2022, Wagemans et al. 2022, Guzmán-Guzmán et al. 2023) and are particularly important to consider when rising incidences of disease are causing even neonicotinoid pesticides to be employed more regularly (Department for Environment Food & Rural Affairs and Spencer 2023, https://www.gov.uk/government/news/emergency-pesticide-authorisation-to-protect-sugar-beet-crop-conditionally-approved?utm_medium=email&utm_campaign=govuk-notifications-topic&utm_source=6e4c6aea-3975–47db-a85c-ecf83c86179f&utm_content=immediately accessed 3 April 2024). The six-year delay in the government's National Action Plan for Sustainable Pesticide Use (Science Innovation and Technology Committee, https://publications.parliament.uk/pa/cm5804/cmselect/cmsctech/326/report.html, date last accessed 16 May 2024), although very worrisome, does provide the opportunity to ensure more sustainable solutions such as biological control agents form its backbone.

Some of the main barriers to biopesticide uptake include their narrow spectrum of pest activity (and hence more restricted target markets) compared to conventional methods, as well as reaching the market in the first place, which involves a complicated, lengthy, and expensive regulatory process. In 2021, the UK Government announced plans to review many of its regulations post-Brexit, which presented an opportunity for the World BioProtection Forum to review regulations for biopesticides in the UK (World Bioprotection Forum, https://www.worldbioprotectionforum.com/regulatory-reform/, date last accessed 4 April 2024). To this end, they wrote an authoritative white paper to guide regulators, which was circulated to the Department for Environment, Food and Rural Affairs (Defra). A meeting was held at the Westminster Ministry in September 2023 (World Bioprotection Forum, https://www.worldbioprotectionforum.com/bringing-biopesticide-regulatory-reform-to-uk-parliament/, date last accessed 4 April 2024), that aimed to discuss regulatory reform in the UK, with promising results to date. The UK is the fifth largest biopesticide user after Spain, Italy, Germany, and France. The effect of regulations on biopesticide uptake by industry is evidenced in Brazil where the biopesticides market grew 45% over the last 5 years after a regulatory change (Embrapa 2024).

Modifying current techniques

Some traditional farming techniques have been shown to negatively impact soil health, such as conventional tillage. In contrast 'conservation agriculture' practices such as minimum or no tillage have been shown to improve soil microbial diversity and soil microbiome stability (Cárceles Rodríguez et al. 2022, Gupta et al. 2022). As such, a movement towards the former could help to increase the health of UK soils in the agricultural setting (Fig. 1). Several conservation agriculture practices worth considering include:

Minimum tillage and no-till farming

Minimum tillage or no-till farming minimize, or altogether avoid, soil disturbance. Implementing reduced tillage practices helps maintain the integrity of the soil structure and reduces disturbance to soil microbial communities, supporting functional biodiversity and improving the overall activity of the soil microbiome (Du et al. 2022). Although initially there may be a slight decline in productivity due to lower soil disturbance, the long-term advantages include enhanced soil health, greater water retention, and improved nutrient cycling. Consequently, productivity is either sustained or potentially increased over time and there are mitigation strategies farmers can implement to improve soil fertility and reduce initial declines in productivity, including crop rotations, cover cropping, and organic amendments.

Cover cropping

Cover cropping is a conservation agriculture practice that entails planting non-monetary crops either during fallow times or alongside cash crops to provide soil cover and protection. Cover crops contribute organic matter to the soil, promoting microbial activity and diversity (Vukicevich et al. 2016). In addition, they decrease erosion and nutrient loss (enhancing soil structure and fertility), inhibit weed growth, increase moisture retention, and can even reduce the need for artificial fertilizer by increasing nutrient availability, depending on the crop type used (e.g. leguminous cover crops) (Scavo et al. 2022). Although they may initially compete with cash crops for resources, potentially resulting in a decreased output, the long-term advantages ultimately lead to increased productivity (Hartwig and Ammon 2002). Optimal selection of cover crops and precise timing of planting can also effectively reduce competition with cash crops (Food and Agriculture Organization of the United Nations and Secretariat of the Convention on Biological Diversity, https://openknowledge.fao.org/server/api/core/bitstreams/bc83d0f5-63e1-4c66-995f-cd27036e513e/content, date last accessed, 30 May 2024).

Crop rotation

Crop rotation is a practice in which various crops are alternated in the same field across consecutive seasons or years. It has a significant impact on the soil microbiome since it disrupts the cycles of pests and diseases, decreases the presence of harmful soil microbes, and enhances positive interactions among beneficial microbes (Liu et al. 2022). As a result, soil health and resilience are increased. Implementing crop rotation may initially lead to decreased yields for certain crops, particularly when transitioning from monoculture; however, over time, it diminishes the presence of pests, enriches the

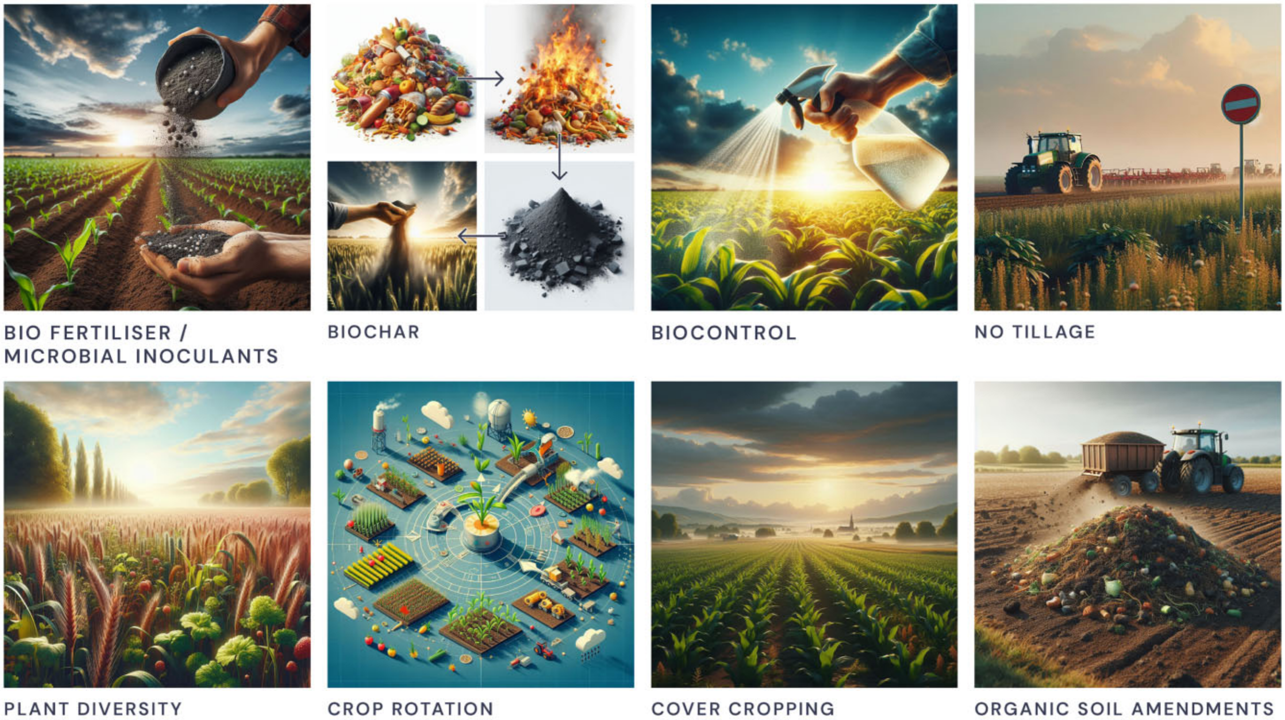

Figure 1. Interim microbial solutions, which can be deployed now to help address the current soil health crisis and increase the health of UK soils in the agricultural settings.

composition of the soil, and improves the accessibility of nutrients, finally leading to an increase in total output (Schöning et al. 2023). Enhancing crop rotations by diversifying and including legumes and other nitrogen-fixing crops can optimize the process of nutrient cycling and decrease variations in crop yield (Drinkwater et al. 1998).

Plant diversity

Different plant species support different microbial species (Chen et al. 2019). Different microbial species have different functions and services, therefore higher plant diversity in a given area encourages a more diverse soil microbiome in that area, enhancing the soil microbiome's ecosystem effects. For example, higher plant biodiversity has been shown to increase carbon storage within soils, a direct consequence of the plant diversity's impacts on the soil microbiome and its associated microbial activities (Lange et al. 2015). Having more plant species has also been shown to support soil microbes in counteracting toxic metal contamination (Stefanowicz et al. 2012) and in improving drought resistance (Li et al. 2022).

From this evidence, a simple—at least in terms of not requiring innovation—but highly effective change to common agricultural practices in the UK would be to reduce the use of monocultures and move towards interspersing different plant species across agricultural land, for example through diversified crop rotations (Iheshiulo et al. 2023) or cover crop choice (Saleem et al. 2020, Wang et al. 2020). This is not a new concept for the UK Government, as shown by the 2019 brief by the Parliamentary Office for Science and Technology entitled 'Reducing the environmental and biodiversity impacts of agriculture' (Parliamentary Office of Science and Technology, https://post.parliament.uk/reducing-the-environmental-and-biodiversity-impacts-of-agriculture/, date last accessed, 12 May 2024). Some encouraging signs around this solution have been noted in the government's Environmental Land Management schemes, such as support for farmers to plant and maintain hedgerows; however, there is significant scope for more to be done.

Organic soil amendments

Organic soil amendments refer to the act of adding organic materials, such as compost, manure, or agricultural leftovers, to the soil to enhance its fertility and structure. These additions serve as a carbon and nutrient supply for soil microbes and also encourage carbon sequestration (Bhattacharyya et al. 2022), which in turn promotes their growth, overall diversity and activity as well as their ability to retain water, resulting in higher crop yields and enhanced resilience to environmental pressures. Organic soil amendments can therefore reduce the reliance on artificial fertilizers. Employing appropriate composting techniques and adhering to recommended application rates in combination with soil nutrient testing will effectively prevent nutrient imbalances and promote optimal soil health. However, care needs to be taken with this approach to ensure unwanted compounds (and their negative effects) within amendments are not applied or encouraged (Urra et al. 2019). For example, manure can often contain antibiotic residues and potential pathogens that can enforce selective pressure on soil microbes and induce antibiotic resistance (AMR). Ecotoxicological assessments should therefore be used as a risk assessment for the potential effect of organic soil amendments on the soil microbiome and consequently soil health. Care should be taken to ensure such assessments consider mixtures of antibiotics rather than the effects of single compounds since mixtures are what exist in the environment.

To summarize, conservation agricultural approaches have numerous advantages for soil health and productivity compared to conventional systems. Although there may be temporary decreases in productivity during the transition phase, the long-term benefits such as improved soil fertility, water retention, and pest management outweigh these disadvantages. By strategically implementing conservation agriculture techniques and employing suitable mitigation strategies, farmers can optimize productivity, support sustainable land management, and safeguard the soil microbiome.

Future considerations

As renewable technologies and infrastructure develop within the UK, it is important to remember that soilless farming techniques may help relieve the pressure on soils in the future. Although this avenue does not present a fully sustainable option yet due to its large energy footprint, organizations such as the World Wide Fund for Nature (WWF) are piloting projects to determine how these issues could be circumvented to unlock the potential of soilless systems in terms of decreasing pressures on land, biodiversity, and climate change (World Wildlife Fund 2022, https://www.worldwildlife.org/publications/indoor-soilless-farming-phase-ii-moving-from-theory-to-action, date last accessed, 11 April 2024).

Conclusion

There is a delicate balance between restoring the health of the UK's soils whilst maintaining sufficient food security. However, historic and current approaches/practices have been, and are, heavily weighted towards the latter. It is understandable that a potential drop in productivity is undesirable both to producers and the government; however, evidence suggests this would represent an initial short-lived challenge to address in the face of much needed industrial change. AMI therefore urge the UK government to consider the long-term sustainability of the UK's agricultural industry and beyond, since healthy soils will be key in reducing the impacts of climate change, feeding a growing nation, protecting the health of humans, animals, and the environment as well as provide the backbone for supporting a thriving biodiverse landscape for future generations. The alternative to facing these initial, short-term setbacks is a nation with soils that—in the not-too-distant future—will no longer be able to function.

AMI strongly advocates that the UK government support the UK agricultural industry in implementing, as a bare minimum, the microbial solutions outlined in the latter half of this policy report to help address the current soil health crisis. Many of these solutions can be implemented immediately, making them valuable in addressing this urgent issue. AMI will continue to promote the potential, untapped value of adopting a microbiome approach to support sustainable UK soils. This is an exciting opportunity to advance the UK's status as a science superpower by pioneering this new approach towards soil health on the global stage.

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Generative artificial intelligence was used to help create the images of interim microbial solutions for UK soil health displayed in Fig. 1.

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Data availability

No new data were generated or analysed in support of this policy-in-practice paper.

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