House of Commons Environmental Audit Committee: UK Soil Health Inquiry

Microbiology Society Written Evidence

Microbiology Society

1. The Microbiology Society is a membership organisation for scientists who work in all areas of microbiology. It is the largest learned microbiological society in Europe, with a worldwide membership based in universities, industry, hospitals, research institutes and schools. The Society publishes key academic journals, organises international scientific conferences, and provides an international forum for communication among microbiologists and supports their professional development. The Society promotes the understanding of microbiology to a diverse range of stakeholders, including policy-makers, students, teachers, journalists and the wider public, through a comprehensive framework of communication activities and resources.

Introduction

2. Soils are estimated to hold a quarter of the world's biodiversity. This biodiversity, of which micro-organisms are a major component, is essential for terrestrial life and the ecosystem services which human society relies upon[1,2]. Typically, one gram of soil contains over a billion bacterial cells and over 10,000 species of bacteria, as well as numerous viruses, fungi, archaea and protozoa.
3. These micro-organisms are important for the formation, fertility, structure and stability of soils, and help deliver numerous essential ecosystem services, including: nutrient cycling and climate regulation; plant growth and agricultural production; water purification and regulation; and pollutant and contaminant. Soil micro-organisms are an important resource that can be harnessed to improve the health of soils (e.g. biofertilisation, pathogen

[1] Turbé, A. *et al.* (2010). *Soil biodiversity: functions, threats and tools for policy makers.* Bio Intelligence Service, IRD, and NIOO, Report for European Commission (DG Environment). Link last accessed: 28/01/2016.

[2] Bardgett, R. D. & van der Putten, W. H. (2014). Belowground biodiversity and ecosystem functioning. *Nature* **515**, 505-511.

suppression, bioremediation) and for other societal benefits (e.g. pharmaceuticals). Consequently failing to protect soil health, including microbial biodiversity, can impact the ability of soils to deliver these vital ecosystem services.

4. The Microbiology Society recently published two briefings[3,4] and a topical issue of *Microbiology Today*[5], which summarise the importance of, and issues relating to, soil microbiology and microbiological research in this area.

5. Measuring and monitoring microbial indicators of soil health is important because of the intrinsic role soil micro-organisms play in soil formation and maintenance, and the delivery of key ecosystem services. Different microbiological measures may, for example, provide an indication of the capacity of soils to recycle nutrients, store organic matter, release greenhouse gases, degrade pollutants, and affect crop yields. Some microbiological indicators can also help us to understand physiochemical properties of soils that can be difficult to measure directly or over longer periods. Such microbiological evidence is important to inform policy, and to develop and optimise soil management practices and biotechnologies to improve soil health and ecosystem service provision.

6. Universally defining and measuring soil health is challenging. While soil must be fit for purpose, from both a microbiological and broader perspective, what is considered 'healthy' varies extensively by soil type, function of interest, and from the perspective of different users. For example, a soil considered healthy for wheat cultivation might not be considered healthy for forestry, grazing or bioremediation. A well-fertilised soil might be good for crop growth but considered unhealthy with regards to fertiliser pollution. A range of microbial, and other, soil health indicators and baselines are needed, which are specific to different soil types and functions.

7. Our evidence focuses on soil microbiology and the importance of microbiological science. However, it is important to understand that soil health is determined by interactions between biological, physical and chemical components, including microbes and larger life forms that make up soil biodiversity. Indeed, the biodiversity and activity of soil microbial communities relies on interactions with other organisms and the local physiochemical environment. Soil monitoring and management strategies must utilise multiple indicators of, and seek to protect, all of the components of healthy soils. An interdisciplinary approach to soil research and management is vital.

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[3] Microbiology Society (2015). *Briefing: Food Security from the Soil Microbiome*. http://www.microbiologysociety.org/policy/briefings.cfm/publication/food-security-from-the-soil-microbiome.

[4] Microbiology Society (2015). *Briefing: Microbiology and Climate Change*. http://www.microbiologysociety.org/policy/briefings.cfm/publication/microbiology-and-climate-change.

[5] Microbiology Society (2015). *Microbiology Today: Soil. Microbiology Today* 42:2. http://www.microbiologysociety.org/publications/microbiology-today/past-issues.cfm/publication/soil.

Benefits of soil microbiology to society and resulting consequences of failing to protect soil health

Nutrient cycling and climate change

8. Soil micro-organisms play a fundamental role in cycling nutrients, including carbon, nitrogen and phosphorus, which are essential for plant growth, and therefore terrestrial life[4,6]. Decomposing soil bacteria and fungi play a key role in the formation, maintenance and breakdown of soil organic matter. The biomass of micro-organisms in soils is itself an important component of the total carbon stored in soils[1]. Soil micro-organisms also convert nutrients, including nitrogen and phosphorus, into forms that are usable by plants and other organisms.

9. Nutrient-cycling micro-organisms naturally use and emit key greenhouse gases, notably carbon dioxide, nitrous oxide and methane. There is evidence that soil degradation and disturbance (e.g. land use change; some intensive farming practices) can enhance microbial decomposition of soil organic matter and consequently the release of carbon dioxide and methane from microbial respiration. Climate change could also potentially enhance microbial respiration in some soils[4,6]. Understanding how soil micro-organisms will respond to land use pressures and climate change is a complex and important research challenge.

10. An important global issue is the release of nitrous oxide from agricultural soils, as a consequence of enhanced microbial nitrification and denitrification, driven by the inefficient application of nitrogenous fertilisers[4,6,7]. Agriculture is estimated to contribute 84% of UK nitrous oxide emissions[8]. Microbial nitrification also produces nitrates, which can leach or run off into water courses causing environmental damage through eutrophication.

11. Managing soil microbial biodiversity and activity, through better soil management, is therefore critical to contribute to climate change mitigation and resilience[4,6,7,8]. For example, it is important that farms monitor nitrogen use and utilise management plans[8]. Microbiologists are also investigating how to improve the efficiency of nitrogen use and reduce the need for synthetic fertiliser inputs[4]. One area is optimising the use in cropping systems of legumes, which supply nitrogen biologically through symbiotic relationships with nitrogen-fixing bacteria. Microbiologists are investigating how crops associate with and affect communities of soil micro-organisms. Harnessing this knowledge could, for example,

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[6] Singh, B. K. *et al*. (2010). Microorganisms and climate change: terrestrial feedbacks and mitigation options. *Nature* **8**: 779−790.

[7] Reay, D. S. et al. (2012). Global agriculture and nitrous oxide emissions. *Nature Climate Change* **2**: 410-416.

[8] Parliamentary Office for Science and Technology (2015). *POSTNote 486: Emissions from Crops*.

enable us to develop crop varieties that produce good yields under lower nitrogen input conditions, or that biologically inhibit denitrification.

Food security and agriculture

12. Micro-organisms are vital for agricultural production[3,9]. Microbes that form associations with plant roots and free-living soil microbes can contribute to crop growth and soil health by:

    - Cycling nutrients that are essential for plant growth (e.g. nitrogen, phosphorus and sulphur).
    - Improving soil structure and organic matter content, which are important for fertility, water retention and minimising soil loss to erosion.
    - Conferring disease resistance to crops by outcompeting pathogenic microbes and stimulating biochemical plant defences.
    - Improving the resilience of plants to environmental stresses, such as fluctuations in temperature and moisture.
    - Enhancing root growth and nutrient uptake.

13. Unsustainable intensive farming methods (e.g. high tillage and continuous cropping), and the selection of crop varieties that are less able to associate with beneficial soil micro-organisms, such as arbuscular mycorrhiza fungi, may negatively affect, and underutilise, soil microbial biodiversity and the services it provides; this may impact agricultural productivity and could contribute to related issues such as soil loss to erosion and reduced water and nutrient retention[3].
14. For example, practices that affect microbial soil biodiversity can increase the susceptibility of crops to soil-borne diseases[3]. The build-up of soil-borne pathogens under intensive cropping regimes is thought to be a driver of oilseed rape yield decline, which can cause 6-25% declines in annual yield. Take-all is a serious fungal root disease of wheat, which appears in the second or third year of continuous cropping. It is estimated to affect half of UK wheat crops, reducing yields by an average of 5–20%, costing tens of millions of pounds each year.
15. Microbiologists are investigating potential approaches that farmers could use to harness the soil microbiome as a tool to suppress pathogens and enhance crop growth[3,9]. Research themes include: understanding what microbes are present, what their function is, and how they interact with plants; promoting crop-microbe associations through inoculating soils with beneficial micro-organisms or developing crop varieties that better associate with soil

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[9] Microbiology Society (2011). *Position Statement on Food Security and Safety*. http://www.microbiologysociety.org/publications/policy-docs.cfm/publication/2011-food-security-and-safety.

micro-organisms; and investigating optimal soil management regimes (e.g. crop rotation, intercropping and reduced-tillage) that promote beneficial microbial biodiversity.

Water purification and regulation

16. Soil micro-organisms play an important role in water purification and the regulation of soil water uptake and storage[1,10], which is important for agriculture and mitigating flooding risks. Fungal mycelia and microbial compounds help to stabilise soil aggregates contributing to drainage, but can also affect soil water repellency. Interactions between roots and mycorrhizal fungi, and also root pathogens, can affect water uptake by plants.

Bioremediation and geomicrobiology

17. Micro-organisms play an important role in degrading soil and groundwater pollutants and contaminants into non-toxic molecules[1]. Bioremediation methods, which stimulate these microbial processes to treat contaminated soils (e.g. hydrocarbon and metal pollution from industrial activity) in situ or ex situ, have been used, and continue to be researched and developed[10,11].
18. Soils play an important role in supporting urban infrastructure, for example providing structural support of buildings, and acting as buffers against flooding and contamination. Soil micro-organisms may contribute to soil stability and permeability by facilitating geochemical processes such as the precipitation of minerals. The potential to harness this geomicrobiology to increase the load bearing capability and liquefaction resistance of soils, and ground water flow control is beginning to be explored[12].

Human Health

19. Human health is benefitted by soil microbial biodiversity in a number of ways[1,13], including supporting ecosystem services such as food production and water cycling, and suppressing soil borne human pathogens.
20. Environmental and land use change, and poor soil management can impede the ability of the soil microbiome to support these services[1,12]. For example, a report by the European Commission Joint Research Council[14] highlighted that more research was needed into soil-borne human diseases, including how land management, land use change and climate change could affect their incidence.

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[10] Rillig, M. C. *et al.* (2010). Mycelium of arbuscular mycorrhizal fungi increases soil water repellency and is sufficient to maintain water-stable soil aggregates. *Soil Biology and Biochemistry* **42**: 1189-1191.

[11] DEFRA (2010). *Defra Research Project Final Report SP1001: Contaminated Land Remediation*.

[12] DeJong, J.T. *et al.* (2010). Bio-mediated soil improvement. *Ecological Engineering* 197-210.

[13] Wall, D. H. *et al.* (2015). Soil biodiversity and human health. *Nature* **528** 69-76.

[14] Jeffery, S. & van der Putten, W. H. (2011). *JRC Scientific and Technical Report: Soil Borne Human Diseases*. European Union.

21. Soil is a well-validated habitat for identifying a wide range of micro-organisms that produce bioactive metabolites (secondary metabolites) with important applications in human and veterinary medicine. For example, 60% of clinically important antibiotics are derived from Actinobacteria. Recent research in the USA used a new approach to isolate previously unculturable soil bacteria, which resulted in the discovery of a new antibiotic called Teixobactin[15]. The Microbiology Society Small World Initiative science engagement project is providing the general public, students and educators in the UK and Ireland the opportunity to work with scientists as part of a global initiative to discover new antibiotics from soil bacteria.

22. Antimicrobial drug resistance has emerged a key national and global public health policy issue, which also links in part with agricultural and environmental policy[16]. Environmental levels of drug-resistant bacteria have been increasing due to antibiotic use in humans and animals. Therefore, an important area of research relating to soil microbiology and soil health is detecting and monitoring environmental reservoirs and transmission routes of antimicrobial drug-resistant micro-organisms.

Measuring and monitoring microbial indicators of soil health

23. Microbiological indicators of soil health include measuring microbial taxonomic diversity and abundance (biodiversity), microbial biomass, and measuring indicators of microbial function (e.g. respiration; nitrification). Measures of microbial diversity and activity might be considered in relation to:

    - Specific organisms, such as plant pathogens, biocontrol agents and plant growth-promoting rhizobacteria, that perform specific functions (desirable or undesirable), often in association with specific plants.
    - Functional microbial groups that perform broader soil functions, such as ammonia oxidisers, nitrate oxidisers and degraders of specific pollutants.
    - The 'total' soil microbial community or 'soil microbiome' for a particular environment, which encompasses a wide diversity of potential indicators, many of which are likely to be, as yet, uncharacterised.

24. Advances in high-throughput sequencing have revolutionised the ability of microbiologists to characterise soil microbial communities through a technique called metagenomics. Total microbial DNA can be extracted from a soil sample and the taxonomic diversity and abundance of different micro-organisms can be assessed using methods including high-

[15] Ling, L. L. *et al.* (2015). A new antibiotic kills pathogens without detectable resistance. *Nature* **517**, 455-459.

[16] Parliamentary Office of Science and Technology (2013). POSTnote 446: Antibiotic Resistance in the Environment.

throughput DNA sequencing, quantitative polymerase chain reaction and bioinformatics. Measuring the presence and abundance of known functional gene sequences or RNA (e.g. sequences related to nitrification) can provide an indication of microbial activity and function. Such measures may also help us to understand physio-chemical properties of soils that can be difficult to measure directly or over longer periods.

25. In the same way metagenomics and molecular characterisation done on the human microbiome project is revealing how human health is related to the associated microbial community, it is likely that understanding the soil microbiome will lead to greater understanding of soil health and yield new ways of managing our soils for healthier and more sustainable natural and productive ecosystems.

26. Another way of assessing abundance and activity is to measure the release of carbon dioxide from soils due to microbial respiration; this can also potentially be used to monitor rates of decomposition of soil organic matter. A full-spectrum of other gases released by microbial processes (e.g. methane, nitrous oxide and other trace gases) may provide assessments of the abundance and/or activity of particular functional groups of micro-organisms.

27. Efforts have been made to identify microbial indicators, and other biological indicators, of soil composition and health, which could be employed in standardised soil monitoring programmes[17,18,19]. Some national-scale surveys of soil microbial biodiversity have also been carried out in the UK[20,21]. For example, molecular approaches have been applied to soils collected from the Countryside Survey to reveal the first map of bacterial distributions across Britain[21]. This study revealed how microbial communities are strongly affected by both natural geological and climatic factors as well as land use change.

28. More broadly, DNA- and RNA-based methods, and other approaches, for measuring soil microbial biodiversity and function are widely used in fundamental and applied research into understanding soil microbiology in relation to specific environments, ecosystem services and issues. Some examples of UK research involving Microbiology Society members include:

- Research into understanding agricultural soil microbiomes and how to manipulate them through soil management or biotechnology to improve crop yields[3].

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[17] Black, H. I. J. *et al.* (2011). *Scoping biological indicators of soil quality Phase II. Defra Final Contract Report SP0534*. Defra.

[18] Ritz, K. *et al.* (2009). Selecting biological indicators for monitoring soils: a framework for balancing scientific opinion to assist policy development. *Ecological Indicators* **9**: 1212−1221.

[19] Stone, D. *et al.* (2016). Selection of biological indicators appropriate for European soil monitoring. *Applied Soil Ecology* **97**: 12−22.

[20] Yao, H. *et al.* (2013) Multi-factorial drivers of ammonia oxidizer communities: evidence from a national soil survey. *Environmental Microbiology* **15**: 2545−2556.

[21] Griffiths, R. I. *et al.* (2011). The bacterial biogeography of British soils. *Environmental Microbiology* **13**: 1642–1654.

- Investigating soil microbial diversity dynamics in relation to upland peat restoration in the Southern Pennines, an approach that could help inform future restoration projects[22].
- International research investigating the potential impacts of climate change on soil respiration and soil carbon stocks[23].
- Research showing that environmental antibiotic resistance gene abundances can correlate geochemical soil conditions, which suggests a potential broader use for soil geochemical data monitoring to inform epidemiological risk studies related to AMR transmission from the environment[24].

29. Despite advances in measuring and monitoring microbial biodiversity and function, particularly from advances in genomics, there are several challenges and needs that continue to be addressed with regards to understanding and monitoring microbial soil health:

- Standardised indicators and methods for monitoring microbial soil health are required. The extensive microbial diversity of soils makes it difficult to identify standard biomarkers (e.g. genetic markers) and correlate them with different soil types, water content and vegetation. Extensive variation in soils and their uses means that a variety of indicators must be developed and used.
- Monitoring programmes will require different baselines of microbial biodiversity and function to be established for different soil environments (e.g. different urban, agricultural and natural soils) and uses, so that a defined healthy and well-functioning soil microbial community for a given environment can be compared with any monitored sites. Continued research is needed to establish baseline data and standardised statistical approaches for mapping monitoring sites against baseline data.
- Linking change in soil biodiversity with change in soil function, and thus ecosystem services, remains a key challenge due to the complexity of soil ecosystems and methodological constraints. Continued research is needed to examine in more detail which specific micro-organisms are responsive to environmental change in different soil habitats, and determine how this context-specific change in diversity affects soil function.

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[22] Elliott, D. R. *et al.* (2015). Bacterial and Fungal Communities in a Degraded Ombrotrophic Peatland Undergoing Natural and Managed Re-Vegetation. *PLoS One* DOI: 10.1371/journal.pone.0124726.

[23] Karhu, K. *et al.* (2014). Temperature sensitivity of soil respiration rates enhanced by microbial community response. *Nature* **513**: 81–84.

[24] Knapp, C. W. (2011). Antibiotic Resistance Gene Abundances Correlate with Metal and Geochemical Conditions in Archived Scottish Soils. *PLoS One* **11**: e27300.

What measures are currently in place to ensure that good soil health is promoted? And what further measures should the Government and other organisations consider in order to secure soil health?

Policy

30. Current UK and EU policy relating to soil health has been effectively summarised in a recent POSTnote[25]. The current lack of a UK-wide soil monitoring scheme, no specific EU legislation on soils, and the importance of biological soil quality indicators was noted.
31. Existing Government policy documents regarding soils already recognise the need to protect UK soils and undertake research and action to address this[26,27]. It is important that measures suggested are taken forward and implemented in new Government strategies. Management of soils to retain and increase organic matter content, for example, would likely benefit microbial biodiversity, biomass and function, and associated ecosystem services.
32. The Food and Agriculture Organization of the United Nations recently published its *Status of World Soil Resources* report[28], which highlights the global importance of, and threats to, soils, and includes recommendations for policy-makers. A European Union report[1] summarises issues and tools for policy-makers that specifically relate to soil biodiversity.

Research and development

33. Fundamental and applied microbiological research can make an important contribution to understanding, monitoring and securing the health of UK soils. As illustrated by the diversity of examples provided above, soil microbiology research can increase our understanding of the biodiversity and function of soil microbiota and how these may be affected by human activities and climate change; inform management methods and policies to improve soil health and productivity; and potentially aid the development of biotechnologies to improve soil health.
34. Scientific skills and capabilities relating to microbiology, soil science, food security and agriculture have been identified as being vulnerable[9,29,30]. For example, given the importance

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[25] Parliamentary Office of Science and Technology (2015). *POSTnote 502: Securing UK Soil Health*.

[26] Defra (2009). *Safeguarding our Soils: A Strategy for England*.

[27] HM Government (2011). The Natural Choice: securing the value of nature.

[28] Food and Agriculture Organization of the United Nations (2015). *Status of the World's Soil Resources Technical Summary*. http://www.fao.org/documents/card/en/c/39bc9f2b-7493-4ab6-b024-feeaf49d4d01/.

[29] BBSC (2015). *BBSRC and MRC review of vulnerable skills and capabilities report*. http://www.bbsrc.ac.uk/about/policies/reviews/consultations/1501-vulnerable-capabilities-report/.

of new molecular methods now and in the future, bioinformatics is still a limiting skill and discipline that is needed to develop better understanding of the highly complex soil microbiome. Any strategy to secure UK soil health needs to consider the importance of continuing to improve and support the capabilities, sustainability and translation of UK soil science. Recently introduced government-funded research and training initiatives, including the Soil Security Research Programme, Soil and rhizosphere interactions for sustainable agri-ecosystems (GFS-SARISA) funding call, and the Soil Training and Research Studentships are examples of good practice in the respect. Investment in research and the next generation of soil microbiologists needs to be long-term and available to all institutes to expand and develop this area into the future as new challenges emerge.

What role (if any) should soil health play in the Government's upcoming 25 year plan for the natural environment?

Soil health policy should feature prominently in the Government's natural environment plan due to the intrinsic role of soils as a part of, and in sustaining, the natural environment and the ecosystem services they provide. Better understanding, protection and sustainable harnessing of UK soils will be important for resilience to challenges such as climate change, food security and antimicrobial resistance. The broad importance and complexity of soil health means that it is important that the Government engages a broad range of stakeholders, across science, agriculture, industry and the wider public, when developing and implementing policies for soil health.

Contact

Please contact Paul Richards, Policy Officer (policy@microbiologysociety.org; tel: 020 7685 2542) with any questions regarding this response or the activities of the Microbiology Society.

[30] *Joint response from the Society for General Microbiology and the Society for Applied Microbiology to the BBSRC/MRC Vulnerable Skills Consultation.* http://www.microbiologysociety.org/policy/consultation-responses.cfm/year/2014/.