Life in Earth - Soil microbes are key to achieving net zero

by KTN, Eagle Genomics and CABI

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Our planet is facing a series of ecological crises - from a catastrophic loss of biodiversity through to environmental degradation, and climate change. Today, 40% of the Earth's land surface is threatened by soil degradation and yet it has been predicted that we will have over 2 billion more mouths to feed by 2050 [1]. Soil microbes are essential for sustaining plant-based food production through the cycling of nutrients and play a crucial role in the associated production and sequestration or fixation of the major greenhouse gases (GHGs), carbon dioxide, methane, and nitrous oxide. In fact, soil is one of the largest carbon stores on Earth, and its microbial inhabitants represent a crucial life support system for the planet [2, 3]. For example, one teaspoon of topsoil alone contains 1 billion microbes that comprise over 10,000 microbial species [4]. These soil microbes play a key role in determining if the carbon captured by plants through photosynthesis or the nitrogen applied to soils as synthetic fertiliser or as manure is captured and stored in the soil or released into the atmosphere.

Globally, agriculture, forestry, and other types of land use (AFOLU) are significant contributors to climate change through greenhouse gas (GHG) emissions and these industries are also impacted by climate change. GHG emissions from AFOLU have been estimated to range from 17 to 25% of total global emissions [5, 6]. To put this into perspective, this level of emissions is comparable to estimates for global transport (cars, planes, ships, trains, and pipelines), which contributes approximately 16% of GHG emissions [7].

AFOLU also includes animal agriculture, which has been estimated to contribute almost 6% of global GHG emissions, in the form of methane (primarily from ruminant 'enteric fermentation' and manure), carbon dioxide and nitrous oxide (N_2O - released mainly from manure). In all cases, microbes play a critical role. With regard to N_2O emissions (a gas with a global warming potential 300 times higher than CO_2), it has been estimated that, in Ireland, which is the largest beef exporter in the EU [8], 90% of N_2O emissions come through the process of bacterial denitrification. Denitrification is modulated by factors such as environmental conditions as well as the soil microbial community structure (or 'soil microbiome'), of which the latter has the ability to reduce N_2O into harmless N_2 [2, 3].

As a vital component of our food systems, soil microbiomes are affected by, respond to, and can be damaged by the effects of climate change (e.g., droughts and flooding) but are also key to reversing it. It is essential to maintain soil microbial biodiversity as this can influence ecosystems and their associated functions such as carbon cycling [3]. A key challenge is to better understand the role of microbes to enable the development of innovative microbial solutions and allied agricultural practices to drive down agricultural GHG emissions, and potentially even to remove carbon from the atmosphere [4].

Several approaches have been proposed to harness microbes to minimise and/or counteract the impact of climate change, including promoting climate change-resistant soils [2]; harnessing microorganisms' capabilities to sequester carbon; utilising their ability to promote the growth of plants (e.g., under conditions of drought or nutrient deficiency); and managing cattle microbiomes to reduce methane emissions. Microbiome engineering could also be used to modify and promote positive interactions between microorganisms and plants or livestock [9]. Microbes, including their associated biodiversity, can also act as a "health indicator" of soil.

To farmers, soil microbes and their composition present potential alternatives to pest control; for instance, controlling plant pathogens such as plant-parasitic nematodes and soil-borne pathogenic fungi [10], which can affect crop outputs and the ability to more sustainably feed a growing population. Biobanks such as the UK Crop Microbiome Cryobank support such alternative approaches by providing opportunities to categorise and better understand soil microbiome composition and biodiversity, and how this may affect food development and production. Conserving 'microbial biodiversity' also provides a 'snapshot in time', contributing a valuable insight into the make-up and functioning of ecosystems before the impacts of our changing climate causes irreversible damage to the equilibrium within plant, animal and soil systems.

Host-microbiome interactions such as plant-microbe interactions in the soil and the human gut microbiome are the subject of intensive research and hold the promise of providing vital solutions to some of society's biggest challenges. These challenges include chronic and infectious human diseases and the ongoing threat of antimicrobial resistance, general consumer health and wellbeing, crop and animal agricultural productivity, as well as climate change and its downstream effects [11] . Properly informed sustainability and environmental policies demand deeper, longer-term study of soil microbiomes and how they respond to perturbations, including those relating to climate change and the loss of biodiversity. It is also important to improve our understanding of soil microbiomes through quantitative modelling to allow for robust predictions of microbial responses to environmental change and vice versa [3].

As stated in the Dasgupta Review [12], future advances in technology and 'big data' could improve the ability to monitor businesses' impact on natural assets, including microbiomes, as part of risk management across a number of industries. Global organisations are already recognizing the prevalent role of the microbiome in future global value chains and how they might drive innovation while also helping to mitigate climate change. The UN FAO has emphasised the role of the soil microbiome and biodiversity in food production, safety, and in terms of sustainability and Horizon Europe selected the "microbiome world" as one of ten pathways to action for solutions to the priorities of Food 2030 [13]. The Panel on Climate Change similarly emphasised the role of the soil microbiome in mitigating climate change [14, 15]. Commercial organisations are uniting through initiatives such as One Planet Business for Biodiversity [16] to drive the future of sustainable value chains.

According to Emeline Fellus, Director, Food Reform for Sustainability & Health (FReSH) at the World Business Council Sustainable Development, new business models are needed to safeguard the resilience and economic viability of our food systems in the medium and long terms, while also protecting our Planet and our People. "As highlighted in WBCSD's Vision 2050 [17] *, business leaders must adopt three mindset shifts: reinventing capitalism that rewards true value creation; focusing on building long-term resilience; and taking a regenerative approach beyond doing no harm. We need to urgently switch our food systems towards regenerative processes which make positive contributions to our ecosystems, and to deliver better* *nutrition for everyone. A comprehensive and coordinated approach across food value chain actors that mixes consumption, transformation, trade and agricultural production levers has the best chance of succeeding. Within this context, natural ecosystems such as the microbiome have a role to play at most, if not every, stage."*

In summary, the microbes that live in the soil, in and on plants and livestock are a precious resource that need to be conserved and preserved through agricultural management practices, novel data-driven solutions and biobanking approaches [18, 11]. As with most facets of anthropogenic greenhouse gas emissions and climate change, the challenge is immense. Inaction is not an option if we want to protect the planet and the life that it supports, including humankind. The agriculture sector is comparable to the transport sector in terms of GHG emissions globally. Fortunately, steps are being taken to address such large challenges, for example via changes in agricultural practices such as the use of precision fertilisers, and the development of microbe-based biological solutions for crops (biostimulants), such as nitrogen-fixing bacterial inoculants and, in the case of livestock, through dietary, husbandry and genetic approaches. These are relatively early days in terms of the scale of the innovation needed. Hence, it is vital that we markedly accelerate biological research aimed at harnessing and modulating soil, plant, and animal microbiomes, to reduce agricultural GHG emissions significantly and deliver a net zero agricultural system that is able to sustainably feed the world's growing population.

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