SOIL BIODIVERSITY FOR SUSTAINABLE ECOSYSTEM SERVICES

J K THAKUR*, ASIT MANDAL, NISHANT K SINHA, RAHUL MISHRA, SANTOSH RANJAN MOHANTY, MONORANJAN MOHANTY

ICAR-Indian Institute of Soil Science, Bhopal, Madhya Pradesh, India

*Corresponding Author, E-mail: jkthakuriiss@gmail.com

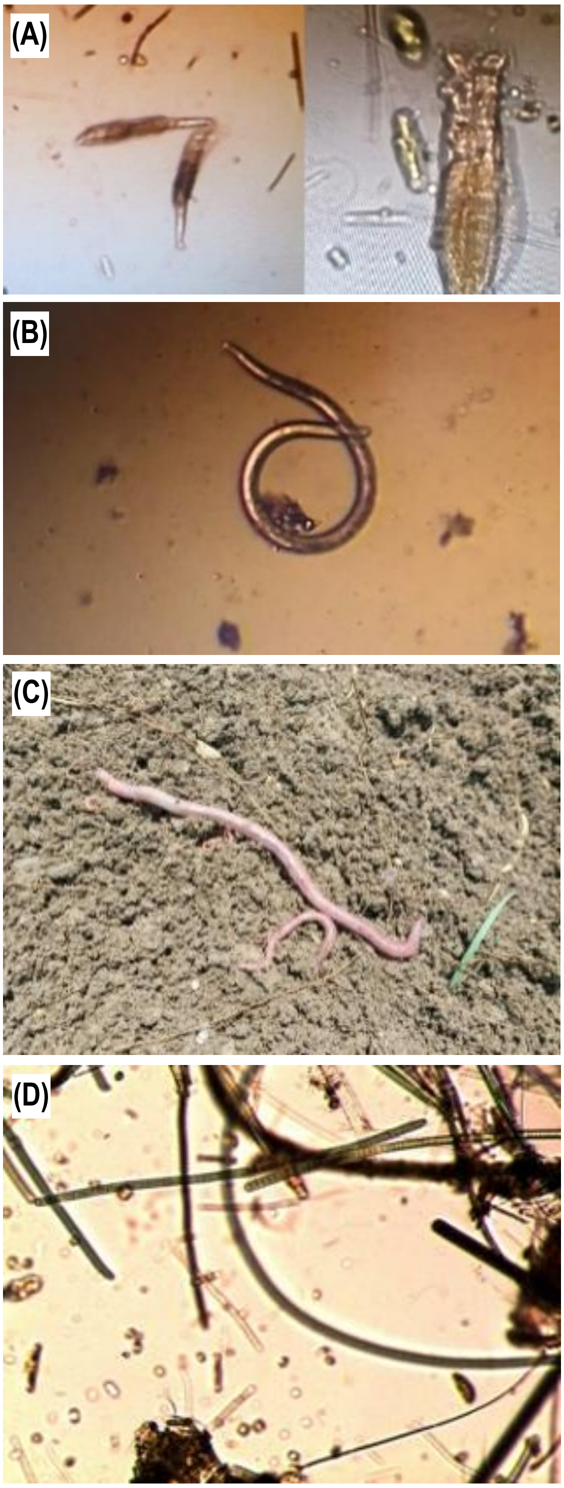
Soil is dynamic ecosystem and composed of biotic (plant roots, micro and macro-organisms) and abiotic components (i.e., mineral particles, water, gases, nutrients, and non-living organic matter). It is habitat for approximately 60% of the Earth's species and hence very rich in terms of biodiversity. These biotas are the drivers of biogeochemical cycling. They carry out elemental transformation processes which ensure proper nutrient cycling and healthy plant growth. Adequate population of different groups of soil biota is essential for being a productive soil. Soil biota is broadly classified into soil fauna (includes soil animals) and soil flora (which includes plant groups). Table1 illustrates the distribution of soil organisms with their approximate length and number. Plate 1 shows a few soil biota.

The soil macrofauna comprise of rodents, larger insects, earthworm, molluscs, millipedes, earwig, fly larvae, wood lice, springtails etc. Mesofauna include springtails, nematodes, pot worms etc while microfauna includes protozoans, rotifers, small nematodes. Each group of organisms in soil performs specific task in soil by converting a substrate into another compound which may be substrate for other group of organisms or may be the end product. Soil macrofauna accelerate the organic matter decomposition by mixing organic matter and soil together. Earthworms improve soil aggregation and aeration through channelling and burrowing in soil. Springtails, wood lice and fly larvae puncture the leaf epidermis in a process called 'fenestration' and open the leaf to microorganisms for further decomposition. Microbial action turns the litter into an integral component of soil through biochemical transformations.

Table 1. Distribution of soil organisms based on their approximate length and number

Organisms	Approx. length (mm)	Organism per 1000cc
Protozoa	0.02-0.2	1×10^9
Nematodes	0.2-2.0	3×10^4
Mites	0.2-2.5	2×10^3
Springtails (Collembola)	0.2-10	1×10^3
Rotifers	0.2-1	5×10^2
Arthropods	1-30	1×10^2
	15-85	2

The soil microflora constitutes one of the most crucial components of soil system which make soil a living system. Microflora includes Chromista (Algae), Fungi, Filamentous Prokaryotes-(Actinobacteria), Eubacteria, Archaebacteria and Viruses & phages. A single gram of healthy soil may contain up to 100 million of bacteria and one million of fungi. These two groups of organisms (bacteria and fungi) contribute to more than 80% of soil biomass followed by macrofauna (14-15%) while meso and micro fauna contributes to approximately 2% of the biomass. Thus, diverse kinds of organisms are required to deliver an ecosystem service. These processes are continued at any time in a soil system without any break hence they are called the silent workers of nature.



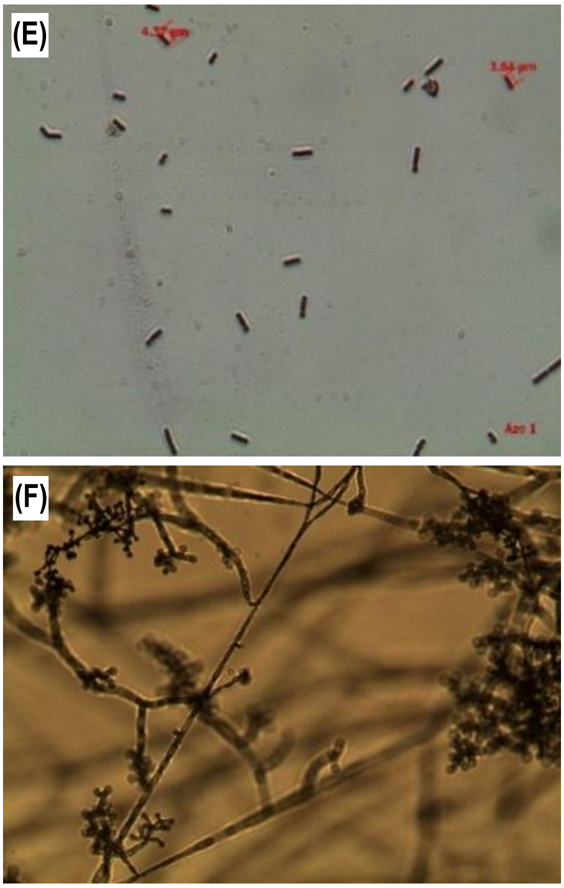


Plate1. Different types of flora and fauna present in soil (A) Rotifers (200X); (B) Nematode (100X); (C) Earthworm; (D) Algal filament (200X); (E) Bacterial cell (1000X); (F) Fungal mycelium (200X))

ECOSYSTEM PROCESS DRIVEN BY SOIL MICROBES

Decomposition: Decomposition of organic waste is one of the most crucial ecosystem services provided by the soil biota. It makes the planet habitable by quick recycling of vast quantities of waste generated every day through natural and anthropogenic activity. Microbes convert organic wastes into nutrient-rich manures for healthy soil. The process drastically cuts landfill waste, reduces methane emissions, lowers chemical fertilizer requirement and sequesters carbon in soil.

Mineralization-immobilization: Microbes in soil break the nutrients locked in organic form to inorganic form which can subsequently be utilized by plants growing in the soil system. Conversely, microbes also use the available nutrient in soils to build their body mass thus making it immobile for plant use. The immobilized nutrient again becomes available to plant upon death and decomposition of organisms. The mineralization-immobilization step keeps the nutrient cycling process running in an ecosystem.

Nitrification: It is a biological process of conversion of ammonia to nitrite and then to nitrate. Nitrogen is the most crucial plant macronutrient which directly affect the crop productivity. The organic form of nitrogen in soil is converted to ammonia with the help of ammonifying organisms. Alternatively, the ammonia added to the soil through chemical fertilizers are to be converted into forms that can be used by most of the plants. During nitrification, ammonia is converted into nitrite (NO_2^-) and then into nitrate (NO_3^-) by nitrifying bacteria and archaea, to make the nitrogen available for majority of plants and other organisms.

Denitrification: Excess nitrogen in available form may be lost through runoff or leached into ground water causing eutrophication, environmental pollution and ground water contamination. Microbes in soil convert the nitrate to nitrogen gas (N_2) and nitrous oxide (N_2O), releasing them into the atmosphere mainly in oxygen-poor (anoxic) and submerged conditions which are more prone to leaching and ground water pollution. Thus, denitrifying microbes in such ecosystem, helps protect groundwater quality.

Plant Nutrient Fixation, Solubilization and Mobilization: Soil microbes are capable of fixing atmospheric nitrogen and providing it to the plants. Nitrogen fixing microbes possess nitrogenase enzyme complex to reduce atmospheric dinitrogen to ammonium ion and providing nitrogen for crop growth thus reduce dependence on chemical fertilizers. Bacteria like Rhizobium, *Azospirillum*, *Azotobacter, Gluconoacetobacter* can supplement 15-50 kg of nitrogen to crops depending upon host and organisms. Other group of bacteria and fungi can solubilize the phosphorus, potassium and other micronutrient present in soil in unavailable form through production of different organic acids and action of enzymes. Mycorrhizae a group of beneficial fungi mobilize the phosphorus in soil to plant roots and protect plants from abiotic stresses.

Detoxification and Remediation of Contaminated Soils: Soil receives many harmful compounds such as pesticides, agro-chemical, heavy metals, aromatic hydrocarbons from dyes and paints, oil spills etc through irrigation and other farm activities. Many of these compounds are toxic to plant, animals and human beings if reaches into the food chain. Microbes in soil modify or break down these compounds to non-toxic molecules so that food chain will not be contaminated. Healthy soils and their diverse microbial communities act as one of nature's largest water filters, thus providing the most vital ecosystem services. Decolorization and degradation of textile dye entering to soil through irrigation by dyeing industry effluent contaminated water soil by soil bacteria is shown in plate 2.

Plate 2. Decolorization and degradation of azo dye by soil bacteria

Protecting Crops from Pests and Diseases: Many soil microbes produce secondary metabolites and antifungal compounds which inhibit the growth and proliferation of pathogenic fungi causing plant diseases. Species of *Bacillus* and Fluorescent *Pseudomonas* have been used as bioinoculant for protecting the crop plants from fungal pathogens. Fungus *Trichoderma viride* and *Trichoderma harzianum* have been commercially used for control of soil borne diseases caused by fungi. Metarhizium anisopliae, *Beauveria bassiana* are eco-friendly fungal bio-pesticides to control insect pests such as aphids, thrips, whiteflies, termites, and caterpillars.

Plate 3. Biocontrol of plant pathogen and insect pest by Fungus **(A)** *Trichoderma* inhibiting growth of plant pathogen *Sclerotium* (left) and *Fusarium* (right); **(B)** Spodoptera caterpillar infected by fungal biopesticide *Metarhizium*)

Greenhouse Gas Mitigation: Soil is a potential sink of greenhouse gases. It can sequester carbon in the form of stable soil organic matter in non-labile pool. Soil microbes facilitate the process of organic matter formation and stabilization thus helps in capturing and sequestering carbon in soil for a long time. In addition, Methane consuming bacteria (methanotrophs) can oxidize approximately 20% of methane gas produced in soil under anaerobic conditions (rice cultivation) thereby converting it into CO_2 having a lower global warming potential. Bacteria such as *Bacillus methanicus*, *Methylomonas, Methylobacter, Methylococcus, Methylocystis*, and *Methylosinus*, are important organism involved in methane oxidation (Hanson and Hanson, 1996). Similarly, Nitrous oxide a potent Green House Gas is converted to benign N_2 gas through action of denitrifying microbes like *Thiobacillus denitrificans*, *Pseudomonas denitrificans*, species of *Paracoccus, Alcaligenes and Bacillus*, keeping natural check on GHG emission.

Plant Growth Promotion: Bacteria and fungi present in plant rhizosphere not only protect the plant against diseases and supply nutrients, but they also produce several bioactive compounds which improve plant growth and vigour. Many strains of *Bacillus, Pseudomonas, Azotobacter, Azospirillum*, produce phytohormones such as auxins, cytokinins, gibberellins, etc. in the rhizosphere which improves root and shoot elongation. ACC deaminase producing strains of *Achromobacter, Aneurinibacillus, Rhizobium* and *Paenibacillus* break 1-Amino-cyclo carboxylate which is the precursor of ethylene into α-ketobutyrate thus delaying senescence, improving plant longevity and shelf life of produce.

WHY SOIL MICROBIAL DIVERSITY IS IMPORTANT?

Soil biodiversity refers to number and types of organisms inhabiting a given volume of soil at any given time. Soil microorganisms provide numerous ecosystem services, many of which are essential for sustainable agriculture, as discussed above. A soil with greater diversity harbours large number of species capable of performing many different activities. Such soil will be able to cope with the stresses more effectively than the soil with lower diversity due to presence of a greater number of functionally active organisms. Thus, to avail sustainable soil ecosystem services, the biological diversity in soil should be higher. A broad summary of the practices that negatively and positively affect soil microbial diversity is given in figure 1. Practices such as intensive tillage, monocropping, excessive pesticides and fertilizer application, dumping toxic materials like heavy metals and chemical wastes, keeping soil uncovered, poor quality of irrigation water, extreme soil pH, lack of organic matter addition etc reduces microbial abundance and richness and restricts ecosystem functions.

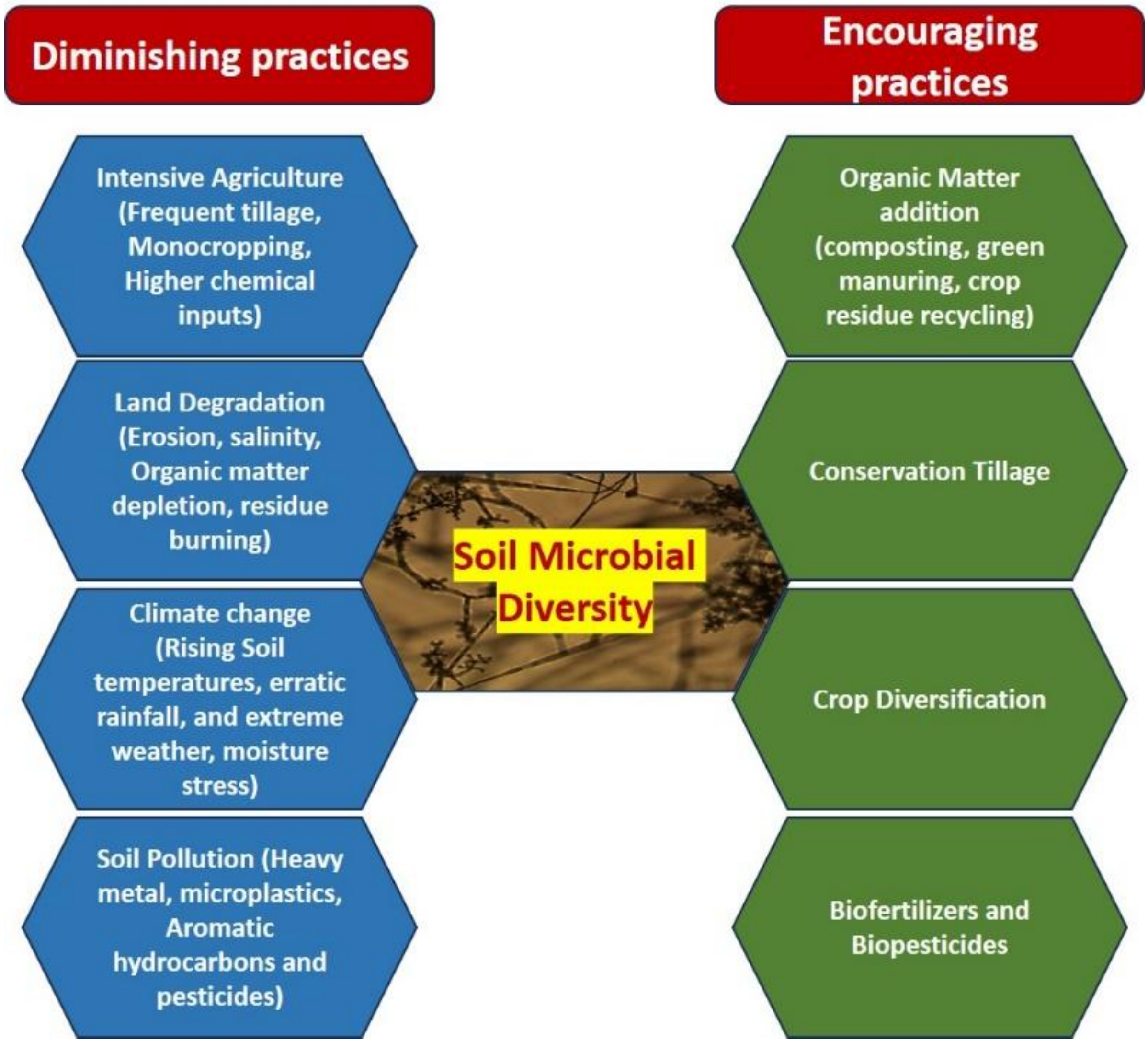


Figure 1. Practices affecting soil microbial diversity

HOW TO RESTORE AND IMPROVE SOIL MICROBIAL DIVERSITY

Following practices may be adopted to augment soil microbial diversity and to sustain soil health

Enriching Soil with Organic Matter: Incorporation of green manure, adding compost, organic mulching enriches the soil with carbon, providing energy and nutrients for soil organisms.

Conservation Tillage: Minimum tillage reduces soil disturbance, preserves microbial habitats and enhances biodiversity.

Crop Diversification: Rotating crops and intercropping support a variety of microbial communities and breaks the pathogen niche.

Biofertilizers and Biopesticides: Microbial inoculants such as nitrogen-fixing bacteria, phosphate-solubilizing fungi, and biocontrol agents reduces chemical inputs and promotes soil health.

Promoting Natural and Organic Farming: Avoiding synthetic chemicals enhances microbial diversity and ecosystem balance. It also encourages ecological balance by synchronizing the population of pest and predator.

Awareness Creation: Educating farmers and other stakeholders, about the value of ecosystem services and role of soil biodiversity in delivering the services, incentivizing conservation practices can make a positive change.

CONCLUSION

Soil is living system to support survival for humanity besides being habitat for vast biodiversity. Microbes in soil make it a living system capable of delivering ecosystem services. Soil biota carry out myriads of biochemical reactions required for performing nutrient transformation, organic matter recycling and soil detoxification. A soil harboring functionally diverse group of organisms will be able to withstand many kinds of stresses and will remain productive in the long term. Practices such as intensive tillage, monocropping, excessive use of agrochemicals, depletion of organic matter, residue burning in fields adversely affect the soil biodiversity and may impede the services rendered by soil. Hence it is essential to adopt practices which augment soil biodiversity and keep the soil healthy for sustainable food production. To restore and improve soil biodiversity practices such as crop rotation, conservation tillage, biofertilizer application, green manuring, addition of composts, good quality of irrigation water are to be adopted. Adoption of organic and natural farming encourage the soil biodiversity through enrichment of soil with organic inputs and biological control of pest and diseases. In view of changing climate scenario, the loss of soil microbial diversity is a major threat for sustainable food production hence it is essential to adopt the practices which will restore and augment soil microbial diversity for long term soil services.

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