AGRI MAGAZINE
(International E-Magazine for Agricultural Articles)
Volume: 02, Issue: 09 (September, 2025)
Available online at http://www.agrimagazine.in

Soil Microbiomes: The Hidden Networks That Sustain Life

*Kore Meghana
M.Sc. (Agri.), Department of Soil science and Agricultural Chemistry, Junagadh Agricultural University, Junagadh, Gujarat, India
*Corresponding Author's email: meghanakore661@gmail.com

Soil, often referred to as the skin of the Earth, is a fundamental natural resource and a vital component of ecosystems. It provides a wide range of ecosystem services, including food production, climate and water regulation, energy provision, and support for diverse life forms. This essential resource is home to a vast and varied community of microorganisms—collectively known as the soil microbiome—which includes both beneficial and pathogenic species. These microorganisms belong to three major domains of life: Archaea, Bacteria, and Eukarya (including fungi, algae, and nematodes). The diversity of the soil microbiome varies depending on environmental conditions and habitat. The efficient soil microbes play an important role, since they are responsible to drive various biological transformations and different pools of carbon (C) and macro- and micronutrients, which facilitate the subsequent establishment of soil-plant-microbe interaction.

Introduction

In a single teaspoon of healthy soil, there can be more microbes than there are people on Earth. These tiny life forms interact in complex, interconnected ways, forming a living web that drives essential processes like nutrient cycling, organic matter decomposition, and even carbon storage. Soil microorganisms are highly sensitive to changes in their environment, especially temperature and pH, which directly influence their activity, diversity, and abundance. Most soil microbes function best between 25°C and 35°C. While some psychrophilic (cold-loving) microbes can thrive below 10°C, and thermophilic (heat-loving) microbes can tolerate temperatures above 45°C, the majority of soil microbial activity slows significantly outside the optimal range. Seasonal and daily temperature fluctuations can thus directly impact microbial-mediated nutrient cycles. Soil microbes typically prefer a pH range of 6.0 to 7.5, which is close to neutral.

- Bacteria generally thrive in neutral to slightly alkaline soils (pH 6.5–8.0),
- Fungi, on the other hand, are more tolerant of acidic conditions and can survive at pH levels as low as 4.0.
- Changes in pH can alter microbial community structure, enzyme activity, and the availability of nutrients, making pH management crucial for soil health.

The Invisible Workforce Beneath Our Feet

1.Nutrient Cycling and Plant Growth: In addition to improving soil fertility, soil microbes play essential roles in nutrient cycling. Plants absorb nutrients from the soil, which are then consumed by humans or animals. These nutrients are eventually returned to the environment when organisms die or when plants shed their leaves. Soil microorganisms decompose organic matter, converting it into inorganic nutrients that become available for plant uptake. Specific bacteria help fix nitrogen from the air into a form that plants can use, while mycorrhizal fungi form symbiotic relationships with plant roots, enhancing water and nutrient uptake. Soil microbes utilize a variety of mechanisms such as nitrogen fixation, solubilization and mobilization of minerals like phosphorus, potassium, zinc, and selenium. They also produce siderophores for iron chelation and release plant growth-promoting hormones like auxins, abscisic acid, cytokinins, gibberellins, and ethylene, all of which contribute to enhanced plant growth (Kour et al., 2019).

2.Weathering of rocks: The disintegration of rocks through the weathering of their constituent minerals is recognized as a primary global process (Barker et al., 1998). Weathering is mediated by biological and chemical processes. when mosses or lichens grow on the exposed rock, they facilitate the deposition of of dust, resulting in higher plnts getting favourable environment to grow. As a result roots of higher plants penetrate inside the rock and disintegrate them physically. The mosses and lichens grow on the rocks secretes chemical exudates which act chemically on the minerals present on the rocks. Microorganisms such as algae, chemolithotrophic and chemorganotrophic bacteria, cyanobacteria, and fungi are vital components of rock microbial communities. The collective activities of these communities significantly influence the rates of rock surface disintegration. Through the excretion of organic acids, certain metabolites, and hydrogen ions (H^+), these microbes can induce chemical weathering of rocks and minerals.

3.Plant protection: Insect' s pest and microbial pathogens such as fungi, bacteria and virus are the one farmer's enemies as they are the major destroyers of the crop production. The use of chemical-based products has also affected human health and microbial populations in the soil. Moreover, the long utilization of such chemicals in agro-systems has led to resistant insect pests and microbial pathogens, which is one major reason to worry. Soil microbes serve as environmentally friendly alternatives to replace existing chemical products like pesticides, fungicides, bactericides, and insecticides. These beneficial organisms can be utilized in agriculture as biopesticides for biological control purposes. Soil microbes, including bacteria, fungi, and nematodes, employ various mechanisms to compete with pathogens for space, nutrients, and iron, or by feeding on them. Through these competitive mechanisms, soil microbes used as biopesticides or bio fungicides prevent pathogens from accessing essential soil nutrients required for their growth, ultimately leading to pathogen suppression.

4. Carbon Sequestration and Climate Change: Soil is one of the largest carbon sinks on the planet, storing more carbon than all the world's vegetation and atmosphere combined. Microbial activity influences how much carbon is stored or released into the atmosphere. Healthy microbial communities can enhance soil's ability to store carbon, making them a powerful ally in the fight against climate change. However, disturbances like deforestation, overgrazing, and intensive agriculture can disrupt these communities and accelerate carbon loss.

5. Decomposition of organic matter: Decomposition is a chemical and biological process involving the physical breakdown and biochemical transformation of raw organic materials from dead matter into simple organic and inorganic molecules, resulting in compost. Bacteria, fungi, actinomycetes, protozoa, and molds, along with saprophytic organisms, initially feed on decaying organic materials. Later stages of composting involve springtails, millipedes, mites, earthworms, centipedes, and beetles, which further break down and enrich the composting materials. The temperature conditions in the pile influence the presence of these organisms, but the goal in composting is to create the most favorable environment for the desired organisms. Soil organic matter serves as a reservoir for sulfur, nitrogen, and phosphorus. While soil contains minimal inorganic nitrogen, much of it is extracted from organic forms. The decomposition of organic matter is primarily an enzymatic process facilitated by extracellular hydrolytic enzymes produced by soil microbiomes. Key soil enzymes involved in biochemical processes during organic matter decomposition include arylsulfatase, amylase, chitinase, cellulase dehydrogenase, urease, and phosphatase, which are released from plants, animals, organic compounds, microorganisms, and soil. Environmental factors such as moisture content, temperature, and microbial diversity influence the rate of soil organic matter decomposition (Debnath and Haira, 1972).

Threats to Soil Microbial Health

Modern agricultural practices—especially excessive tillage, monocultures, and overuse of chemical fertilizers and pesticides—have significantly harmed soil biodiversity. These practices can degrade soil structure, reduce organic matter, and disrupt microbial networks, leading to lower productivity and increased vulnerability to erosion and disease.

Urbanization, pollution, and climate change further exacerbate the stress on soil microbiomes. Once disrupted, these microbial ecosystems can take decades to recover—if at all.

Regenerative Solutions and the Path Forward

To restore and protect soil microbiomes, scientists and farmers are turning to regenerative agriculture. This includes practices like:

- **Cover cropping**: Growing plants that protect the soil between main crops.
- **No-till farming**: Reducing soil disturbance to maintain microbial habitats.
- **Composting and organic amendments**: Feeding the soil with natural inputs to boost microbial life.
- **Crop rotation and polycultures**: Increasing plant diversity to support diverse microbial populations.

Conclusion

The soil microbiome is a hidden world, yet it underpins the health of every ecosystem on Earth. From the food we eat to the air we breathe, the microbes beneath us are key to sustaining life. By respecting, protecting, and restoring soil microbial communities, we're not just taking care of the ground—we're securing our future.

References

1. Barker, W., Welch, S., Chu, S., Banfield, J., 1998. Experimental observations of the effects of bacteria on aluminosilicate weathering. Am. Mineral. 83, 1551-1563.
2. Debnath,N., Harija, J., 1972. Transformation of organic matter in soil relation to mineralisation of carbon and nutrient availability. J. Indian Society of soil science
3. Devi,R., Kaur,T., Guleria., Rana, Kour, D., Yadav, N., etal, 2020. Fungal secondary metabolites and their biotechnological applications for human health. In: Rastegari, A.A., Yadav, A.N., Yadav, N. (Eds.), Trends of Microbial Biotechnology for Sustainable Agriculture and Biomedicine Systems: Perspectives for Human Health. Elsevier, Amsterdam, pp. 147–161.
4. Kaur, T., Rana, K.L., Kour, D., Sheikh, I., Yadav, N., Kumar, V., et al. (2020). Microbe-mediated biofortification for micronutrients: present status and future challenges. In Rastegari, A.A., Yadav, A.N., Yadav, N. (Eds.), *Trends of Microbial Biotechnology for Sustainable Agriculture and Biomedicine Systems: Perspectives for Human Health*. Elsevier, Amsterdam, pp. 1–17.