Unveiling the Green Beneath: A Comprehensive Review of Microbial Contributions in Agriculture

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Agriculture is a diverse network of plant-microorganism interactions. There is an increasing demand for ecologically compatible, environmentally friendly agricultural techniques that may provide a plentiful supply of nutrients for the growing human population through better quality and quantity of agricultural products and services. Although soil is the primary source of plant nutrients, soil quality is required for agricultural production. Soil microorganisms (bacteria, fungus and protists) present in the soil system can improve soil quality and maintenance. Farmers commonly think of bacteria as pests that ruin their crops, although many microbes are beneficial. Soil microorganisms, particularly bacteria and fungus are essential for decomposing organic matter, recycling old plant material and forming interactions with plant roots that deliver critical nutrients such as nitrogen and phosphorus. Fungi can colonize the higher sections of plants and provide numerous benefits such as drought endurance, heat tolerance, insect resistance and plant disease resistance. Microbes are major catalysts of global carbon and nitrogen cycles in terrestrial ecosystems including the generation and consumption of greenhouse gases in soil. While decomposing organic matter in soil, some bacteria produce the greenhouse gases carbon dioxide (CO_2) and nitrous oxide (N_2O). Others consume methane (CH_4) from the atmosphere, so contributing to climate change mitigation. Each of these processes is influenced by human activity and has an impact on the warming potential.

Soil microbes

Microbes are the most ancient form of life on Earth, accounting for a huge portion of the planet's living material. They are microscopic organisms that are too small to be seen with the naked eye. Soil bacteria perform critical roles in ecosystems, influencing a wide range of critical ecosystem processes such as nutrient absorption, nitrogen cycling, carbon cycling, and soil formation. Efficient and potential soil microorganisms including all five major groups i.e. bacteria, viruses, fungi, algae and protozoa can significantly benefit the Agricultural practices (Bagyaraj and Rangaswami, 2007)

Bacteria: Bacteria are small, single-celled organisms that flourish in a wide range of settings. They can be found in animals' digestive systems, the ocean and fresh water, compost piles (even at temperatures above 130°F), and soils. Their number per gram of soil reaches from 100,000 to several hundred millions. Arthrobacter, Bacillus, Pseudomonas, Clostridium and Micrococcus are common soil microorganisms.

Fungi: Fungi are eukaryotic organisms, which means that their cells include membrane-bound organelles and clearly defined nuclei. They are more abundant in the surface layers of well-aerated and cultivated soils, and they predominate in acidic soils. The physical structure of soil is improved by the accumulation of mold mycelium within it. Soil fungi include Aspergillus, Mucor, Penicillium, Trichoderma, Alternaria, Fusarium and Rhizopus.

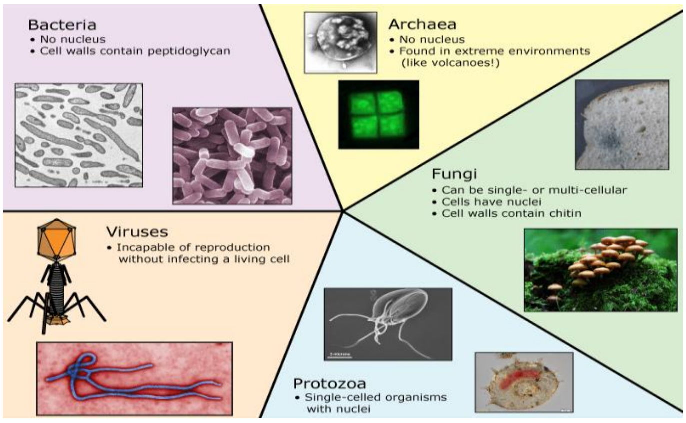

Figure 1: The different types of microbes

Algae: They have a lower population density than bacteria and fungus. They exist on the soil's surface or subsurface. Algae may grow in relatively dry soils (100 to 10,000 per gram of soil) and develop mutually beneficial interactions with other creatures. Lichens on rocks are a combination of a fungus and an alga. Green algae and diatoms are the most common.

Protozoa: Protozoa are unicellular organisms with populations ranging from 10,000 to 100,000 per gram of soil. They are mostly secondary organic material consumers, feeding on bacteria, fungi, other protozoa, and organic molecules dissolved in soil water. Protozoa are thought to be responsible for mineralizing (releasing nutrients from organic molecules) much of the nitrogen in agricultural soils by grazing on nitrogen-rich organisms and excreting waste. The majority of soil forms are flagellates, amoebae, or ciliates. They feed on soil bacteria and are found in abundance in the upper layer of the soil. They maintain the biological balance in the soil.

Viruses: Viruses are microscopic parasites that are far smaller than bacteria. They are unable to thrive or multiply outside of a host body. Bacterial, plant, and animal viruses enter soil by the addition of plant and animal wastes.

Microbial diversity and its interaction with plant-soil system

Soil microorganisms such as bacteria, algae, fungus, protozoa, and infective agents such as viruses are the bodies that exist among the vast resources of microscopic diversity. These soil microorganisms have various beneficial roles as well as some negative effects. The impact of soil biota in the soil profile is diverse and challenging since the same action can be destructive or beneficial depending on its position. Plants, on the other hand, exhibit a diverse spectrum of interactions with these soil microbes, extending the complete range of biological possibilities (competitive, exploitative, neutral, commensal and mutualistic).

Figure 2: Interaction among microbes and plants within the soil system (Source: Toor and Adnan, 2020)

As the interactions between plant and microscopic communities are influenced by various agronomic managements and biological factors, particularly in the current situation of global revolution, the impact of ecological stress factors must be considered, as they affect proper management of crop-micro biome interactions. The creation of soil with a high level of soil fertility is the consequence of hundreds of years of soil "evolution"; this assertion is not surprising given the complicated interactions between microbes and the plant-soil system. Figure 2 depicts the interaction of bacteria and plants within the soil system.

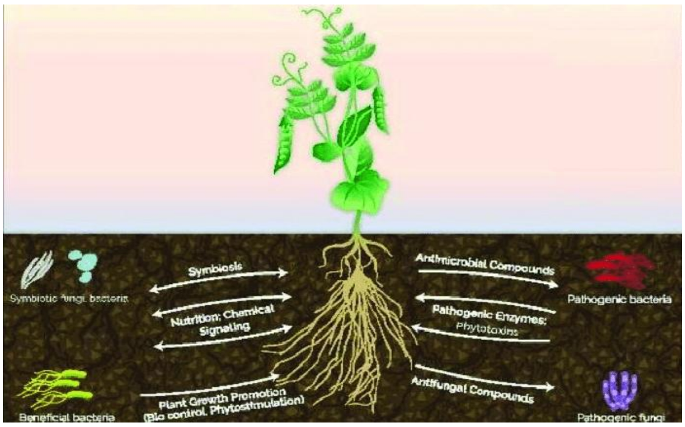

Figure 3: Schematic diagram of plant-soil interaction in rhizosphere (Source: Bramhachari et al., 2015)

Soil microorganisms (bacteria and fungus) are required for organic matter decomposition and the recycling of old plant material. Some soil bacteria and fungus create interactions with plant roots, supplying essential nutrients such as nitrogen and phosphorus. Fungi can colonize the higher sections of plants and provide numerous benefits such as drought endurance, heat tolerance, insect resistance, and plant disease resistance. Viruses are almost always thought of as disease agents. This is due to the fact that the ones that cause disease have been investigated. Although half of the wild plants have viruses, the majority do not appear to be sick. The viruses appear to be harmlessly living in the plants.

Importance of soil microbes to plants

Plants cannot acquire nutrients from soil unless bacteria work in the soil. Microbes are alive and require sustenance to survive, which comes from organic stuff. Microbes assimilate numerous components such as nitrogen, carbon, oxygen, hydrogen, phosphorus, potassium, and micronutrients for plants as they consume food. Microbes are responsible for converting NPK and minerals into a form that plants may use for growth and development. The following are some of the most important roles of soil microorganisms.

Production of plant growth regulators

Plant growth regulators are synthetic chemicals that are useful in agriculture because they govern plant development. Various soil microorganisms, including bacteria, fungus and algae are responsible for creating physiologically active chemicals such as plant growth regulators, which can influence plant growth and development (Ahemad and Kibret, 2014). Plant growth promoting rhizobacteria (PGPR) can modify root architecture and promote plant growth by producing phytohormones such as indole acetic acid (IAA), gibberellic acid (GA), cytokinins, and important metabolites such as siderophores, HCN, and antibiotics (Kloepper et al., 2007).

Plant growth may be aided by PGPR through the suppression of root pathogens via the production of siderophores (compounds secreted by microorganisms that bind iron, making it less available to pathogens) or the production of antibiotics, nitrogen fixation, and plant hormone production. Plant growth and root colonization are stimulated by PGPR when combined with mycorrhizae. PGPR has had some success in agriculture, and commercial preparations are imminent. Rhizobium symbiosis with legumes and free-living associative rhizosphere soil bacteria Azotobacter and Azospirillum are two of the most important. Rhizobacteria, primarily Pseudomonas, Erwinia, Flavobacterium and Bacilli are another category of beneficial microbes that increase agricultural plant health and productivity through a range of secondary metabolites and are involved in root growth promotion.

Table 1: Production of plant growth regulators (PGRs) by PGPR (Source: Prasad et al., 2015)

PGPR	PGRs	Plant	References
Pseudomonas fluorescens	Indole-3-acetic acid	Groundnut	Dey et al. (2004)
Azospirillum lipoferum strains 15	Indole-3-acetic acid	Wheat	Muratova et al. (2005)
Bacillus sp.	Indole-3-acetic acid	Rice	Beneduzi Paenibacillus et al. (2008)

Nutrient management

Nutrient management encompasses conservation measures that directly or indirectly aid in the optimization of use in nutrient use efficiency, hence improving plant quality, soil health, and the environment. Microbes in the soil and atmosphere play an important role in nutrient management. Soil microorganisms, notably bacteria and fungi, are shown to be critical in digesting organic materials in the soil and recycling organic leftovers. Many substances are secreted from various sections of the plant root system, which may generate a unique environment in the rhizosphere. These substances are known as root exudates.

Several environmental factors e.g. temperature, light, age and soil type can directly or indirectly affect the nature and timing of root exudation. Potentiality of microbes such as Aspergillus niger, A. chroococcum, Azospirillum brasilense, Bacillus subtilis, Pseudomonas corrugata, Rhizobium sp. and Streptomyces nojiriensis in enhancing plant growth as well as pest and disease suppression has been reported (Bhattacharyya and Jha, 2012).

P solubilising Biofertilizers (PSB)

The amount of phosphorus available for plant growth is determined not only by the overall amount of phosphorus in the soil, but also by its solubility. The amount of P available to plants is determined by the composition of the soil (soil texture) and its acidity (pH) (Muraleedharan et al., 2010). Inorganic phosphate compounds such as tricalcium phosphate, dicalcium phosphate, hydroxyapatite, and rock phosphate can be solubilized by several bacterial and fungal taxa. Among the bacterial genera with this capacity are Pseudomonas, Bacillus, Rhizobium, Burkholderia, Achromobacter, Agrobacterium, Microccocus, Aereobacter, Flavobacterium and Erwinia.

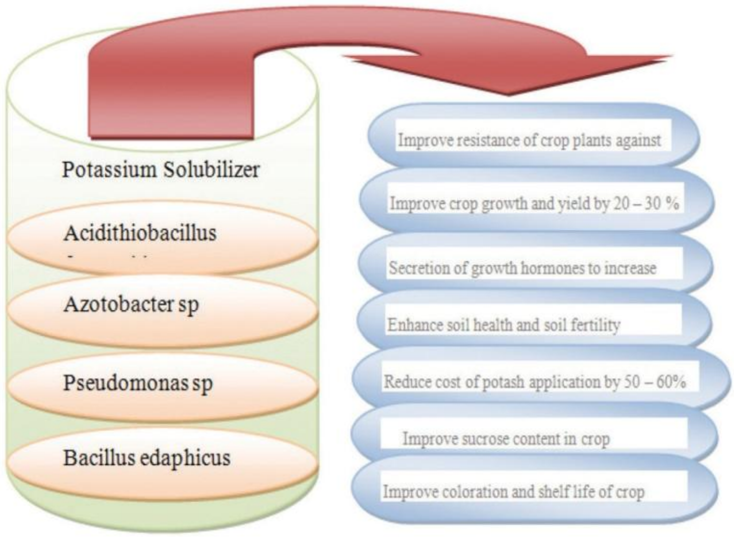

Figure 4: Role of potassium solubilizers in agriculture (Toor and Adnan, 2020)

Nitrogen fixing biofertilizers

Nitrogen is a vital ingredient for all forms of life. It can be present in amino acids, proteins, and many other chemical substances. Nitrogen is a minor mineral nutrient that regulates the strength of organic matter formation. The atmosphere is the source of soil nitrogen, with nitrogen gas accounting for around 79% of total atmospheric gases. Although nitrogen is abundant in nature, it frequently limits plant productivity because atmospheric nitrogen is only available to a narrower variety of organisms that symbiotically and non-symbiotically associate with higher plants (Franche et al., 2009). Global nitrogen consumption is roughly 2.6x1011 kg per year, with biological nitrogen fixation accounting for nearly 70%.

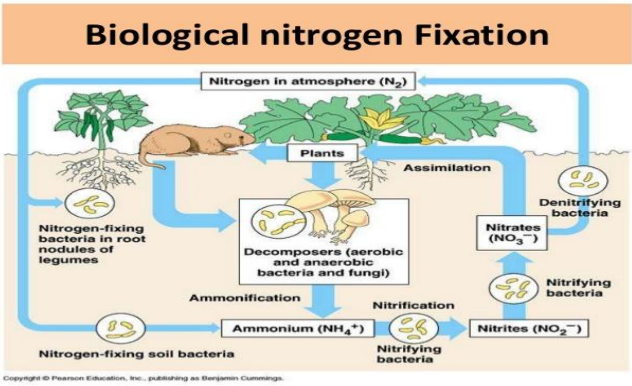

Figure 6: Biological Nitrogen Fixation
(Source: https://socratic.org/questions/how-can-nitrogen-be-fixed-naturally-for-plant-use)

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