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Biofertilizers-Sustainable Goals and Government Initiatives in India

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Abstract: ***Modern agricultural practices have significantly impacted the environment, biodiversity, and human health. The agricultural sector faces the dual challenge of increasing food production for a projected global population of 9.7 billion by 2050 while simultaneously addressing climate change, resource scarcity, and environmental degradation. Biofertilizers, which consist of beneficial microorganisms that enhance nutrient availability, promote plant growth, and improve soil health, represent a promising alternative to synthetic agrochemicals. This article focuses on importance of biofertilizers for sustainable agriculture, highlighting their mechanisms of action, including nutrient solubilization, phytohormone production, stress mitigation, and modulation of the soil microbiome. Key microbial genera, including Rhizobium, Azotobacter, Azospirillum, cyanobacteria, Arbuscular mycorrhizal fungi, Pseudomonas, Bacillus, etc. are stated for their contributions towards crop productivity and resilience. This article also highlights the market trends of biofertilizers in India, Government initiatives, limitations and future prospects of biofertilizers for sustainable agriculture.***

Keywords: Biofertilizers, sustainable agriculture, biodiversity, eco-friendly, Integrated Nutrient Management, Government initiatives

1. Introduction

By 2050, the world's population could reach 9.7 billion, which will put more pressure on food production (Ntsomboh-Ntsefong et al., 2025). Meeting this need while protecting the environment and making sure everyone is treated fairly is a major challenge. Traditional farming relies heavily on artificial fertilizers and pesticides, which have led to soil damage, water pollution, and loss of wildlife. In contrast, sustainable farming aims to care for the environment, act responsibly, and remain practical for farmers. It helps maintain natural processes like building healthy soil, moving water, and balancing the climate (Tiwari et al., 2022). Sustainable farming also supports rural communities, improves access to food, and helps keep farming communities healthy. Approaches such as agroecology, permaculture, and regenerative farming can help to address climate change, protect wildlife, and build a more just food system (Li et al., 2024; Sher et al., 2024)

In these situations, biofertilizers offer a promising way to support sustainable farming. Biofertilizers are products that contain helpful microorganisms. These microorganisms give plants important nutrients, improve soil health, and reduce the need for artificial fertilizers (Sharma et al., 2023). They enrich the soil and help protect the environment. By using biofertilizers, more nutrients become available in the soil, which helps plants grow better. They also provide essential micronutrients that boost plant health and resilience ((Ntsomboh-Ntsefong et al., 2025). When farmers use biofertilizers, they depend less on synthetic fertilizers and pesticides, which helps reduce soil and water pollution and protects biodiversity (Alnaass et al., 2023). Overall, biofertilizers can help increase crop yields and improve food security (Daniel et al., 2022).

Because of these benefits, biofertilizers are a practical way to improve soil fertility, plant nutrition, and environmental sustainability in farming. (Bhardwaj et al., 2014) This article highlights the benefits of biofertilizers, market trends, Government initiatives, and future prospects of biofertilizers for sustainable agriculture.

Importance of biofertilizers in agriculture

Biofertilizers help improve soil fertility and lower the need for chemical fertilizers. They boost grain yields, raise the harvest index, and strengthen soil structure. Biofertilizers help plants access nutrients from the soil and air. Studies show they work well, are affordable, and are safe for the environment. They offer organic inputs that turn key elements into forms plants can use through natural processes. The microbes in biofertilizers help restore the nutrient cycle, maintain soil nutrient levels, and add organic matter to the soil. This leads to healthy plant growth and keeps soil fertile (Singh et al., 2025; Shahzad et al., 2025).

Biofertilizers improve soil fertility and provide plants with the nutrients they need. They make nutrients available right away and for later use, and they help plants grow by releasing vitamins and phytohormones. They also aid composting and help manage pests and soilborne diseases (Javiya et al., 2026). A detail list of biofertilizers and their role with target crops has been given in Table-1.

Table 1: Types of Biofertilizers, their function and target crops

Biofertilizer type	Microorganisms	Major function (mechanisms)	Target crops
Nitrogen-fixing biofertilizers (Symbiotic)	*Rhizobium* spp.	Fix atmospheric N2 into ammonia via the nitrogenase enzyme and making it available to the plants	Pulses, soybean, groundnut, legumes
Nitrogen-fixing biofertilizers (Free-living)	*Azotobacter* spp.		Cereals, vegetables, cotton
Nitrogen-fixing biofertilizers (Associative)	*Azospirillum* spp.		Rice, wheat, maize, millets
Cyanobacterial biofertilizers (Free-living)	*Anabaena*, *Nostoc*, *Scytonema, etc.*	Nitrogen fixation through heterocyst improves soil fertility in flooded systems.	Rice (paddy fields)
Azolla biofertilizer (Symbiotic)	*Azolla–Anabaena* symbiosis	Biological nitrogen fixation and organic matter addition	Rice (paddy fields)
Phosphate-solubilizing biofertilizers (PSB)	*Pseudomonas* spp., *Bacillus* spp.	Solubilize insoluble P by secretion of organic acids and phosphatases	Cereals, oilseeds and vegetables
Phosphate-mobilizing biofertilizers	Arbuscular mycorrhizal fungi (AMF), Ectomycorrhiza	Mobilize P through an extensive hyphal network beyond the root depletion zone	Cereals, pulses, horticultural crops
Potassium-mobilizing biofertilizers	*Frateuria aurantia, Bacillus* spp.	Release K+ from mineral sources by organic acid production and mineral weathering.	Sugarcane, cereals, horticultural crops
Plant Growth-Promoting Rhizobacteria (PGPR)	*Pseudomonas fluorescens, Bacillus subtilis, Agrobacterium* sp. *Erwinia* sp.	Produce phytohormones, enhance nutrient uptake, suppress pathogens (ISR)	Cereals, vegetables, pulses, oilseeds

The significances of biofertilizers are summarized below -

Effect of biofertilizers in crop production

Beneficial microorganisms are used by biofertilizers to improve crop output and soil fertility. They secrete plant growth hormones, fix atmospheric nitrogen, and solubilize insoluble potassium and phosphorus. This biological activity controls soil-borne illnesses, increases crop yields by 20% to 30%, and organically enhances root development (Patel et al., 2026).

1) **Managing Nutrient Availability, Organic Matter in Soil and Boosting Crop Yields and Economic Gains**: Biofertilizers add helpful microorganisms to the soil. These microbes break down organic matter and help recycle nutrients, making nitrogen, phosphorus, and potassium more available to plants. Nitrogen-fixing bacteria turn atmospheric nitrogen into forms plants can use, while other microbes help plants absorb phosphorus and potassium, leading to better crop growth (Bhattacharyya & Jha, 2012; Rai et al., 2023; Figiel et al., 2025).

   Biofertilizers help crops grow better by improving root development, nutrient absorption, and plant efficiency. They do this by producing plant hormones and boosting activity around the roots. Using biofertilizers means farmers can use less chemical fertilizer, spend less on inputs, and earn more, making them a cost-effective choice for crop production (Kumar et al., 2017; Chaudhary et al., 2022; Sharma et al., 2024).
2) **Contribution to Integrated Nutrient Management (INM) and Reducing Reliance on Chemical Fertilizers:** Microbial inoculants play a key role in Integrated Nutrient Management by working alongside chemical fertilizers and organic materials. Biofertilizers help plants use nutrients more efficiently, reduce nutrient loss, and maintain soil life, supporting sustainable crop production over time (Shabbir et al., 2019; Ntsomboh-Ntsefong et al., 2025).

   Regular use of biofertilizers means farmers can depend less on synthetic fertilizers, as some crop nutrient needs are met naturally. This helps lower production costs and reduces problems like soil degradation and nutrient loss to the environment (Bhattacharyya & Jha, 2012; Sharma and Bhardwaj, 2025).

Effect of Biofertilizers in Modifying Soil Properties

By adding helpful microorganisms that fix atmospheric nitrogen, solubilize bound nutrients, and produce organic acids, biofertilizers change the characteristics of soil. These inoculants enhance biological activity (microbial biomass, enzyme function), chemical composition (pH regulation, nutrient availability), and physical structure such as aggregation, water-holding capacity etc. (Patel et al., 2026).

1) **Improving Soil Fertility and Increasing Beneficial Microbial Activity in Soil:** Biofertilizers make essential nutrients such as nitrogen, phosphorus, and potassium more available in the soil. Nitrogen-fixing microbes turn atmospheric nitrogen into forms plants can use, while other microbes help dissolve nutrients that are otherwise hard for plants to access. Continuous application of biofertilizers increases nutrient availability and reduces the need for synthetic fertilizers over time (Bhattacharyya & Jha, 2012; Javiya et al., 2026).
   Biofertilizers increase the number of helpful microbes in the soil, raise the amount of organic carbon, and boost enzyme activity. They encourage good relationships between microbes, help move nutrients around, and can even reduce harmful soil diseases. This all leads to better nutrient cycling and healthier soil (Bhattacharyya & Jha, 2012; Backer et al., 2018; Sharma & Bhardwaj, 2025).
2) **Enhancement of Soil Structure and Water Retention:** The helpful microbes in biofertilizers produce substances that help soil particles stick together and hold water better. This creates more space in the soil, lowers its density, and helps it keep more moisture. As a result, the soil has better air flow, roots can grow more easily, and moisture is retained, which is especially useful in poor or sandy soils (Chaudhary et al., 2022; Sharma & Bhardwaj, 2025).
3) **Balancing Soil pH Levels:** Some biofertilizers, especially those that dissolve phosphate, can change soil pH by producing organic acids such as gluconic, citric,

and oxalic acids. These acids lower the pH in alkaline soils and help release nutrients bound to calcium, making them more available to plants. This process helps plants take up nutrients more efficiently and maintains soil balance (Kumar et al., 2017; Timofeeva et al., 2022; Sharma & Bhardwaj, 2025).

4) **Contribution to Sustainable Soil Management and Reduction in Soil Degradation Process:** Using biofertilizers regularly helps keep soil healthy by increasing the variety of life in the soil, improving how nutrients move, and supporting organic matter. These benefits make the soil stronger and more productive over time, without causing damage, so biofertilizers are important for sustainable soil management (Ntsomboh-Ntsefong et al., 2025).
   Biofertilizers help prevent soil damage by reducing the need for too many chemical fertilizers and pesticides. This limits nutrient loss and pollution, maintains a balanced soil ecosystem, and prevents soil quality from worsening over time, supporting sustainable farming (Shabbir et al., 2019; Chaudhary et al., 2022).

Effect of biofertilizers on Fertilizer Use Efficiency (FUE)

Through the conversion of atmospheric nitrogen, the solubilization of soil-bound phosphorus, and the expansion of root systems, biofertilizers greatly improve Fertilizer Use Efficiency (Patel et al., 2026).

1) **Improvement of Nutrient Availability and Uptake:** Biofertilizers help plants use fertilizers more efficiently by making soil nutrients easier to access. Microbes that dissolve phosphate release acids to break down hard-to-use phosphates, which improve how plants use phosphorus. Nitrogen-fixing azotrophs such as *Rhizobium*, *Azotobacter*, and *Azospirillum* convert atmospheric nitrogen into ammonia, so plants need less synthetic nitrogen fertilizer and use nitrogen more efficiently (Bhattacharyya & Jha, 2012; Sharma & Bhardwaj, 2025).
2) **Promotion of Root Growth and Nutrient Absorption:** Biofertilizers help plants use fertilizers more effectively by encouraging roots to grow longer and stronger, allowing them to absorb more nutrients. Certain bacteria make plant hormones that help roots grow, and mycorrhizal fungi extend the root system even further, so plants can reach more nutrients and water. This better connection between roots and soil means fertilizers are used more efficiently (Backer et al., 2018; Chaudhary et al., 2022; Sharma & Bhardwaj, 2025).
3) **Synergistic Effects with Chemical Fertilizers:** Biofertilizers and chemical fertilizers can work well together in nutrient management. When farmers use biofertilizers along with lower amounts of chemical fertilizers, nutrients are used more efficiently, less is lost, and crops take up more nutrients. This combination helps the environment and improves the effectiveness of fertilizers. Research shows that combining both yields better results than using only chemical fertilizers (Shabbir et al., 2019; Javiya et al., 2026).
4) **Environmental and Economic effects of Improved FUE (**Fertilizer Use Efficiency**):** When biofertilizers help plants use fertilizers more efficiently, less fertilizer is lost, costs go down, and there is less risk of pollution from things like nitrate and phosphorus runoff. This supports sustainable farming and keeps soil healthy for the long term, while still allowing for high crop yields (Kumar et al., 2017; ICAR, 2021).
5) **Role of biofertilizers in biotic and abiotic stress management**
   Biotic stresses are significant factors that limit crop productivity. Various scientific approaches have been extensively employed to mitigate the impact of thesestresses on crops, with Plant Growth-Promoting Rhizobacteria (PGPRs) playing a pivotal role as bioprotectors (Sharma et al., 2024). Biofertilizers that produce growth hormones like IAA and cytokinins have been utilized to combat abiotic conditions including drought stress. For example, *Pseudomonas putida* inoculation can boost the production of flavonoids, salicylic acid, and abscisic acid, which protect the soybean plant from stress caused by drought (Sharma et al., 2024).

Limitations of Biofertilizers

While biofertilizers contribute to sustainable agriculture, several limitations hinder their widespread and consistent use. Assessing these constraints is important for balanced understanding and effective field implementation (Patel et al., 2026).

1) **Limited Shelf Life:** Biofertilizers have living microorganisms that do not stay active for long in storage. Their shelf life is usually 3 to 6 months, depending on how they are made and stored. Heat, sunlight, or poor packaging can reduce the number of useful microbes, which can impair their performance in the field. (Sathish Kumar et al., 2022).
2) **Sensitive to Changes in Temperature and Moisture:** Biofertilizers perform best under optimal environmental conditions. High soil temperatures, drought, flooding, or salty soils can lower the survival and activity of the microbes. If the soil is too dry when applied, the microbes may not settle in the root zone. (Rai et al., 2023).
3) **Effectiveness Depends on Crop and Soil Type:** Biofertilizers usually work best with certain crops and soils, so they cannot be used everywhere. For example, Rhizobium strains only work with specific types of legumes. Soil features such as pH, organic matter, local microbes, and nutrients also affect how well they function. (Sharma et al., 2024; Javiya et al., 2026).
4) **Inconsistent Performance under Field Conditions:** Biofertilizers may work well in labs or test plots, but results can vary a lot on real farms. Changes in soil, weather, farming methods, and product quality all play a role. This makes farmers less confident in biofertilizers than in chemical fertilizers, which provide more predictable results. (Javiya et al., 2026).
5) **Limited Farmer Awareness and Adoption:** Many farmers lack sufficient knowledge of biofertilizers or how to use them. They may not be sure about the right way to apply them, when to use them, or how they work with chemical fertilizers. There are also not enough training programs or demonstrations to help farmers learn. (Kumar et al., 2017; Sathish Kumar et al., 2022; Ntsomboh-Ntsefong et al., 2025).

6) **Challenges in Quality Control and Standardization:** The quality of biofertilizers can vary due to differences in the microbes used, the carriers that deliver them, or contamination during production. Without strong quality checks and rules, poor-quality products can reach the market. (Bhattacharyya & Jha, 2012; Ntsomboh-Ntsefong et al., 2025).
7) **Delayed Response Compared to Chemical Fertilizers:** Biofertilizers work slowly and provide long-term benefits rather than quick results. Because of this, farmers who want fast yield increases, especially in intensive farming, may not prefer them. (Shabbir et al., 2019; Sathish Kumar et al., 2022; Rai et al., 2023).

These challenges show that there is a need for better methods for producing biofertilizers, stronger quality standards, and guidance that fits local conditions.

Biofertilizer Market Trends in India

The Indian biofertilizer market is projected to reach 152.5 million by 2033, expanding from 152.5 million in 2025 at a compound annual growth rate (CAGR) of 8.9%. Biofertilizers provide sustainable, environmentally friendly alternatives to chemical fertilizers, which are essential to contemporary agricultural practices. Key market drivers include increased awareness of biofertilizer advantages, rising demand for organic produce, and government policies that encourage adoption. Emerging trends involve the development of advanced biofertilizer formulations, integration with precision agriculture technologies, and targeted initiatives to enhance soil health (Data Insights Market, 2026).

Major participants in the Indian biofertilizer market include GrowTech Agri Science Private Limited, Gujarat State Fertilizers & Chemicals Ltd, and National Fertilizers Limited. The Indian biofertilizer market demonstrates notable geographical concentration, with primary production and consumption hubs in Maharashtra, Gujarat, Andhra Pradesh, and Tamil Nadu. These states collectively account for over 60% of the nation's total biofertilizer output and usage, underscoring their central role in market dynamics and their status as early adopters of sustainable agricultural practices (Data Insights Market, 2026).

Nitrogen-fixing biofertilizers are expected to lead the market in 2025 with a 55.0% share, driven by their role in increasing soil nitrogen and supporting sustainable crop nutrition across diverse regions. Cereals and grains are projected to hold a 40.0% share, reflecting the widespread cultivation of rice, wheat, and maize, which benefit significantly from biological nutrient inputs. *Rhizobium* is the largest microorganism segment at 28.0%, due to its proven effectiveness in nitrogen fixation for leguminous and pulse crops. South India is forecasted to lead the market with a 34.0% share, supported by strong adoption of organic farming, high productivity, and government initiatives for sustainable agriculture. The Indian biofertilizer market remains moderately competitive, with public sector, cooperative, and private firms focusing on product innovation, distribution expansion, and strategic partnerships (IMARC, 2026).

The present Biofertilizer market is growing but still there are many challenges and constraints in the Indian Biofertilizer Market. The primary concern is the limited awareness among farmers about the benefits and correct application of biofertilizers contributes to skepticism and underutilization. The evident high initial cost of biofertilizers relative to conventional chemical fertilizers remains a barrier, despite their long-term economic advantages. The market is limited caused by the challenge of maintaining consistent quality, shelf-life, and availability of biofertilizers across diverse regions, especially in remote areas. The research and development infrastructure is insufficient for creating biofertilizer strains tailored to specific Indian soil types and crops. Moreover, limitations in supply chain and distribution networks, particularly in effectively reaching remote agricultural regions, hinder market growth.

Government initiatives for Biofertilizer popularization

The adoption of biofertilizer has been accelerated nationwide largely due to the shift in India's regulatory structure. Nationally funded programs provide financial support for bio-inputs, allowing farmers to purchase biofertilizers at subsidized rates. The need for biofertilizer is being radically pulled by the fast growth of India's organic food sector, as farmers using natural and organic farming methods need chemical-free, compatible inputs for nutrient management. The increasing awareness among farmers, researchers, and extension workers of the long-term risks of chemical fertilizers is driving a shift toward bio-based alternatives that improve and restore soil health. Now, the government is promoting the adoption of biofertilizers, which serve as cost-effective, environmentally sustainable nutrient sources. These inputs are recognized as essential components of organic farming and Integrated Nutrient Management.

Biofertilizers are supported through the Paramparagat Krishi Vikash Yojana (PKVY) and the Mission Organic Value Chain Development for North Eastern Region (MOVCDNER) schemes. Under PKVY, farmers receive financial assistance of Rs 15,000 per hectare for three years via Direct Benefit Transfer (DBT) for both on-farm and off-farm organic inputs, including biofertilizers. Under MOVCDNER, financial assistance of Rs 32,500 per hectare for three years is provided for similar inputs (PIB, Govt. of India, 2024). The National Center of Organic and Natural Farming (NCONF) and its regional centers in Ghaziabad, Nagpur, Bangalore, Imphal, and Bhubaneswar conduct training and awareness programs focused on organic farming and the production and application of organic and biofertilizers. In addition to training and awareness initiatives, biofertilizers are regulated under the Fertilizer Control Order (1985), which establishes mandatory quality standards for manufacturers. Over the past five years, Rs 693.30 crore under PKVY and Rs 236.78 crore under MOVCDNER have been transferred to farmers' accounts via DBT for the purchase of inputs, including biofertilizers (PIB, Govt. of India, 2024).

The Indian Council of Agricultural Research (ICAR) has developed efficient biofertilizer strains suited to various crops and soil types, aiming to reduce reliance on chemical fertilizers. ICAR advocates for the integrated use of fertilizers and manures. Both liquid and powdered biofertilizers have been advanced and promoted through the All India Network Project on Soil Biodiversity. Specialized biofertilizers for phosphorus solubilization, nitrogen fixation, and solubilization of potassium and zinc have been developed for diverse crops nationwide, with many now commercialized. ICAR also provides training, conducts frontline demonstrations, and organizes awareness programs to educate farmers on the use of biofertilizers (PIB, Govt. of India, 2024).

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To promote the adoption of biofertilizers among farmers, the government has implemented several initiatives, including the following:
1) The integrated application of biofertilizers, organic fertilizers, and organic manure is now a core component of the recommended agricultural practices developed by ICAR and State Agricultural Universities.
2) ICAR has introduced liquid biofertilizer technology with extended shelf life and has developed improved strains tailored to specific crops and soil types.

The government is implementing the PKVY and MOVCDNER schemes nationwide, providing financial assistance of Rs 15,000 per hectare for three years through DBT to support farmers in purchasing organic inputs, including biofertilizers (PIB, Govt. of India, 2024).

2. Future Directions and Prospects

Enhancing the consistency, credibility, and widespread adoption of biofertilizers requires research that extends beyond single-strain products and short-term trials. The following priority areas warrant focused investigation.
1) **Molecular and Genomic Methods**: Advanced molecular and genomic techniques, including genomics, transcriptomics, and metabolomics, facilitate the identification of functional genes involved in nutrient solubilization, nitrogen fixation, and stress tolerance. These tools will lead to strain improvement and quality control in biofertilizer development (Bhattacharyya & Jha, 2012; Berg et al., 2020; Patel et al., 2026).
2) **Biofertilizers Based on Consortium**: Microbial consortia offer synergistic benefits (Khan, 2022) by integrating nutrient mobilization, hormone production, and biocontrol activities. This approach enhances stability and field performance compared to single-strain inoculants (Chaudhary et al., 2022; Sharma et al., 2025; Patel et al., 2026).
3) **Advanced Delivery Systems and Nano-Biofertilizers**: According to Beig et al. (2022), nano-biofertilizers improve microbial viability, controlled nutrient release, and nutrient utilization efficiency. However, there are substantial study gaps on long-term environmental safety and thorough field validation (Raliya et al., 2017; Dimkpa & Bindraban, 2017; Garg et al., 2023; Patel et al., 2026).
4) **Crop and Region-Specific Strain Development**: The effectiveness of biofertilizers is influenced by crop genotype, soil characteristics, and agro-climatic conditions. This underscores the need to develop region-specific microbial strains and conduct multilocation field validations (Ganesh et al., 2023; Patel et al., 2026).
5) **Bioinoculants Resistant to Climate Change:** Bioinoculants with ACC-deaminase activity, osmolyte production, and enhanced antioxidant capacity can increase plant tolerance to drought, salinity, and heat stress. However, these require extensive long-term field evaluation under extreme climatic conditions (Nadeem et al., 2014; Backer et al., 2018; Patel et al., 2026).
6) **Regulation, Quality Control, and Standardization**: Inadequate strain authentication, contamination, and suboptimal carrier materials contribute to inconsistent biofertilizer performance. Implementation of molecular tools along with strong regulatory frameworks is crucial for standardization and quality assurance (Bhattacharyya & Jha, 2012; Chari & Sodimalla, 2019; Patel et al., 2026)
7) **Technology Transfer and Farmer Awareness**: Limited awareness among farmers, insufficient extension services, and the absence of on-farm demonstrations hinder biofertilizer adoption. This highlights the importance of participatory research and effective extension strategies (Kumar et al., 2017; Patel et al., 2026).

3. Conclusion

Indian agriculture is at a critical juncture and requires solutions that are sustainable, environmentally responsible, and economically viable. Biofertilizers are not merely an alternative; they are essential. These inputs improve soil health, enhance productivity, reduce input costs, and increase farmers' and communities' resilience to climate-related challenges. Biofertilizers have the potential to transform Indian agriculture, provided that government support, private sector innovation, and farmer participation are aligned. Collaborative efforts among all stakeholders are necessary to achieve the objective of "Healthy Soil, Healthy Crop, Healthy India." The central issue is not whether India will adopt biofertilizers, but rather when this transition will occur. Immediate action will yield greater benefits and contribute to a more robust future for Indian agriculture.

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