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Biofertilizers in Agriculture: Boosting Plant Growth and Soil Fertility

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SUMMARY

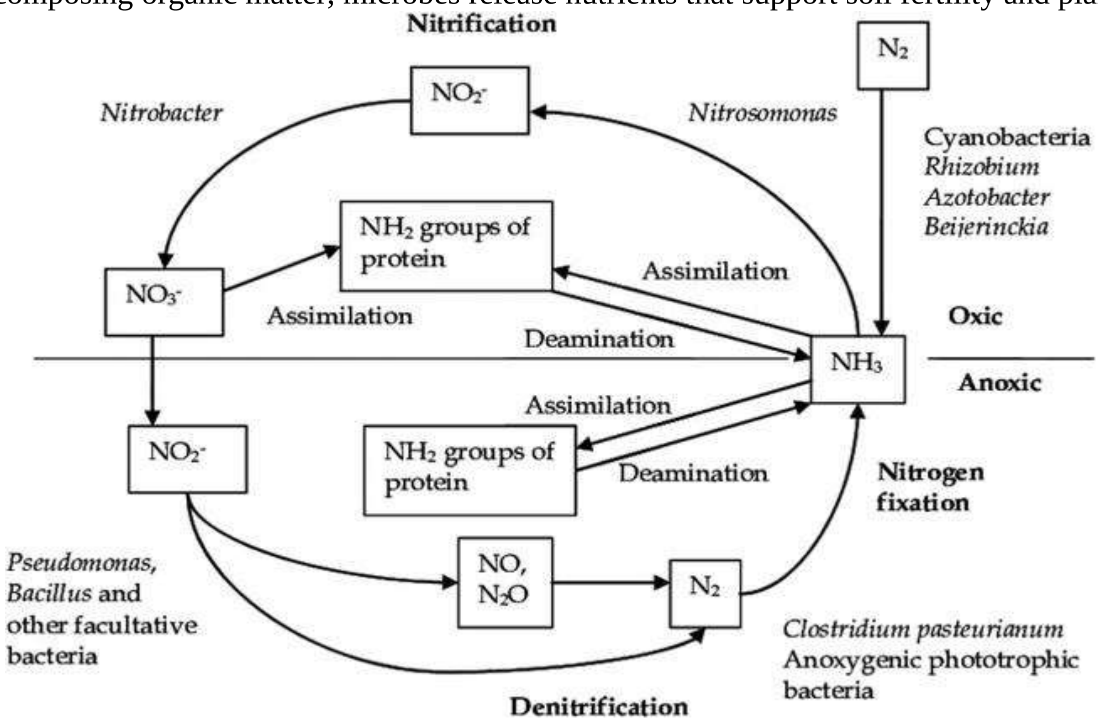
In developing countries, one of the key challenges is meeting the food demands of a rapidly growing population while managing limited arable land. In this scenario, biofertilizers emerge as a highly promising solution. These biologically sourced products help reduce reliance on energy-intensive chemical inputs, making them an affordable and eco-friendly alternative for small and marginal farmers. Biofertilizers, which consist of beneficial microbes, play a crucial role in enhancing soil fertility by extracting nitrogen from the atmosphere, solubilizing phosphorus, and making it available to plants. This process improves the overall health of the soil and supports a thriving crop-microbial-soil ecosystem. By promoting sustainable agricultural practices, biofertilizers contribute to long-term ecological stability, enhance environmental quality, and increase food security. Moreover, their use reduces environmental pollution from synthetic fertilizers, offering a more sustainable path for food production in resource-limited settings.

INTRODUCTION

The overuse of chemical fertilizers has led to soil degradation, prompting interest in biofertilizers as eco-friendly alternatives. Biofertilizers, including bacterial, fungal, and algal bioinoculants, offer significant potential for transforming agriculture, particularly in developing countries. A deeper understanding of their mechanisms and ensuring high-quality standards are crucial for optimizing their benefits. These microorganisms enhance nutrient uptake and soil processes, making nutrients more available to plants. Biofertilizers are cost-effective and essential for integrated nutrient management, though they can't yet fully replace chemical fertilizers. Research shows they also promote root growth and increase enzyme activity in crops.

Role of Microbes in Nutrient Transformation

Microbes play a vital role in soil nutrient cycling by converting nitrogen, phosphorus, and sulfur into plant-available forms. Nitrogen-fixing bacteria, nitrifying bacteria, and denitrifying bacteria regulate nitrogen, while mycorrhizal fungi enhance phosphorus uptake. Sulfur-oxidizing bacteria convert sulfur compounds into sulfate. By decomposing organic matter, microbes release nutrients that support soil fertility and plant health.



Nitrogen Transformation

Nitrogen transformations in the soil involve specific groups of microbes that convert nitrogen into organic, inorganic, and volatile forms. Additionally, a small portion of the vast nitrogen reservoir (N2) in the atmosphere is converted into organic compounds by certain free-living microorganisms or through plant-microbe associations, making nitrogen available for plant growth. While atmospheric nitrogen makes up about 78% of the air in its gaseous form, it cannot be directly utilized by plants and other organisms, a process known as biological nitrogen fixation. The following details describe the nitrogen transformations in soil and the microbial roles involved.

Biological Nitrogen Fixation

Biological nitrogen fixation is a key part of the nitrogen cycle, where specific soil microorganisms convert atmospheric nitrogen into forms that plants can use. This nitrogen-fixing ability is limited to certain bacteria and a few actinomycetes, collectively known as diazotrophs. These diazotrophic microbes are widespread in soil and are classified based on how they fix nitrogen for plants, as shown in Table 1.

S. No.	Groups	Examples
1	Free living	Azotobacter, Beijerinckia, Clostridium, Anabaena, Nostoc
2	Symbiotic	Rhizobium, Frankia, Anabaena azollae
3	Associative Symbiotic	Azospirillum

Biological nitrogen fixation was first documented in the anaerobic bacterium *Clostridium pasteurianum*, from which the enzyme nitrogenase was isolated. However, this organism is not commercially utilized for nitrogen fixation today. Nitrogen fixation is facilitated by the enzyme nitrogenase, which reduces atmospheric nitrogen into ammonia. All diazotrophs are known to possess this enzyme and follow a similar mechanism for nitrogen fixation.

Important diazotrophs in commercial use

Rhizobium is the most extensively studied bioinoculant, forming a symbiotic relationship with leguminous plants. It was first demonstrated by Boussingault that leguminous plants can fix atmospheric nitrogen, a process later clarified by Hellriegel and Wilfarth, who showed that bacteria in the roots of these plants are responsible for this fixation. The purified bacterium has been thoroughly studied, and now, well-established nitrogen-fixing strains are available for commercial use. Rhizobium is specific to legume crops, forming nodules in the plant roots and enriching soil fertility even after the crop is harvested, making it a preferred bioinoculant. In addition to root-nodulating Rhizobium, there are strains like *Azorhizobium* found in *Sesbania rostrata*, which nodulate stems. Rhizobium species are specific to legumes due to the nod factors they produce. However, some leguminous plants can form effective nodules when inoculated with Rhizobium strains from other legume groups, a process known as cross-inoculation, as shown in Table 2.

Rhizobium spp.	Crops	Host
Rhizobium leguinosarum	CIG	Host it can nodulate
Bv. viceae	Pea	Pea, lentils, vicia
Bv. phaseoli	Bean	Phaseolus spp
R. meliloti	Alfalfa	Alfalfa, clover, fenugreek
R. loti	Lotus	Trifoli, lupine
R. fredii	Soyabean	Soyabean
R. spp.	Cowpea group	Vigna, Arachis, Cajanus, Dolichus

Azospirillum

Azospirillum is a group of diazotrophic bacteria that form a symbiotic relationship with the roots of graminaceous plants, particularly rice. These microaerophilic, gram-negative bacteria fix atmospheric nitrogen and produce growth-promoting substances like indole-3-acetic acid (IAA). Key species include *A. brasilense*, *A. lipoferum*, *A. amazonense*, and *A. halopraeferens*.

Azotobacter

Azotobacter is a gram-negative, free-living bacterium found in the rhizosphere. It fixes nitrogen, produces auxins, and is used commercially as *Azotobacterin* for various crops. It also aids in bioremediation by mobilizing heavy metals and degrades aromatic compounds. Some species produce alginic acid, used in the medical and food industries.

Algal Biofertilizer

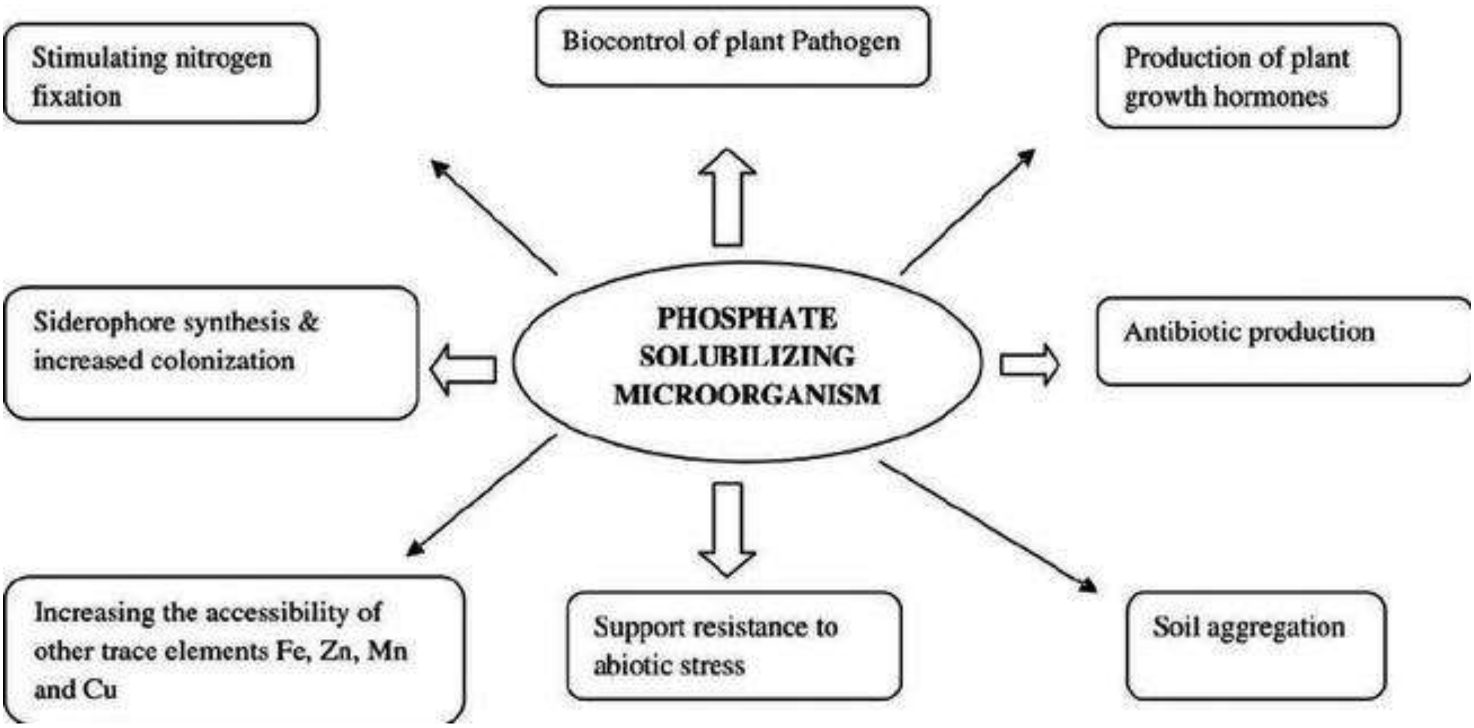
Blue-green algae, including species like *Gloeothece*, *Synechococcus*, *Anabaena*, and *Nostoc*, fix nitrogen and enhance soil fertility, particularly in rice. *Anabaena azollae* forms a symbiotic relationship with *Azolla*, a water fern, to reduce nitrogen needs by 20-25% in rice cultivation.

Phosphorus Solubilizing and Mobilizing Bioinoculant

Phosphorus is the second most important element for plant growth after nitrogen. While Indian soils often contain substantial amounts of inorganic phosphorus, it remains inaccessible to plants due to its insoluble form. Therefore, it must be solubilized for plant uptake. Additionally, phosphorus exists in organic forms in the soil, which must be mineralized for plants to utilize. Consequently, the mineralization and solubilization of phosphorus in soil are crucial for supporting plant growth.

Phosphorus Solubilizing Bioinoculant

Phosphorus is vital for plant growth but often inaccessible in soil due to its insoluble forms. Bioinoculants, such as *Bacillus megatherium*, *Bacillus subtilis*, and *Penicillium sp.*, solubilize phosphorus by producing organic acids, converting insoluble forms into absorbable ones. These bioinoculants help make phosphorus available for plant uptake, improving soil



Phosphorus Mobilizing Bioinoculant

Mycorrhizae, mutualistic fungi-plant relationships that have existed for over 450 million years, are found in 95% of vascular plants. These fungi enhance plant growth by increasing root surface area, improving nutrient and water uptake, mobilizing phosphorus, providing disease tolerance, and aiding nutrient recycling. Mycorrhizal fungi are categorized into ectomycorrhizas and endomycorrhizas. Ectomycorrhizas, found in woody plants, form a root sheath and improve nutrient absorption, particularly phosphorus, zinc, and copper. The fungus *Pisolithus tinctorius* enhances nutrient absorption in exchange for carbohydrates from the plant.

Endomycorrhizae

Endomycorrhizae, particularly arbuscular mycorrhizae (AM), involve fungi whose hyphae penetrate and colonize root cells. These fungi, from genera like *Gigaspora* and *Glomus*, form arbuscules to facilitate nutrient transfer and extend hyphae into the soil to increase nutrient and water access. The plant provides carbohydrates, while AM fungi produce vesicles for storage and spores that can endure extreme conditions, making them ideal for inoculants. Root colonization takes 2–6 weeks and persists throughout the plant's life.

Plant Growth Promoting Rhizobacteria (PGPR)

PGPR, such as *Pseudomonas*, *Bacillus thuringiensis*, and *Trichoderma viride*, colonize the rhizosphere to control pests and diseases. They produce siderophores, contributing to nitrogen fixation and nutrient transformations. PGPR enhance plant growth by producing growth regulators, improving root development, and boosting nutrient and water uptake. They also suppress pathogens through competition, antibiosis, and enzyme production. Notable PGPR include *Azotobacter*, *Azospirillum*, *Klebsiella*, *Pseudomonas*, and *Rhizobium*.

CONCLUSION

In developing countries, a major challenge is producing enough food for a growing population on limited land. In this context, biofertilizers offer a promising solution by replacing some energy-intensive inputs with biologically sourced products. For small and marginal farmers, biofertilizers present an affordable way to boost productivity. These microbes extract significant amounts of nitrogen from the atmosphere, solubilize phosphorus, and enrich the soil with this essential yet limited nutrient. By enhancing the crop-microbial-soil ecosystem, biofertilizers contribute to sustainable agriculture, promoting ecological stability and improving environmental quality.

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