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Editorial: Soil Microbes: The Hidden Allies in Combating Climate Change and Feeding the Future

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Editorial

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Editorial on the Research Topic: Soil Microbes: The Hidden Allies in Combating Climate Change and Feeding the Future

Soil may look inert, but beneath its surface lies one of the most dynamic ecosystems on Earth, teeming with microbial life that shapes plant health, climate resilience, and global biogeochemical cycles [1]. In the era of climate change, these invisible farmers offer one of the most underutilized solutions to improving agriculture and restoring ecological balance. We often think of climate action in terms of reducing fossil fuel use or planting trees. But the role of soil microbiology, specifically microbial communities that drive carbon sequestration, nutrient cycling, and crop growth, has remained relatively underappreciated. As the agricultural sector faces mounting pressure to produce more with fewer inputs and lower emissions, soil microbes emerge as a powerful force for sustainable transformation [2].

Modern agriculture has delivered tremendous yield gains over the past century. But it has come at a cost. Over-tillage, monocropping, and excessive use of synthetic fertilizers and pesticides have led to soil degradation, declining microbial diversity, and disrupted carbon and nitrogen cycles [3]. Soils globally store more carbon than the atmosphere and all vegetation combined. But this carbon reservoir is under threat. Degraded soils release carbon dioxide, nitrous oxide, and methane, greenhouse gases that accelerate climate change [4]. Poor soil microbial activity also hampers oxygen exchange and reduces the buffering capacity of soils to cope with heat, drought, and floods.

Soil microorganisms, including bacteria, fungi, actinomycetes, and archaea, play vital roles in nutrient cycling, organic matter decomposition, and the formation of soil structure, with their influence extending far beyond the rhizosphere [5]. In carbon cycling, decomposer microbes convert plant residues into stable soil organic carbon, while others, such as mycorrhizal fungi, form symbiotic relationships with plants to increase carbon flow into the soil and stabilize it within microaggregates. Microbial consortia also enhance oxygen balance by promoting root growth and soil aeration, and in anaerobic conditions, certain microbes regulate redox reactions that influence greenhouse gas emissions (Gao et al., 2025). Additionally, nitrogen-fixing and phosphate-solubilizing microbes improve nutrient use efficiency, reducing dependency on synthetic fertilizers and lowering nitrous oxide emissions, a greenhouse gas significantly more potent than carbon dioxide. These microbes also boost plant resilience by enhancing root development, improving resistance to drought and disease, and increasing nutrient uptake, all of which contribute to higher biomass production and greater carbon capture.

To unlock this potential, we must rethink soil management, not as treating soil as a passive substrate for crops, but as a dynamic, living ecosystem. This shift requires changes in both research and practice. First, reviving microbial diversity is essential, as land use intensification often reduces microbial richness; implementing crop rotation, cover cropping, and organic amendments can restore diverse microbial communities that are more effective at carbon sequestration and nutrient cycling, especially under stress. Second, promoting indigenous bio-inputs by harnessing locally adapted microbes, rather than importing strains, enhances crop productivity and rhizosphere health, an approach supported by my research on native nitrogen-fixers and plant-derived bioformulations. Third, integrating microbial monitoring into climate models is critical since current global carbon models often overlook microbial mediation; advances in soil metagenomics and microbial functional analysis now enable the inclusion of microbial activity in predicting soil carbon dynamics and greenhouse gas emissions. Finally, investing in farmer education and policy incentives is vital, as smallholder farmers are key stewards of soil microbiomes and need training on practices such as composting, reduced tillage, and biological inputs, while policymakers should implement incentive-based programs to reward soil restoration and carbon farming efforts.

Emerging multi-omics tools, such as metagenomics, transcriptomics, and proteomics, are revolutionizing our understanding of soil microbiomes by allowing us to identify which microbes are present, what roles they perform, and how they respond to environmental changes. This knowledge paves the way for microbiome engineering, where tailored consortia of microbes can be selected or designed for targeted functions like carbon capture, drought tolerance, or disease suppression. When applied responsibly, these innovations offer transformative solutions for climate-smart agriculture.

The climate crisis calls for integrated, scalable, and science-driven responses, and soil microbes, though invisible to the naked eye, are indispensable allies in this fight. They not only address carbon and nutrient challenges but also provide a blueprint for regenerative agriculture that harnesses nature's intelligence rather than suppressing it. We must move beyond seeing microbes as academic curiosities and place them at the core of agricultural and climate policies. As scientists, editors, and practitioners, it is our duty to advance this dialogue through research, advocacy, and action. Ultimately, our future may well depend on what lies beneath our feet.

Author Contributions

AAM design and writing of this Editorial.

Conflict of interest

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