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SOIL MICROBIOME: ROLE IN AGRICULTURE AND AGRONOMIC MANAGEMENT

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ABSTRACT

The soil microbiome, comprising bacteria, fungi, and archaea, is pivotal in agriculture. These microorganisms enhance nutrient availability through biological nitrogen fixation, phosphorus solubilization, potassium mobilization, and siderophore production, thus boosting soil fertility and crop yields. They also improve soil structure, suppress pathogens, and support plant growth through symbiosis. However, they can cause nutrient losses and harbor harmful pathogens, affecting plant health. Understanding these interactions informs sustainable farming practices, potentially reducing reliance on synthetic fertilizers and chemicals, thereby promoting eco-friendly agriculture and improved crop productivity.

KEYWORDS: Decomposition, Nutrient Cycling, Soil Microbiome, Sustainable Agriculture

INTRODUCTION

The soil microbiome, a complex community of microorganisms including bacteria, fungi and archaea, plays a crucial role in agriculture. On the positive side, these microorganisms drive nutrient cycles like biological nitrogen fixation, solubilization of insoluble phosphorus, mobilization of potassium, and siderophores production for enhancing iron availability and mineralization of other nutrients. They also improve soil structure, suppress pathogens through induced systemic resistance and facilitate plant growth through symbiotic relationships, leading to improved crop yield and soil fertility. However, the soil microbiome can also cause nutrient losses through nitrification/ denitrification and harbor harmful pathogens, that negatively affect plant health and productivity (Pasmionka et al., 2021). Understanding the soil microbiome's intricate interactions and functions, both beneficial and detrimental, opens new avenues for sustainable farming practices and effective agronomic management. Hence, soil microbiome pave the way for eco-friendly farming approaches by substituting the use of synthetic and harmful chemicals and fertilizers.

ROLE IN DECOMPOSITION

Decomposition is a biological process driven by various microorganisms that convert complex biomass compounds into simpler molecules through oxidative or enzymatic hydrolysis. This process involves different thermophilic stages: mesophilic, thermophilic, cooling, and maturation phases, which together complete the composting process. The result is a stable, dark, and nutrient-rich substrate similar to humus, with its specific composition varying based on the original waste material.

The dominant bacterial phyla and their specific role at respective stages in the composting process (Ana et al., 2023) are as follows:

Bacterial phyla	Role	Dominant stages	Temperature range
Firmicutes	Lignocellulose degradation	Mesophilic stage	20-60°C
Proteobacteria	Mineralization of nitrogenous organic substrate under anaerobic conditions	Mesophilic	20-50°C
Actinobacteria	Degradation of recalcitrant materials and suppression of pathogens	Thermophilic stage	50-60°C
Bacteroidetes	Lignocellulosic biomass decomposition under anaerobic conditions	Cooling phase	-
Chloroflexi	Biogeochemical cycle of chlorine	Maturation phase	-

In comparison to bacteria, fungi are the dominant and efficient organic compound decomposers, attributed to their hyphae - producing nature. Basidiomycota and Ascomycota are worth mentioning examples.

ROLE IN NUTRIENT ACQUISITION

The positive impact of fungi on nutrient uptake is due to three main factors:

- Enhanced absorption of accessible nutrients from the soil through the expansion of root surface area.
- Improved nutrient availability by solubilizing insoluble nutrients, such as phosphorus.
- Increased nutrient mobility due to faster intracellular transport.

The nitrogen - fixing ability of several microorganisms had already been exploited. With or without the formation of association with plant system, either having nodule formation or not, the nitrogen - fixing bacteria contributes to a significant amount of nitrogen fixation inside the soil. The increased soil nitrogen status will further enhance crop growth, supporting improved yield. Plant growth-promoting rhizobacterial strains, mainly *Bacillus pumilus* S1r1 and *Klebsiella pneumoniae* Fr1 significantly increased the biomass yield of maize (67.98 and 67.20 g plant-1, respectively). Greater increment noted in *Bacillus pumilus* S1r1 was attributed to better biological nitrogen fixation (up to 304 mg N2 fixed plant^{-1}) and other plant growth-promoting abilities like, indole acetic acid (IAA) production and phosphate solubilization (Kuan et al., 2016).

The potassium mobilization and release from the fixed sites of soil is mediated by soil microorganisms, which will increase the different fractions of potassium, thereby contributing to crop growth and development. Basak and Biswas (2019) reported that inoculation of *Bacillus mucilaginosus* significantly improved the potassium (K) solubilization and K release from the waste mica, which increased the biomass yield and K uptake of sudan grass by more than 1.3 and 1.5 times, respectively in comparison to without inoculation.

The formation of the siderophore metal complex by bacteria increases the uptake of several essential micronutrients, especially iron which will be present in ferric form, an unavailable form for plants. These siderophores from bacteria will take the ferric form of iron, even under deficit conditions and will cross the cell's outer layer through specialized channels, which later release these ions into the cytoplasm. The low molecular weight siderophores produced by Bacillus subtilis LSBS2 were found to increase the iron content in leaf, shoot and seed of sesame (484, 563 and 562.6 µg g-1, respectively). Along with the ability of IAA production and phosphorous solubilization, Bacillus subtilis inoculation recorded higher dry weight (2 g plant-1) and pod number (12 plant-1) than control and pure siderophore inoculation (Nithyapriya et al., 2021).

ROLE IN SOIL AGGREGATION

Soil microorganisms produce a wide array of organic compounds, that can bind soil particles, form aggregates and improve their stability. Glomalin, a glycoprotein produced in the hyphae of *Gigaspora gigante* had higher insolubility and hydrophobicity, imparting greater stability to soil aggregates. The iron content of glomalin (0.8 - 8.8 %) was considered as the main reason for soil aggregation, as the low inherent iron content of Texas soil resulted in decreased aggregate stability (Wright and Upadhyaya, 2018).

ROLE IN STRESS ALLEVIATION

Stress is anything that hinders plant growth. Microorganism have their role in both, causing stress and curbing as well. Apart from biotic factors, heavy metal, water deficiency, salinity and extreme temperatures have negative impacts on crop growth, which constitute an abiotic group of stress factors. However, microorganisms can reduce the impact of these factors on crop performance. Wu et al. (2016) reported that the arbuscular mycorrhizal fungi, *Rhizophagus irregularis* produced significant amounts of extracellular polymeric substances on the fungal surface, which adsorbed and reduced Cr(VI) to Cr(III)-phosphate analogs. Additionally, the intraradical fungal structures and cell walls in mycorrhizal roots reduced Cr(VI) to Cr(III) and complexed Cr(III) by carboxylic ligands. Thus, reduced the Cr translocation to plant cytoplasm and imparted resistance against heavy metal stress.

The fungi and bacteria also have a role in defending the plant system by altering their gene expressions, to impart resistance against the infestation from harmful microbes. Xing et al. (2020) identified the resistance-inducing determinants from Bacillus simplex strain against soybean cyst nematode, *Heterodera glycines*. The six identified compounds, cyclic (Pro-Tyr), cyclic (Val-Pro), tryptophan, cyclic (Leu-Pro), uracil and phenylalanine reduced the development of nematodes in soybean roots. However, the first three compounds also had a role in reducing the nematode number.

ROLE IN NUTRIENT LOSSES

Under the nitrification process, ammonia gets oxidised into nitrite and then to nitrate, mediated by *Nitrosomonas europea* and *Nitrobacter winogradskyi*, respectively under aerobic conditions, leading to potential leaching loss of nitrogen from soil. However, the nitrate might get reduced into nitrous oxide and molecular nitrogen through denitrification by anaerobic bacteria like *Pseudomonas* sp. and Micrococcus sp. etc. (Pasmionka et al., 2021).

CONCLUSION

Soil microbiome has a significant role in agriculture and agronomic management. The role starts from solubilizing the unavailable form of nutrients to make them bioavailable and even controls the induction of systemic resistance against biotic stress. They also trigger the production on antioxidative enzymes to scavenge free radicals or reactive oxygen species produced in plants under different stress situations. Hence, there is a need to preserve, support and enhance the growth of soil microbiome, which has huge potential to replace substantial amounts of inorganic fertilisers and synthetic protection chemicals. Thus, acts as a major step towards sustainable production.

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