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Unveiling Nature's Guardians: How Microbes Elevate Soil Fertility

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SUMMARY

The primary focus of the article revolves around the impact of microbial actions in enhancing soil productivity. Soil functions as a home to a diverse array of microorganisms and larger organisms, collectively contributing to the upkeep of biogeochemical cycles within the environment. These organisms serve as a crucial link between living organisms and non-living elements, playing a pivotal role in sustaining this connection. The article provides a comprehensive overview encompassing various categories of soil microbes, their ecological significance, and their contributions towards enhancing soil fertility.

INTRODUCTION

Soil represents a complex blend of organic matter, minerals, gases, liquids, and living organisms that collectively nurture life. Its roles encompass serving as a foundation for plant development, a reservoir for water storage, distribution, and purification, an influencer of Earth's atmosphere, and a habitat supporting various organisms. The field of soil science is divided into two main branches: Edaphology, which explores how soil impacts living organisms, and Pedology, which delves into the genesis, physical characteristics (morphology), and categorization of soils in their natural settings. An average soil composition comprises around 50% solids (comprising 45% mineral matter and 5% organic material) and 50% voids or pores, where half the space is filled with water and the other half with gases.

Soil texture is determined by the proportions of sand, silt, and clay particles. The percentages of soil minerals and organic content typically remain relatively constant, whereas soil water and gas content fluctuate significantly—when one increases, the other decreases in equilibrium. Pores in the soil facilitate air and water movement, both crucial for supporting life within it. Soil fertility denotes the soil's capacity to sustain agricultural plant growth, offering a suitable habitat for plants and ensuring consistent, productive yields of high-quality crops. Plants engage in various interactions with the myriad organisms inhabiting the soil, ranging from competitive to exploitative, neutral, commensal, and mutually beneficial relationships (Jacoby et al., 2017).

Factors That Enhance Soil Fertility:

- Adequate soil depth that allows for optimal root growth and effective water retention.
- Efficient internal drainage ensuring ample aeration, crucial for ideal root development.
- Presence of a well-structured topsoil or horizon O containing adequate soil organic matter, fostering healthy soil structure and moisture retention.
- Maintaining a soil pH within the range of 5.5 to 7.0.
- Essential plant nutrients available in adequate concentrations and accessible forms for plant uptake.
- Existence of a diverse array of microorganisms that actively support and facilitate plant growth.

Soil Microbiology:

Soil Microbiology involves studying the diverse organisms present in soil, their roles, and their impact on soil characteristics. This field classifies these organisms into categories such as bacteria, actinomycetes, fungi, algae, protozoa, and viruses. Importantly, these organisms do not operate in isolation; their interactions significantly influence soil fertility, sometimes to a greater extent than their individual actions. There exists immense potential for enhancing soil fertility through microorganisms. These microorganisms possess regulators and catalysts crucial for nutrient recycling within the soil, converting nutrients into accessible inorganic forms that boost soil fertility. This, in turn, improves soil health and functionality, ultimately reducing agricultural input costs and enhancing crop profitability (Mohamed et al., 2021).

Bacteria: Microscopic and abundant, a single teaspoon of fertile soil can contain anywhere from 100 million to one billion bacteria. They function as decomposers, breaking down dead plant material and organic waste to release nutrients.

Soil Microbe

Actinomycetes: Similar to both bacteria and fungi, actinomycetes contribute to the characteristic smell of soil.

Fungi: These organisms, distinct from both plants and animals, form hyphae that aggregate into mycelium, often spanning several meters in length but less than 0.8 mm in width (Figure 1). Fungi are beneficial as they possess the ability to decompose nutrients that other organisms cannot. They establish beneficial relationships with plant roots in a symbiotic association known as mycorrhizal, where fungi provide essential nutrients to the plant while receiving carbohydrates in return. However, some fungi can function as parasites, attaching themselves to plants to acquire nutrients.

Fungal filaments or hyphae extending into soil

Actenomycetes: Algae inhabit most soils where there is both moisture and sunlight. Typically, their population in the soil varies between 100 to 10,000 per gram of soil.

Functions and Roles of Algae in Soil:

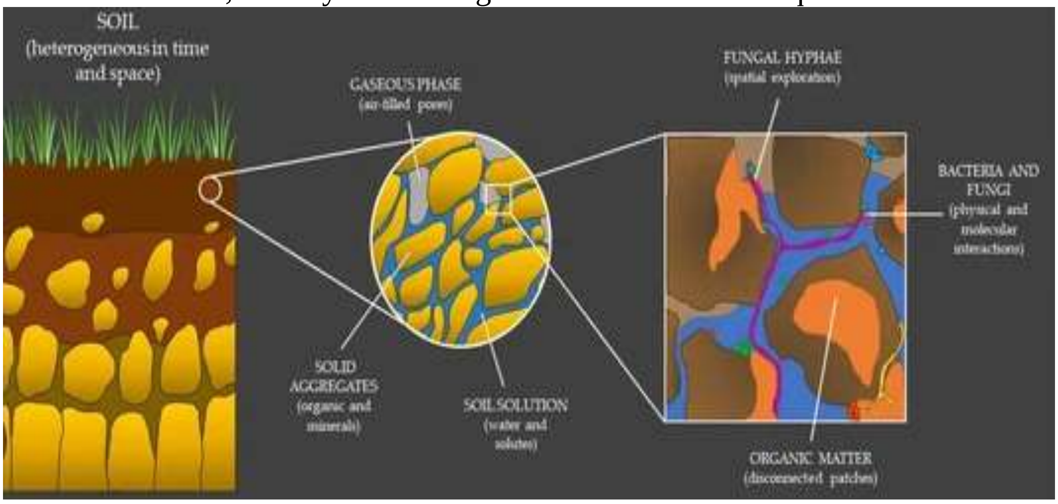
Algae contribute significantly to maintaining soil fertility, particularly in tropical soils.When algae die, they add organic matter to the soil, consequently augmenting the soil's organic carbon content. Acting as a binding agent, algae help in cementing soil particles, thereby mitigating and preventing soil erosion. They enhance the soil's water retention capacity, allowing it to retain water for more extended periods. Through photosynthesis, algae release substantial amounts of oxygen into the soil, facilitating aeration even in submerged conditions.

Protozoa:

Protozoa are colorless, single-celled organisms resembling animals. They are larger than bacteria, ranging from a few microns to a few millimeters in size. In arable soil, their population ranges from 10,000 to 100,000 per gram of soil, predominantly found in surface soil layers. Protozoa demonstrate resilience against adverse soil conditions due to a protected, dormant stage in their life cycle.

The primary functions, roles, and characteristics of protozoa include:

Nutritional Role: Protozoa primarily obtain their nutrition by consuming soil bacteria. Their feeding habits and ingestion of bacteria are crucial in maintaining a balance within the microbial community in the soil. They regulate the population size of soil bacteria, thereby influencing the overall microbial equilibrium in the soil ecosystem.



Functional Roles of Soil Microorganisms:

Releasing Nutrients from Organic Matter: Soil microorganisms play a significant role in breaking down organic matter, utilizing the carbon and nutrients present within it for their own growth. In this process of decomposition, they release excess nutrients back into the soil, making them available for plant uptake. However, if the organic matter has a low nutrient content, microorganisms will extract nutrients from the soil to fulfill their requirements.

Fixing Atmospheric Nitrogen: Certain symbiotic relationships, such as those between legumes (plants like peas, beans, or clover) and specific bacteria like rhizobia or bradyrhizobia, facilitate the fixation of nitrogen from the atmosphere. In this mutualistic association, these bacteria convert atmospheric nitrogen gas into a usable form for the legume plants. The bacteria obtain carbon from the plants in exchange for providing nitrogen. Moreover, various other nitrogen-fixing bacteria and cyanobacteria like Azotobacter sp., Bacillus sp., Beijerinckia sp., Clostridium sp., Klebsiella sp., Nostoc sp., Anabaena sp., Anabaenopsis sp., among others, also contribute to elevating the nitrogen levels within the soil.

Functions and Roles of Soil Microorganisms:

Increasing Phosphorus Availability: Phosphate solubilizing bacteria and fungi contribute to enhancing phosphorus availability in the soil. Additionally, the symbiotic relationship between most agricultural plants and mycorrhizal fungi assists in boosting phosphorus uptake by plants. These fungi extend hyphal strands from plant roots into the soil, accessing phosphorus beyond the reach of plant roots.

Degrading Pesticides: Microorganisms primarily facilitate the degradation of agricultural pesticides in soil. Some soil microorganisms produce enzymes capable of breaking down these pesticides or other toxic substances added to the soil. The duration these substances persist in soil depends on their susceptibility to degradation by microbial enzymes.

Controlling Pathogens: While certain microorganisms and soil-dwelling animals can infect plants and diminish plant yield, many soil organisms aid in controlling the spread of pathogens. For instance, certain protozoa consume pathogenic fungi, decreasing their occurrence in the soil. Numerous relationships within the soil food web function to reduce the abundance of plant pathogens.

Improving Soil Structure: Biological processes in the soil contribute to enhancing soil structure. Certain bacteria and fungi produce substances during the decomposition of organic matter that bind soil particles chemically and physically into micro-aggregates. The hyphal strands of fungi intertwine soil particles, aiding in the formation and maintenance of aggregates, which safeguard the soil against erosive forces.

Role in the Carbon Cycle: Microorganisms play a crucial role in the carbon cycle, facilitating the exchange of carbon among the biosphere, pedosphere, geosphere, hydrosphere, and atmosphere. Many fungi and bacteria attack cellulose and release carbon as part of this cycle. For instance:

- Fungi such as Trichoderma sp., Aspergillus sp., and Penicillum sp. target cellulose.
- Certain fungi like Marasmius sp., Ganoderma sp., Psalliotta sp. attack lignin.
- Bacteria contribute to degrading cellulose and hemicelluloses.
- Actinomycetes sp. also play a role in breaking down lignin.

Nitrogen Cycle: Microbes play a fundamental role in the nitrogen cycle by converting atmospheric nitrogen gas (N2) into biologically accessible forms through nitrogen fixation. This process is primarily carried out by two groups of microorganisms:

Symbiotic group: Including Rhizobium sp. in legumes.

Non-symbiotic group: Comprising aerobic autotrophs like Nostoc sp., Anabena sp., aerobic heterotrophs such as Azatobacter sp., Pseudomonas sp., anaerobic autotrophs like Chlorobium sp., Chromatium sp., and anaerobic heterotrophs such as Clostridium sp., Desulfovibrio sp. Microbes fix approximately 60% of nitrogen to meet plant requirements.

Phosphorus Cycle: Microorganisms significantly influence the phosphorus cycle, particularly in phosphate solubilization. Fungi and bacteria like Aspergillus, Penicillum, Bacillus act as potential solubilizers of bound phosphates. Plant growth-promoting rhizobacteria (PGPR) exhibit phosphate solubilization abilities, thereby making phosphorus more available to plants through mineralization and solubilization processes.

Sulfur Cycle: Soil microbes, including chemoautotrophic and photosynthetic bacteria, are involved in oxidizing elemental sulfur and inorganic sulfur compounds (e.g., H2S, sulfite, thiosulfate) into sulfate (SO4). Examples of sulfur oxidizing microorganisms include Thiobacillus, Beggiatoa, Thiothrix, Thioploca, Aspergillus, Penicillium. Meanwhile, sulfur-reducing microorganisms like Desulfovibrio and Desulfatomaculum sp. reduce sulfate to hydrogen sulfide (H_2S).

Biofertilizers: These are microbial inocula contained within carriers, comprising efficient strains of specific microorganisms that enhance soil fertility through various means such as nitrogen fixation, solubilization or mineralization of nutrient elements, decomposition of organic waste, and the production of plant growth substances. Examples include nitrogen-fixing microbes like Azotobacter, Beijerinkia, Clostridium, Rhizobium, and phosphate-solubilizing bacteria such as Bacillus subtilis, Pseudomonas striata, and fungi like Penicillium sp., Aspergillus awamori.

Microbes in Biodegradation: Biodegradation refers to the breakdown of materials through biological means, carried out by bacteria, fungi, or other biological agents. The term was first documented in biological texts in 1961. When discussing the breakdown of material into its base components of carbon, hydrogen, and oxygen by microorganisms, the term "biodegradation" is used. Biodegradable matter primarily consists of organic material that serves as nutrition for microorganisms. This organic material can undergo degradation either aerobically (in the presence of oxygen) or anaerobically (in the absence of oxygen). Various factors influence biodegradation, including the composition of the microbial community, oxygen availability, nutrient content, as well as abiotic factors such as temperature, pH, salinity, and light exposure.

CONCLUSION

Soil plays a vital role in maintaining biodiversity both above and below ground. The diversity of life beneath the soil is extensive but often underestimated, with millions of microorganisms inhabiting a mere few grams of topsoil. A substantial amount of organisms (up to 2 tons per hectare) reside in the surface 10 centimeters of cropping soil, and a significant portion of these organisms (about 25%) inhabit the top 2 centimeters. It is crucial to conserve the microbial community in soil through comprehensive exploration and conduct of adequate studies to appreciate and preserve this vital component of ecosystems.

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