International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X

www.agronomyjournals.com
2024; 7(4): 144-149
Received: 02-01-2024
Accepted: 06-02-2024

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Bio-fertilizer: An alternative to chemical fertilizer in agriculture

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DOI: https://doi.org/10.33545/2618060X.2024.v7.i4c.539

Abstract
The widespread use of chemical fertilizers in agriculture has led to a range of harmful effects on both the environment and human health. These synthetic fertilizers contribute to soil degradation, disrupt the natural balance of nutrients, and result in the accumulation of toxic substances in the soil. Runoff from fields treated with chemical fertilizers can contaminate water bodies, leading to eutrophication and harming aquatic ecosystems. Moreover, the overreliance on chemical fertilizers can decrease soil's natural fertility, necessitating continuous and escalating usage, which further exacerbates the negative impacts. Biofertilizers offer a sustainable and eco-friendly alternative to chemical fertilizers. Biofertilizers consist of live microorganisms that enhance nutrient availability and plant growth. They promote soil structure, increase water-holding capacity, and foster the growth of beneficial microorganisms in the soil. These microorganisms establish symbiotic relationships with plants, fixing nitrogen from the atmosphere and making it available for plant uptake. As a result, biofertilizers can substantially reduce the need for chemical fertilizers, mitigating their detrimental effects on the environment. Furthermore, biofertilizers improve soil health over time, leading to more resilient and productive agricultural systems. By adopting biofertilizers, farmers can transition towards a more sustainable and balanced approach to agriculture, minimizing the harm caused by chemical fertilizers and ensuring the well-being of both the ecosystem and human communities.

Keywords: Bio-fertilizer, soil health, plant health

Introduction
Modern agriculture emphasizes the use of hybrid and high-yielding seeds that are particularly responsive to massive amounts of chemical fertilizer and irrigation. The indiscriminate use of synthetic fertilizers has resulted in pollution and poisoning of soil and water basins. As a result, the soil is depleted of important plant nutrients and organic matter. It has resulted in the depletion of beneficial microorganisms and insects, lowering soil fertility and making crops more susceptible to disease. The global population is still growing, and it is expected to reach 9.7 billion people by 2050 (Ehrlich & Harte 2015) [4]. This tremendous expansion is naturally linked to intensive industrialization, urbanization, and agricultural productivity. According to UN demographic projections, India's population is predicted to around 1718 million by 2065, with a total need for food of 567 million tones. (Jain 2011) [9] Traditional agricultural methods, on the other hand, rely heavily on the widespread use of synthetic fertilizers and pesticides for plant nutrition and disease control (Vasile *et al*. 2015) [32]. The wise application of these chemical inputs has undeniable benefits not just for plant development, crop output, and quality, but also for farmers' revenue. Unfortunately, the rising use of synthetic supplies may contaminate water, air, and soil, posing a significant hazard to the natural environment (Rahman & Zhang 2018) [23]. Chemical fertilizers, which have become widely used since the green revolution, have depleted soil health by rendering soil ecology uninhabitable for soil microflora and microfauna, which are mainly accountable for maintaining soil fertility and providing some vital and crucial nutrients to plants. Organic farming represents a holistic and sustainable approach to agriculture that prioritizes environmental conservation, soil health, and the production of healthy, chemical-free food. Organic farming is a comprehensive and long-term strategy for agriculture that prioritizes environmental conservation, soil health, and the

production of nutritious, chemical-free food (Niggli 2015) [18]. Organic farming, as opposed to conventional farming, depends on natural processes and avoids the use of synthetic chemicals, pesticides, and genetically modified organisms. It emphasizes soil fertility through practices such as crop rotation, composting, and cover cropping, all of which improve soil structure and nutrient content (Brenes-Muñoz *et al*. 2016) [3]. To deal with pests and diseases, organic farmers frequently use integrated pest management approaches, which promote biodiversity and reduce the need for toxic pesticides. Farmers support healthier ecosystems, minimizes water pollution, and produce food that is not only free of chemical residues but also often richer in key nutrients by adhering to high organic standards. The total area under organic certification in India (Registered under the National Programme for Organic Production) is 10.17 million hectares (2022-23). This contains 5.39 million hectares of cultivable land and another 4.78 million hectares set aside for wild harvesting. (Ministry of Commerce and Industry 2023) The application of biofertilizers offers a multitude of beneficial effects in agriculture and environmental sustainability (Raja 2013) [24]. Firstly, biofertilizers enrich soil fertility naturally by introducing beneficial microorganisms like nitrogen-fixing bacteria and mycorrhizal fungi. These microorganisms enhance nutrient availability to plants, particularly nitrogen, phosphorus, and potassium, promoting healthier and more robust crop growth. Moreover, biofertilizers contribute to improved soil structure, water retention, and aeration, thus mitigating soil erosion and enhancing overall soil health (El-Lattief 2016) [5] and detoxify of pollutants presented in soil, such as heavy metals (Siddiquee *et al*. 2013) [27], 1,4-dichlorobenzene (Pant *et al*. 2016) [20], pentachlorophenol (Singh *et al*. 2009) [29], atrazine (Pelcastre *et al*. 2013) [22] or pesticide mixtures (Fragoeiro & Magan 2008) [6]. Their eco-friendly nature reduces the need for chemical fertilizers, minimizing the risk of soil and water pollution while also lowering production costs for farmers. Furthermore, biofertilizers foster sustainable agricultural practices, supporting long-term soil vitality and reducing the environmental footprint of farming (Swapna *et al*. 2016) [31]. In a world increasingly focused on sustainable food production, biofertilizers emerge as a vital tool in achieving environmentally friendly, high-yield agriculture.

History of biofertilizer used in India

N. V. Joshi initiated systematic research on biofertilizers in India in 1920. Rhizobium was originally isolated from several cultivated legumes, and then Gangulee, Sarkaria, and Madhok conducted significant studies on the physiology of the nodule bacteria, as well as its inoculation for improved crop output (Panda 2011) [34].

Rhizobium and Blue Green Algae (BGA) are now regarded established biofertilizers, while *Azolla*, *Azospirillum*, and *Azotobacter* are still in the early stages. (Panda 2011) [34]. Table 1 provides a brief background on biofertilizer development.

Table 1: Some Important Milestones in Research, Production and Promotion of Biofertilizers in India (Panda 2011) [34]

Year	Events
1920	The First Study on Legume- *Rhizobium* Symbiosis by N. V. Joshi.
1934	The Earliest Documented Production of *Rhizobium* Inoculant by M. R. Madhok.
1939	Discovery of Nitrogen Fixation by Blue Green Algae (BGA) In Rice Fields by P. K. Dey.
1939	Report on the Performance of *Azotobacter* in Rice Soil by B. N. Uppal.
1956	First Commercial Production of Biofertilizer.
1957	Study on Solubilization of Phosphate by Microorganisms by Sen and Pal.
1958	The First Attempt to Standardize the Quality of Inoculant by A. Sankaran.
1960	First Isolation of Non-Symbiotic N-Fixing Organism *Derxiagummosa* in the world by P. K. Dey and R. Bhattacharya
1964	Spurt In demand for Soyabean Particularly In Madhya Pradesh.
1968	All India Pulse Improvement Project and Soyabean Project Set Up by ICAR where *Rhizobium* Study got Priority
1969	Use of Indian Peat as Carrier Report by V. Iswaran
1975	Coal as an Alternate Carrier to Peat, Reported by J. N. Dube
1976	Indian Standard Specification for *Rhizobium*
1977	Use of ISI Mark for *Rhizobium*
1979	Initiation of the All India Coordinated Project on BNF
1979	ISI Standard for *Azotobacter* Inoculant
1983	Setting up of the National Project on Development and Use of Biofertilizer by the Ministry of Agriculture, Govt. of India.
1985	First National Productivity Award on Biofertilizer
1988	Setting up of National Facility Centre for BGA at IARI

Biofertilizers and their roles

Biofertilizers are biological preparations that contain efficient microorganisms that improve nutrient uptake and thereby stimulate plant development. They increase soil productivity by fixing atmospheric nitrogen, releasing soil phosphorus, and encouraging plant development. Biofertilizers, in other words, are natural fertilizers that are living microbial inoculants of bacteria, algae, and fungi alone or in combination that increase the availability of nutrients to plants (Kumar *et al*. 2017) [11].

- **Nutrient Fixation:** Nutrient fixation, especially nitrogen fixation, is one of the fundamental functions of biofertilizers. Nitrogen-fixing bacteria, such as Rhizobium and Azotobacter, transform atmospheric nitrogen into an amino acid that plants can utilize. This procedure enriches the soil with nitrogen, a necessary component for plant growth, hence lowering the demand for synthetic nitrogen fertilizers. Phosphorus-solubilizing microorganisms, such as mycorrhizal fungi and phosphate-solubilizing bacteria, facilitate in the release of inorganic phosphorus from the soil, increasing its availability to plants. This is essential since phosphorus is another essential ingredient for plant growth. Plant roots form symbiotic or mutualistic connections with biofertilizers. This improves plant nutrient uptake. Mycorrhizal fungi, for example, create associations with plant roots, increasing the total surface area available for nutrient absorption. The primary function of biofertilizers is to enhance plant growth while minimizing environmental impact and boosting crop yields (Mishra *et al*. 2013) [13].
- **Increase Crop Yield:** Biofertilizers frequently boost crop

yields by improving nutrient availability, improving soil structure, and offering protection against pests and diseases. This can lead to increased agricultural productivity and financial benefits for farmers. According to a 2018 study by Schutz *et al*. inoculation with biofertilizers boosted yields of crops by 16.2% on average when compared to non-inoculated controls.

- **Soil Health:** Microbial biofertilizers have an important role in maintaining soil fertility at an adequate level and enhancing soil structure by affecting soil particle aggregation (Rashid *et al*. 2016) [25]. Some biofertilizers, such as Bacillus thuringiensis (Bt) strains, have insecticidal qualities. They are able to control specific insect pests naturally when applied to crops, minimizing the need for chemical pesticides. Biofertilizers can also help to control soil-borne diseases by competing with or reducing the growth of pathogens. This can lead to better crop growth and less dependency on chemical fungicides. Biofertilizers aid in the improvement of soil structure and aggregation. Beneficial microbial secretions and metabolic activities contribute to the formation of a crumb-like soil structure, which improves aeration, water retention, and root penetration (Rashid *et al*. 2016) [25]. They also improve plant-water relations (Xiang *et al*. 2012) [33], provide drought resistance, make plants less susceptible to some soil-borne diseases, including those caused by fungi that also produce mycotoxins (Simarmata *et al*. 2016) [28], and reduce the incidence of insect pests (Bhattacharjee & Dey 2014) [2].
- **Environmental Impact:** The use of biofertilizers decreases agriculture's environmental impact. It reduces the leaching of surplus nutrients into bodies of water, which can cause pollution and eutrophication. Furthermore, it promotes soil health and minimizes the risk of soil erosion. Biofertilizers are an essential component of sustainable agriculture. They promote long-term soil fertility while decreasing reliance on synthetic inputs. This, in turn, helps conserve natural resources and decreases farming's ecological footprint. Farmers can cut production costs over time by using less expensive synthetic fertilizers, herbicides, and soil conditioners.

Table 2: Types of Biofertilizers (Kumar *et al*. 2017) [11]

Sl. No.	Types of Biofertilizers	Examples	Importance
N_2 fixing Biofertilizers			
1	Free living	*Azotobacter*, *Beijerinkia*, *Clostridium*, *Klebsiella*, *Anabaena*, *Nostoc*	Converts the atmospheric nitrogen into usable forms for plants Better synthesis and availability of hormones, vitamins, auxins and other growth promoting substances improves plant growth
2	Symbiotic	*Rhizobium*, *Frankia*, *Anabaena azollae*	
3	Associative Symbiotics	*Azospirillum*	
P- solubilizing biofertilizers			
1	Bacteria	*Bacillus megaterium var. phosphaticum*, *Bacillus subtilis*, *Bacillus circulans*, *Pseudomonas striata*	Insoluble phosphate is solubilized from organic and inorganic sources Insoluble phosphorus is released and fixed in clay minerals Organic acids are released and the pH is lowered to dissolve bound phosphates in soil
2	Fungi	*Penicillium sp*, *Aspergillus awamori*	
P- Mobilising Biofertilizers			
1	Arbuscular Mycorrhizae (AM)	*Glomus* sp., *Gigaspora* sp., *Acaulospora* sp., *Scutellospora* sp. & *Sclerocystis* sp.	Increases surface area of the roots Stimulate metabolic processes Fungus penetrates the cortical cells of the roots Arbuscles absorb these nutrients into the root system Displaces the absorption equilibrium of P-ions which increases the transfer of P-ions
2	Ectomycorrhiza	*Laccaria* sp., *Pisolithus* sp., *Boletus* sp., *Amanita sp*	
3	Ericoid mycorrhiza	*Pezizella ericae*	
4	Orchid mycorrhiza	*Rhizoctonia solani*	
Biofertilizers for Micro nutrients			
1	Silicate and Zinc solubilizers	*Bacillus* sp.	Degrades Silicates and Aluminium silicates in soil Helps in Silicate Weathering Bacterial species are Silicate and Zinc solubilizers
Plant Growth Promoting Rhizobacteria			
1	Pseudomonas	*Pseudomonas fluorescens*	Improves nutrient availability Suppression of Plant Disease Produces phytohormones (Bio stimulants)

Production of biofertilizers

The development and production of a successful biofertilizer is a multistep procedure, including the following stages:

a) Selecting an adequate culture and isolating effective microbes
b) Determining the features of selected microorganisms on a suitable medium with acceptable growth conditions
c) Microbial biomass upscaling
d) Carrier selection
e) Bioinoculant formulation
f) Field studies
g) Large-scale experiments and industrial production
h) Establishment of a quality control, storage, and transportation system (Shaikh & Sayyed 2014; Stamenković *et al*. 2018) [26, 38].

Each of the above processes is critical for producing high-quality biofertilizer and must be carried out under tightly regulated conditions (Mohod *et al*. 2015) [15]. Certain properties of microorganisms utilized as biofertilizers impact their utility and efficacy. High rhizosphere competence, stimulating plant growth and development by various processes or by secretion of biologically active compounds, and compatibility with indigenous rhizobacteria populating soil are among these features. They should also be easy to mass replicate, have a wide spectrum of action, and pose no damage to the ecosystem as a whole (Nakkeeran *et al*. 2005) [17]. Large-scale growth of selected microbes occurs on a selected medium, which should be affordable, easily accessible, and contain the essential nutrients required for obtaining microbial strains in sufficient quantities (Glick & Glick 2020) [8].

This step in the manufacturing of biofertilizers is accomplished by the use of liquid, semisolid, and solid-state fermentation processes. It has been established that various forms of Chemically Defined Media (CDM) are utilized for the maximum development of microbes because they allow for the changing of the proportions of elements influencing microbial strain development (Stamenković *et al*. 2018) [30]. Then, based on the qualities of the applied microbial strains and the required form of the final product, a high-quality carrier must be chosen. To obtain liquid formulations, the carrier is impregnated with a fully developed microbial slurry or cultivated cells are immobilized. Before being commercialized, biofertilizer must go through a series of greenhouse tests or field trials and meet certain criteria that confirm: (i) absence of ecotoxicological consequences; and (ii) a favourable impact in terms of encouraging plant development and boosting crop yields. The biofertilizer must be registered and approved by regulatory authorities (Bashan *et al*. 2013) [1]. Formulated biofertilizers are packed, and each package should include the following information: the name of the product, the microbial strain (s) contained in it, the plants for which it is intended, the name and address of the manufacturer, the date of production, the expiry date, and instructions and application recommendations (García-Fraile *et al*. 2015) [17]. The state wise production of carrier based and liquid based biofertilizer production is presented in Figure 1 and Figure 2 respectively.

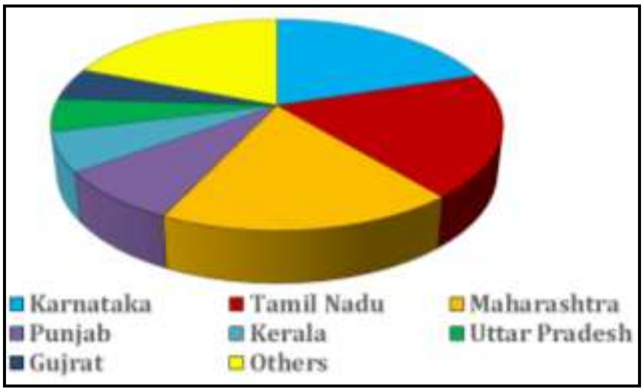

Fig 1: Carrier based biofertilizer production.

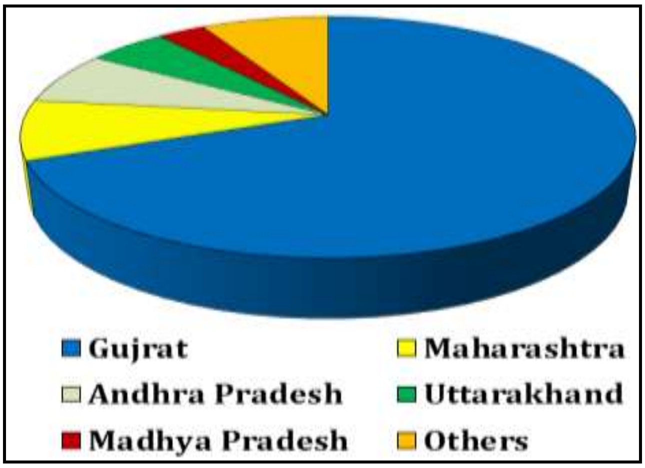

Fig 2: Liquid based biofertilizers production.

Marketed biofertilizers

The following types of microorganisms as biofertilizers are available to farmers:

- Nitrogen fixers: Rhizobium, *Brady rhizobium*, Azospirillum, Azotobacter, Acetobacter, Azolla and BGA.
- Phosphorus solubilizer: Bacillus, Pseudomonas, and Aspergillus
- Phosphate mobilizer: VAM like Glomus
- Potassium solubilizer: *Frateuria aurantia*.
- Silicate solubilizer: *Thiobacillus thiooxidans*
- Plant growth-promoting fertilizers: *Pseudomonas* sp. (Mishra and Arora 2016; Muraleedharan *et al*. 2010).

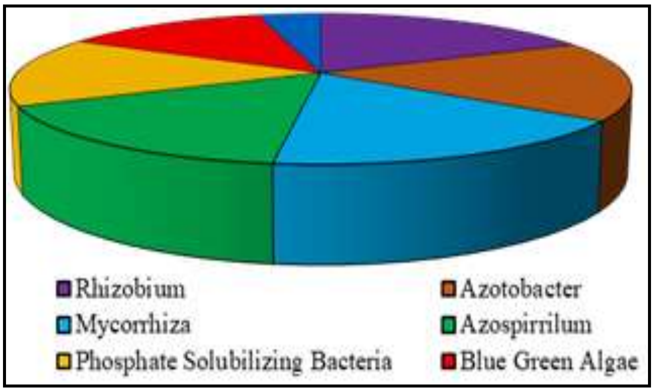

Fig 3: Current status of the application of biofertilizers

Constraints of biofertilizers

Even though biofertilizers are a commercially promising approach in sustainable agriculture, there are few drawbacks making them less competitive, such as limited self-life, lack of the suitable materials for production, increased sensitivity to high temperature and difficulties connected with the storage and transportation (Patil and Solanki 2016) [21]. Apart from that, microbial fertilizers require higher amounts to provide plants with enough nutrient content, their effectiveness depends on the soil conditions prevailing in the application zone and results of their action are noticeable after prolonged use (Jangid *et al*. 2012) [10]. However, new technologies are being developed to overcome the disadvantages associated with the application of biofertilizers in agricultural ecosystems.

1. Lack of relevant strains: One of the biggest restrictions in the manufacturing of biofertilizers is the scarcity of certain strains. Based on the fact that certain strains can thrive in both the broth and the inoculant carrier
2. Lack of a suitable carrier: It is difficult to sustain the shelf life of biofertilizers if a suitable carrier is not available. The order of applicability is peat, lignite, charcoal, FYM, soil, and rice husk. Good quality peat is hard to come by in India. Good quality carriers have a high moisture retention capacity and are devoid of hazardous chemicals.
3. Inadequate and inexperienced personnel. (Bhattacharjee & Dey 2014)
4. Financial constraints like non-availability of sufficient funds and problems in getting bank loans
5. Environmental constraints like seasonal demand for biofertilizers, simultaneous cropping operations, a short span of sowing or planting in a particular locality, etc.
6. Problem in adoption of the technology by the farmers due to different methods of inoculation no visual difference in the crop growth immediately as that of inorganic fertilizers.
7. Marketing constraints like non availability of right inoculant at the right place at the right time, a lack of retail outlets, or a lack of a market network for the producers
8. The different constraints in one way or another, affect the

technique at production, marketing or usage (Kumar *et al*. 2017)

Future Scopes

1. Selection of multi-functional bio-fertilizers that can be both effective and competitive for a variety of crops.
2. Quality control system for inoculant manufacture and field application to ensure and investigate the benefits of plant-microorganism symbiosis.
3. Investigation of the microbiological persistence of biofertilizers in stressed soil environments
4. Bio-fertilizer agronomic, soil, and economic evaluation for various agricultural production systems.
5. Bringing biofertilizer production technology to the industrial level and optimizing formulation.
6. Enactment of the "Bio-fertilizer Act" and tight quality control regulations in markets and applications.

Conclusion

Biofertilizers, being essential components of organic farming, play a vital role in maintaining long term soil fertility and sustainability by fixing atmospheric di-nitrogen, mobilizing fixed macro and micro nutrients in the soil into forms available to plants. Currently, there is a gap of ten million tons of plant nutrients between the removal of crops and their supply through chemical fertilizers. In the context of both the cost and environmental impact of chemical fertilizers, excessive reliance on chemical fertilizers is not practicable in the long run because of the cost, both in domestic resources and foreign exchange, involved in setting up fertilizer plants and sustaining their production. In this context, biofertilizers would be a viable option for farmers to increase productivity per unit area. Further, they are eco-friendly, pose no danger to the environment, and can be replaced in place of chemical fertilizers.

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