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The role of biofertilizers in sustainable agriculture and soil improvement

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Abstract

The rapid growth of the global human population poses a significant threat to food security, as agricultural land is limited and, in some regions, steadily diminishing. Consequently, agricultural production must be substantially increased in the coming decades to meet the rising food demands. Moreover, the heavy reliance on chemical fertilizers to boost crop productivity can have detrimental effects on the environment, human health, and soil quality. In this context, the use of microbes as biofertilizers is gaining attention as a sustainable alternative to chemical fertilizers, owing to their immense potential in enhancing agricultural.

Keywords: Crop production, Soil health, Bio-fertilizers

Introduction

The term "bio-fertilizer" refers to a substance containing living microorganisms that enhance plant growth by improving the availability of essential nutrients to the host plant when applied to seeds, roots, or soil. Bio-fertilizers enrich plants through natural processes such as nitrogen fixation, phosphorus solubilization, growth stimulation, and the production of growth-promoting compounds. Their application can increase plant growth by 20-30%, replace up to 25% of artificial nitrogen and phosphorus fertilizers, and enhance overall plant health. Additionally, bio-fertilizers may confer resistance to drought and soil-borne diseases. By introducing beneficial microorganisms into the soil or onto plant surfaces, bio-fertilizers improve nutrient availability, support soil health, and enhance microbial activity (Bhattacharjee and Dey, 2014).

Agriculture is a cornerstone of national development and food security, making the maintenance of crop productivity and quality crucial for feeding populations and supporting exports. Over the years, scientific advancements have enhanced agricultural efficiency (Ajmal, 2018). Modern agriculture relies heavily on chemical fertilizers and pesticides to boost global food production. While these act as a rapid nutrient source, their indiscriminate use degrades soil quality, reduces fertility, and leads to the accumulation of heavy metals in plant tissues, negatively affecting the nutritional value and safety of crops (Farnia and Hasanpoor, 2015).

To address these challenges, organic fertilizers have been developed as natural stimulators of plant growth. Among these, bio-fertilizers contain plant growth-promoting microorganisms, such as nitrogen-fixing or phosphate-solubilizing microbes, which enhance nutrient availability. Given the increasing global demand for safe and nutritious food, sustainable agricultural practices, and concerns over environmental degradation caused by agrochemicals, organic farming and bio-fertilizers have become areas of significant research interest (Ghany et al., 2013).

Biological fertilization involves the use of organic inputs, including fertilizers, organic wastes, sewage, animal manure, and beneficial microorganisms such as bacteria and fungi. These inputs improve nutrient fixation in the rhizosphere, stimulate plant growth, enhance soil structure, provide biological control against pathogens, recycle nutrients, support mycorrhizal symbiosis, and aid in bioremediation of contaminated soils. Bio-fertilizers offer rapid productivity gains, consume less energy, prevent soil and water contamination, improve soil fertility, and promote antagonism against phytopathogens.

Classification of bio-fertilizers

Bio-fertilizers are classified based on the type of microorganism used and their functional role in agriculture:

a) **Rhizobium:** Rhizobium bacteria colonize legume roots and fix atmospheric nitrogen symbiotically. They are highly selective for nodulation and are classified into cross-inoculation groups, containing seven genera. Rhizobium is among the most efficient bio-fertilizers for nitrogen fixation.

b) **Azotobacter:** *Azotobacter chroococcum* is a common nitrogen-fixing species in arable soils. It produces slime that improves soil aggregation. Due to low organic matter and competitive soil microbes, its population in Indian soils rarely exceeds 10^5 g^{-1}.

c) **Azospirillum:** Species such as *Azospirillum lipoferum* and *A. brasilense* inhabit the rhizosphere and intercellular spaces of graminaceous plants. They provide associative nitrogen fixation and produce growth-promoting substances like IAA, enhancing drought tolerance and disease resistance.

d) **Cyanobacteria:** Free-living and symbiotic cyanobacteria (blue-green algae) have historically been used as bio-fertilizers in rice cultivation in India. They can contribute 20–30 kg N ha^{-1} under optimal conditions, though labor-intensive production limits their widespread adoption.

e) **Azolla:** Azolla, a free-floating water fern, hosts nitrogen-fixing cyanobacteria (*Anabaena azollae*). It can supply 40–60 kg N ha^{-1} per rice crop, serving as a partial substitute for synthetic nitrogen fertilizers and improving soil organic matter and potassium content.

f) **Phosphate solubilizing microorganisms (PSM):** Bacteria and fungi such as *Pseudomonas, Bacillus, Penicillium,* and *Aspergillus* release organic acids that solubilize bound phosphates, increasing phosphorus availability. Inoculation with these microbes enhances wheat and potato yields.

g) **Arbuscular mycorrhizal (AM) fungi:** Intracellular obligate fungi from genera such as *Glomus, Gigaspora,* and *Acaulospora* transfer nutrients from soil to root cells via arbuscules and vesicles. AM fungi enhance nutrient uptake, drought tolerance, and disease resistance.

h) **Silicate solubilizing bacteria (SSB):** SSB degrade silicates and aluminum silicates through organic acid production, releasing silicon and other nutrients such as potassium, calcium, magnesium, iron, and zinc.

i) **Plant growth-promoting rhizobacteria (PGPR):** PGPR colonize roots and the rhizosphere, promoting growth through nutrient acquisition, phytohormone production, and biocontrol of pathogens. Genera such as *Pseudomonas* and *Bacillus* produce IAA, cytokinins, gibberellins, and ethylene inhibitors, enhancing root development and nutrient absorption.

Methods of bio-fertilizer application

- **Seed Treatment:** Mix 200 g of bio-fertilizer with 300–400 ml water and coat 10 kg of seeds using adhesives like gum acacia or jaggery. Dry in the shade before sowing.
- **Seedling root dip:** Used for transplanted crops. Seedling roots are dipped in water containing recommended bio-fertilizers for 8–10 hours before transplanting.
- **Soil treatment:** Mix 4 kg of each bio-fertilizer in 200 kg of compost and leave overnight. Incorporate this mixture into the soil at the time of sowing or planting.

Key characteristics of bio-fertilizers

Biological nitrogen fixation: Nitrogen fixation in legumes was first identified by Hellriegel and Wilfarth (1886). Later, Beijerinck isolated *Rhizobium leguminosarum*, while Azotobacter and Clostridium strains were identified in the early 1900s. Nitrogen-fixing cyanobacteria were later discovered, providing significant benefits for plant growth (Stewart, 1969; Barman et al., 2017).

Specific bio-fertilizers

- **Rhizobium:** Supplies reduced nitrogen to legumes, enhancing plant growth.
- **Azospirillum:** Improves germination, nitrogen accumulation, and yield.
- **Azotobacter:** Produces gibberellins and cytokinins, mitigating stress.
- **Azolla:** Supplies nitrogen and improves wetland rice soil properties.
- **Phosphate mobilizers:** Increase phosphorus availability in both acidic and calcareous soils via P-solubilization and mycorrhizal symbiosis.
- **K and Si solubilizers:** Release potassium and silicon from soil minerals, improving nutrient uptake and crop productivity.
- **Zn solubilizers:** Convert unavailable zinc to plant-accessible forms, enhancing growth and biofortification.
- **PGPR:** Enhance growth through direct nutrient provision, phytohormone production, and biocontrol of pathogens.

Table 1: PGPR and their effect on crop yields (Abd El-Lattief, 2016).

Plant Growth Promoting Rhizobacteria	Crop Parameter
Rhizobium leguminosarum	Direct the growth promotion of canola and lettuce.
Pseudomonas putida	Early developments of canola seedlings, growth stimulation in tomato plant.
Azospirillumbrasilense and A. Irakense	Growth of wheat and maize plants.
P. flurescens	Growth of pearl millet, enhance growth, leaf nutrient contents and high yield of banana.
*Azotobacter*and *Azospirillum*spp.	Growth and productivity of canola.
P. alcaligenes, *Bacillus polymyxa*, and *Mycobacterium phlei*	Improves the uptake of N, P and K by maize crop.
*Pseudomonas, Azotobacter*and *Azospirillum*spp.	Stimulates growth and increase the yield of chick pea.
R. leguminismarum and Pseudomonas spp.	Enhances the yield and phosphorus uptake in wheat.
*P. putida, P. flurescens, A. brasilense*and *A.lipoferum*	Enhances seed germination, seedling growth and yield of maize.
P. putida, P. fluorescens, P. fluorescens, P. putida, A. lipoferum, A. Brasilense	Enhances seed germination, growth parameters of maize seedling in green house and also gain yield on maize.

Table 2: Amount of nutrients fixed by some bio-fertilizers in various crops Kumar *el al*, 2017

Microorganisms used as Bio-fertilizer	Nutrient fixed (kg/ha/year)	Beneficiary crops
Rhizobium	50 to 300 kg N ha^{-1}	Groundnut, Soybean, Redgram, Greengram, Black-gram, Lentil, Cowpea, Bengal-gram and Fodder legumes
Azotobacter	0.026 to 20 kg N ha^{-1}	Cotton, Vegetables, Mulberry, Plantation Crop, Rice, Wheat, Barley, Ragi, Jowar, Mustard, Safflower, Niger, Sunflower, Tobacco, Fruit, Spices, Condiment, Ornamental Flower
Azospirillum	10-20 kg N ha^{-1}	Sugarcane, Vegetables, Maize, Pearl millet, Rice, Wheat, Fodders, Oil seeds, Fruit and Flower
Blue Green Algae	25 kg N ha^{-1}	Rice, banana
Azolla	25 kg N ha^{-1}	Rice
Phosphate solubilizing bacteria and fungi	Solubilize about 50-60% of the fixed phosphorus in the soil	All Crops (non- specific)

Advantages of using bio-fertilizers

Bio-fertilizers offer several benefits, including:

- They are environmentally friendly and cost-effective.
- Their use enhances soil fertility, improving soil quality over time.
- Although results may not be immediate, the long-term benefits are substantial.
- Bio-fertilizers capture atmospheric nitrogen and make it directly available to plants.
- They increase soil phosphorus content by solubilizing and releasing phosphorus that would otherwise remain inaccessible.
- The production of growth-promoting hormones by bio-fertilizers stimulates root development.
- Microorganisms in bio-fertilizers convert complex nutrients into simpler forms that plants can readily absorb.
- They ensure that host plants receive an adequate supply of nutrients while supporting proper growth and physiological functions.
- Crop yields can increase by 10–25% with the use of bio-fertilizers.
- To some extent, bio-fertilizers can protect plants from soil-borne diseases.

Constraints in bio-fertilizer technology

Despite being a low-cost and environmentally sustainable technology, the adoption of bio-fertilizers faces several challenges:

a) **Technological limitations** – scarcity of high-quality carrier materials and a shortage of skilled technical staff in manufacturing units.

b) **Infrastructure issues** – inadequate availability of essential equipment and reliable power supply.

c) **Financial constraints** – insufficient funding and difficulties in obtaining loans.

d) **Environmental limitations** – seasonal demand for bio-fertilizers, overlapping agricultural operations, and short sowing/planting periods in certain regions.

e) **Human resource and quality issues** – lack of technically trained personnel and inadequate training in production processes.

f) **Awareness and adoption challenges** – farmers may hesitate to adopt bio-fertilizers due to varied inoculation methods and the absence of immediate visible differences compared to chemical fertilizers.

g) **Marketing barriers** – limited availability of inoculants at the right time and place, coupled with a weak distribution network.

h) **Overall impact** – these constraints collectively affect production, marketing, and proper utilization of bio-fertilizers.

Conclusion

Bio-fertilizers play a crucial role in organic farming by fixing atmospheric nitrogen and mobilizing soil macro- and micronutrients into plant-available forms, thereby supporting long-term soil fertility and sustainability. Currently, there is a 10-million-tonne gap between nutrient removal by crops and chemical fertilizer supply. Excessive reliance on chemical fertilizers is unsustainable due to financial costs, environmental impacts, and the resources required for manufacturing and maintaining fertilizer production. In this context, bio-fertilizers represent a viable and eco-friendly solution for farmers to increase crop productivity per unit area.

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References

1. Abd El-Lattief EA. Use of *Azospirillum* and *Azobacter* bacteria as biofertilizers in cereal crops: a review. *Int J Appl Sci Eng Res*. 2016;6(7):36-44.
2. Devi AP, John NS, John KS, Jeeva ML, Misra RS. Rock inhabiting potassium solubilizing bacteria from Kerala, India: characterization and possibility in chemical K fertilizer substitution. *J Basic Microbiol*. 2016;56:67-77.
3. Archana D, Nandish M, Savalagi V, Alagawadi A. Characterization of potassium solubilizing bacteria (KSB) from rhizosphere soil. *Bioinfolet Q J Life Sci*. 2013;10:248-57.

4. Archana DS, Nandish MS, Savalagi VP, Alagawadi AR. Screening of potassium solubilising bacteria (KSB) for plant growth promotional activity. *Bioinfolet Q J Life Sci*. 2012;9:627-30.
5. Alori ET, Glick BR, Babalola OO. Microbial phosphorus solubilization and its potential for use in sustainable agriculture. *Front Microbiol*. 2017;8:971.
6. Ajmal M, et al. Bio-fertilizer as an alternative for chemical fertilizers. *J Agric Sci*. 2018;7(1):1-7.
7. Avakyan ZA, Pavavarova TA, Karavako GI. Properties of a new species, *Bacillus mucilaginosus*. *Microbiol*. 1986;55:477-82.
8. Barman M, et al. Bio-fertilizer as prospective input for sustainable agriculture in India. *Int J Curr Microbiol Appl Sci*. 2017;6(11):1177-86.
9. Bhardwaj D, Ansari MW, Sahoo RK, Tuteja N. Biofertilizers function as key players in sustainable agriculture by improving soil fertility, plant tolerance and crop productivity. *Microb Cell Fact*. 2014;13:66.
10. Basak BB, Biswas DR. Co-inoculation of potassium solubilizing and nitrogen fixing bacteria on solubilization of waste mica and their effect on growth promotion and nutrient acquisition by a forage crop. *Biol Fertil Soils*. 2010;46:641-8.
11. Bhattacharjee R, Dey U. Biofertilizer, a way towards organic agriculture: a review. *Afr J Microbiol Res*. 2014;8(24):2332-43.
12. Bhuvaneshwari K, Singh PK. Response of nitrogen-fixing water fern *Azolla* bio-fertilization to rice crop. *Biotech*. 2015;5(4):523-9.
13. Chinnasami KN, Chandrasekaran S. Silica status in certain soils of Tamil Nadu. *Madras Agric J*. 1978;65:743-6.
14. Ciobanu I. Investigation on the efficiency for biocontrol of *Macrophomina phaseolina* bacterial fertilizers applied to cotton. *J Biol Cent Exp Control*. 1961;8:41-4.
15. Duarah I, Deka M, Saikia N, DekaBoruah HP. Phosphate solubilizers enhance NPK fertilizer use efficiency in rice and legume cultivation. *Biotech*. 2011;1(4):227-38.
16. Etesami H, Emami S, Alikhani HA. Potassium solubilizing bacteria (KSB): mechanisms, promotion of plant growth, and future prospects—a review. *J Soil Sci Plant Nutr*. 2017;17(4):897-911.
17. Farnia A, Hasanpoor K. Comparison between effect of chemical and biological fertilizers on yield and yield components in wheat (*Triticum aestivum* L.). *Indian J Nat Sci*. 2015;5(30):7792-800.
18. Ghany TMA. Role of bio-fertilizers in agriculture: a brief review. *Mycopathol*. 2013;11(2):95-101.
19. Gyaneshwar P, Kumar NJ, Pareka LJ, Podle PS. Role of soil micro-organisms in improving P nutrition of plants. *Plant Soil*. 2002;245(1):83-93.
20. Gupta GN, Srivastava S, Khare SK, Prakas V. Role of phosphate solubilising bacteria in crop growth and disease management. *J Pure Appl Microbiol*. 2014;8(1):461-74.
21. Hao X, Cho CM, Racz GJ, Chang C. Chemical retardation of phosphate diffusion in an acid soil as affected by liming. *Nutr Cycl Agroecosyst*. 2002;64(3):213-24.
22. Kumar AI, Bahadur BR, Maurya R, Raghuwanshi. Does a plant growth promoting rhizobacteria enhance agricultural sustainability? *J Pure Appl Microbiol*. 2015;9(2):715-24.
23. Lauwers AM, Heinen W. Biodegradation and utilization of silica and quartz. *Arch Microbiol*. 1974;95:67-78.