POSTPRINT ACCEPTED FOR PUBLICATION IN MICROBIOLOGY ON NOV 21ST 2020

PERSONAL VIEW
van Keulen, Microbiology
https://doi.org/10.1099/mic.0.001001

Microbiology Challenges and Opportunities in Soil Health

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Background

The United Nations Sustainable Development Goals (UN-SDGs) are 17 global goals and 169 targets adopted by all UN Member States in September 2015 (United Nations, 2015). These targets follow on from the Millennium Development Goals, but have a greater breadth of activity and are substantially more ambitious. The goals aim to tackle major global challenges by 2030 and focus heavily on inequality and climate change. As scientists aiming to understand how things work and how we can exploit these underlying mechanisms to make the world a better place, many of us will feel we have an obligation to try and better focus our work in contributing to achieving some of the major challenges outlined in the UN-SDGs. Unsurprisingly, health and the environment also feature predominantly and microbiologists globally are constantly engaged in trying to address biological problems through innovative approaches and scientific method. The ongoing coronavirus pandemic aptly exposes the threat that infectious disease poses to humankind, but also highlights how science can respond rapidly and collaboratively to generate novel methods to reduce the impact of a disease. But how do we approach such daunting tasks and what exiting knowledge do we have that can be directly applied to the UN-SDGs?

The COVID-19 experience has been a lesson and a severe warning shot for the challenges we face. The lessons learned from different approaches adopted by governments globally will inform the response to other pandemics in the future. The current crisis has shown us that we must work as a community and to make our research ever more applied to address these longer-term threats to humankind such as pandemics, food security, environmental sustainability, and antimicrobial resistance (AMR). The Microbiology Society recognises these challenges and sees enormous potential in the microbiology research community in the UK and Ireland to jointly apply their skills in tackling these major global issues. Consequently, the Society created an expansive project entitled “A Sustainable Future” in 2019, which is working to define a principal role for microbiology in achieving relevant key aspects of the UN-SDGs. This is an ongoing mission and the scope of the UN defined goals is exceptionally broad and often interlocked. However, engagement with the Society’s membership identified three specific areas where the expertise of microbiologists in the UK and Ireland is particularly relevant. These areas are: *AMR*, which is widely recognised as one of the biggest threats to humanity; the *Circular Economy*, encompassing regenerative approaches aiming to maximise the most efficient use of the world’s finite resources; and *Soil Health*, which is essential to achieve sustainable health of ecosystems, the growing human population, and our economies.

The workshop

As opposed to dictating the agenda, as a Society we have continuously sought to engage with the community as much as possible to direct ideas and to focus efforts on the key expertise already held within its membership enhanced further by expertise from associated subject areas and sectors. As a

component of the Soil Health project we invited 33 participants from academia, research institutes, industry, farming, and social, regulatory and political institutions to a week-long workshop in the summer of 2020 to identify challenges and opportunities for microbiology in soil health. As many of the raised concepts may not be feasible given current structures we also asked what more could be done if there were fewer barriers, and what interventions would be needed to take the generated ideas to the next level.

Given this workshop was performed during the ongoing pandemic it was conducted online via four separate focus groups, each covering a specific area of soil health: Microbiology research and innovation; Interdisciplinary collaboration; Industry and farming; Social, policy, regulatory and political institutions.

Prior to the workshop, each focus group was asked to submit suggested topics for discussion, after which the two most common topic clusters were selected for framing the discussion around challenges and opportunities for microbiology in soil health and how we could respond as a community. The topic clusters for each group were: Microbiology research and innovation: (1) building a strong and resilient research community and (2) disseminating research; Interdisciplinary collaboration: (1) structures and funding and (2) managing expectations and internal communication; Industry: (1) research and industry collaboration and (2) policy, regulations and market and; Social and political institutions: (1) policy context and (2) engagement and culture.

The discussion

The focus groups were purposely composed of people from a range of backgrounds, geographical locations, and scientific seniority. The discussions were vibrant, occasionally passionate and generated a spectrum of opinions that could be directed into potential policy documents for how to both utilise and adapt the current microbiology research landscape in the UK and Ireland. Here, I outline some of the key thoughts and perceptions generated during these 90-minute discussions (Figure 1). As a group we have tried to distil these into some key concepts that may provide a focus into how the microbiology research community in the UK and Ireland can contribute to achieving healthier soils.

Workshop recommendations on Microbiology research and innovation

Healthy, sustainably managed soil is a critical ecosystem for continuous sustenance of plants, animals and humans globally. While the concept of 'soil health' still continues to evolve (see e.g. Lehmann et al 2020 for a recent perspective), the versatility of the concept allows its adoption by many stakeholders, thereby enabling improved translation of fundamental research findings in soil microbiology. As soils are complex heterogeneous systems, it is important for researchers to develop and identify precise and actionable microbial indices for soil health metrics of interest that are suitable for adoption across many soil types and can be easily interpreted in specific soil contexts.

Microbes are critical for food security, e.g. through enhancing crop production and sustainable agriculture (SDG2), for water and soil quality, e.g. via bioremediation of pollution and the promotion and prevention of soil formation and soil erosion respectively (UN-SDGs 6 and 15), climate control, e.g. via soil carbon sequestration and decreasing greenhouse gas emissions (UN-SDG13), and human health, e.g. via improved control of pollutants, pathogens and nutrients (UN-SDG3). It is therefore important for microbiologists to continue to communicate and increase awareness of the role of microbiology in addressing global challenges linked to soil health.

Microbiologists should commit and be expected to make academic research outcomes better accessible to communities outside academia. Such communications and community engagement not only ensure that microbial indices for soil health are better understood by stakeholders, it also contributes to better managing of expectations of long-term monitoring and intervention applications of research outputs in real-world settings. Through establishing networks of environmental microbiology outreach in schools it is also possible to address poor understanding and visibility of non-

medical microbiology by the general public, which is also likely to result in a larger and more diverse workforce through promotion of educational and career perspectives.

Workshop recommendations on Interdisciplinary collaboration

Soils and soil health are studied by a wide range of researchers from disciplines covering (agro)economics, soil, plant and (micro)biological sciences, hydrology, ecology, chemistry, physics, engineering and data science. Similarly, the vast interests in soils and its functions from non-academic stakeholders and sectors include agriculture and industry, sport and exercise, culture and recreation, health, policy, landowners and society at large. The topic of soil health is therefore innately interdisciplinary, and should be viewed and discussed with an as broad as possible ecosystem functioning perspective. This potentially creates a (mis)communication issue between academia and stakeholders, especially if one discipline area is not sufficiently clear in defining the meaning of soil health (metrics) and their relevance when communicating with associated disciplines and stakeholder sectors.

Soils mostly change slowly upon implementation of intervention and management strategies derived from novel scientific insights. The current research and innovation funding model leads to a lack of continuity in soil science funding, creating gaps in knowledge and understanding of long-term effects in soil adaptation. It is therefore recommended that soil microbiology and soil science research benefit from long-term financial support to allow data collection and interpretation to support sustainable interventions in soil management at the longer term in order to achieve healthy soils.

Funding bodies therefore ought to work together to develop a coherent long-term strategy for sustained commitment to large, longer term soil health research projects with interdisciplinary collaboration at its heart to ensure the important continuity of research and monitoring over larger (time) scales that are relevant to soils. In a similar manner, professional and learned societies that usually serve the membership in one discipline, could also enhance efforts to bring researchers from a wide range of disciplines together in joint meetings for more effective communication. The Microbiology Society could also showcase examples of successful integration between disciplines at events to spark interest in cross-disciplinary projects.

The focus group furthermore acknowledged a need to educate and (re)train the new generation of inter- and cross-disciplinary workforce. In Ireland there is also a need for increased training in this area to address the lack of capacity, which prevents researchers from responding to funding calls in soil health. It is therefore recommended that the education sector, research funding bodies and learned societies join efforts to ensure soil health researchers and sector employees obtain the knowledge, skills and competencies to successfully contribute to interdisciplinary projects. For example, the Microbiology Society could advocate for and facilitate cross-disciplinary training of soil scientists and encourage ecologists and agronomists to learn more about soil microbiology, and vice versa.

Workshop recommendations on Industry & Farming

Improving interdisciplinary communication and collaboration will advance knowledge and practical, actionable metrics on achieving healthy soils. However, landowners and farmers will need further support for implementing and maintaining sustainable management of their soils, especially if a direct economic benefit of changing soil management is unclear. Such support can take the form of policy development to enact, encourage, and/or reward ‘good’ management. It is also recommended to develop a new food labelling system, e.g. advancing the Red Tractor logo, to include certified sustainably managed soils to establish a societal market demand for sustainable produce.

Bioinoculants are agricultural amendments that aim to take advantage of beneficial microbes sourced from the rhizo- or phyllo-sphere, or function as endophytes, in order to promote plant health and enhance crop yields. A huge diversity of bioinoculant products of ranging effectiveness makes it difficult for farmers to confidently choose and apply such products. While bioinoculants are a rapidly growing industry with huge potential to soil health and sustainable agricultural systems, the current lack of independent quality control on claims on product effectiveness prevent confident adoption

across the agri- and horticultural sector. It is therefore recommended to consider implementation of an independent quality control centre where product effectiveness is tested, which could possibly be funded by industry.
Researchers and industry should improve communication and knowledge exchange to manage expectations of real world field applications of modern soil and soil microbiology methods. Advances in DNA sequencing enable a wealth of scientific information on soil ecosystem functioning and soil health that is difficult for stakeholders to keep up with. Scientists should engage better with farmers and landowners on how to effectively translate academic outputs into farmer-friendly, accessible technology that is affordable, practical and easy to interpret on-site. The time and resources required for upscaling, implementing field trials and longer-term monitoring of novel technologies aimed to improve soil health should be clearly communicated, which will also enable realistic expectations of the maturation of technology. Researchers could engage more with organisations such as the Agriculture and Horticulture Development Board which already have effective relationships with agriculture for improving knowledge exchange.

Workshop recommendations on Social and political institutions
Currently, soils are not viewed as a 'common good' protected by a dedicated Directive, while water and air have regulatory mechanisms providing actionable indicators. As a direct result of regulation, most of the funding to monitor our natural environment is allocated to air and water, with less than half a percent of funding allocated to monitor soils. Adoption of sustainable soil management for improving soil health and soil ecosystem services requires a set of physical, chemical and (micro)biological metrics and indices that are applicable and practical for many soil types and soil uses. Having suitable soil metrics and indices will therefore also aid development of policy and regulation towards a soil directive supporting sustained monitoring of soils thereby forming a comprehensive monitoring system for all of our natural environments.
Innovation in soil health should be encouraged further. This can take the form of *living labs*, where researchers work with farmers on the field to develop new technologies, *lighthouses*, where farmers trial technologies and feedback to researchers, and re-instatement of *independent field advisors*, who promote knowledge exchange in the agricultural sector. There could be a role for universities and agricultural colleges to train the next generation of advisors, and they could be funded through the new payments scheme.
As already indicated, improved communication between researchers, farmers and landowners will enhance knowledge exchange towards improvements in soil health. Equally important is further communication efforts in education, outreach and knowledge exchange for the raising of public awareness of sustainable management and soil health. The Microbiology Society could, e.g., reach out to other societies to bridge the gap in communication and pinpoint the right people to help facilitate conversations and events, especially outside university cities/towns. Learned societies and their membership should continue to promote membership engagement in events aimed at political and policy knowledge exchange, e.g. Parliamentary Links Day in Westminster and events at the parliaments of the devolved nations such as 'Science and the Senedd', 'Science and Stormont' and 'Science and the Parliament' at Holyrood, to raise political awareness of (the role of microbes in) sustainable management and soil health towards achieving the UN-SDGs.

Closing remarks
In summary, the Sustainable Future Workshop on Soil Health has highlighted opportunities and challenges on the role of microbiology for achieving healthy soils as well as pinpointing barriers and potential interventions. Sustained support from industry, government, regulatory bodies and professional societies is required for the continuation and newly to be formed long-term interdisciplinary collaborations and communications to ensure validation and integration of chemical,

physical and (micro)biological parameters of soil health valid for soils across the board. Development and implementation of evidence-based policies will be critical to achieving a sustainable future for generations to come.

Acknowledgments
I am deeply grateful for the support of the Policy team the Microbiology Society, especially Hannah Norman, Jack Doughty, and Eva Scholtus. I like to thank all of the workshop members for participating and contributing to a most interesting discussion.

The author declares that there are no conflicts of interest.

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Figure 1. Wordcloud of the Soil Health Workshop Summary Document