International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Biofertilizers and Organic Fertilizers: Significance, Role in Soil Fertility, and Their Contribution to Promoting Organic Farming in India

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Abstract

Soil fertility degradation, declining soil organic matter, nutrient imbalances, and increasing dependence on chemical fertilizers have emerged as major challenges to the sustainability of Indian agriculture. Biofertilizers and organic fertilizers offer important opportunities to improve soil fertility, enhance nutrient-use efficiency, promote beneficial soil microbial activity, and support environmentally sustainable agricultural production. Biofertilizers contain beneficial microorganisms capable of fixing atmospheric nitrogen, solubilizing or mobilizing phosphorus and other nutrients, producing plant growth-promoting substances, and improving plant nutrient acquisition. Organic fertilizers, including farmyard manure (FYM), compost, vermicompost, green manure, oil cakes, and other biologically derived materials, supply nutrients while contributing to soil organic matter and improving soil physical, chemical, and biological properties.

This review emphasizes the significance of biofertilizers and organic fertilizers in maintaining soil fertility and promoting organic farming in India. It discusses their mechanisms of action, effects on soil health, nutrient cycling, crop productivity, and environmental sustainability. Particular attention is given to Indian agricultural conditions, government initiatives, organic certification systems, and the integration of microbial inoculants with organic nutrient sources. Recent statistics from the Agricultural and Processed Food Products Export Development Authority (APEDA), the Government of India, and the National Centre for Organic and Natural Farming are incorporated to illustrate the expansion of organic agriculture and the growing importance of biological nutrient management. The review emphasizes that biofertilizers and organic fertilizers should be integrated within location-specific nutrient management strategies rather than considered universal substitutes for all mineral fertilizers. Strengthening quality control, microbial strain development, organic resource recycling, farmer training, and market infrastructure will be essential for realizing their full potential in India's transition toward sustainable and organic agriculture.

Keywords: Biofertilizers, organic fertilizers, soil fertility, soil health, organic farming, nutrient cycling, microbial inoculants, India, integrated nutrient management.

1. Introduction

Agriculture is the foundation of India's food security, rural livelihoods, and economic development. The productivity and sustainability of Indian agriculture depend substantially on the maintenance of soil fertility, efficient nutrient cycling, and the availability of essential plant nutrients. However, intensive cultivation, nutrient imbalances, declining soil organic carbon, soil erosion, and the inefficient application of fertilizers have contributed to concerns regarding long-term soil health.

The expansion of chemical fertilizer use following the Green Revolution substantially increased agricultural productivity in India. Nevertheless, prolonged dependence on mineral fertilizers without adequate organic matter recycling, balanced nutrient application, and soil conservation has created challenges in several agricultural regions. Excessive or unbalanced fertilizer application can contribute to nutrient losses, soil acidification, environmental pollution, and reduced nutrient-use efficiency.

Accordingly, sustainable nutrient management increasingly emphasizes the integration of biological processes, organic resource recycling, soil conservation, and balanced nutrient application.

Biofertilizers and organic fertilizers represent two important components of this approach. Biofertilizers improve nutrient availability and plant nutrient acquisition through beneficial microorganisms. Organic fertilizers supply nutrients and organic carbon while contributing to soil structural stability, water retention, and biological activity. Their combined application can create favorable conditions for plant growth and support long-term soil fertility.

The importance of these inputs is particularly relevant to Indian agriculture because of the country's diverse agroclimatic conditions, substantial livestock population, crop-residue availability, and growing interest in organic and natural farming.

India has also established institutional mechanisms for promoting organic agriculture. The Paramparagat Krishi Vikas Yojana (PKVY), Mission Organic Value Chain Development for North Eastern Region (MOVCDNER), National Programme for Organic Production (NPOP), and Participatory Guarantee System for India (PGS-India) provide different forms of support for organic production, certification, and market development.

According to APEDA, India had approximately 3.97 million hectares of cultivated land under NPOP certification during 2024–2025, including 2.25 million hectares of certified organic land and 1.71 million hectares under conversion. An additional 2.26 million hectares was registered for wild-harvest collection. These figures demonstrate the considerable scale of India's organic production and certification activities (Agricultural and Processed Food Products Export Development Authority [APEDA], 2025).

The development of efficient biofertilizer and organic fertilizer technologies is therefore essential for improving soil fertility, supporting sustainable crop production, and strengthening India's organic farming sector.

1.1 Objectives of the Review

The principal objectives of this review are:

- To explain the concepts, classification, and significance of biofertilizers and organic fertilizers.
- To examine their mechanisms of action in improving soil fertility and plant nutrient availability.
- To evaluate their effects on soil physical, chemical, and biological properties.
- To discuss their contribution to organic farming and sustainable agriculture in India.

- To review relevant government policies, certification systems, and recent statistical developments.
- To identify major constraints and future research priorities for their effective utilization.

1.2 Review Methodology

This manuscript is prepared as a narrative review based on scientific literature, institutional publications, government reports, and agricultural policy documents. The principal sources include the Indian Council of Agricultural Research (ICAR), National Centre for Organic and Natural Farming (NCONF), APEDA, the Food and Agriculture Organization of the United Nations (FAO), and peer-reviewed research publications.

Recent literature published between 2020 and 2025 has been emphasized, while selected foundational studies have been included to explain established scientific mechanisms. Official organic farming statistics for 2024–2025 are incorporated where available.

The review is not presented as a systematic review or meta-analysis; consequently, no pooled effect size or formal systematic literature selection procedure is claimed.

2. Concept and Classification of Biofertilizers

2.1 Definition of Biofertilizers

Biofertilizers are formulations containing living or dormant beneficial microorganisms that improve nutrient availability, nutrient acquisition, or plant growth through biological processes.

Unlike conventional fertilizers, biofertilizers generally do not supply substantial quantities of nutrients directly. Instead, they facilitate the conversion of nutrients into plant-available forms or improve the ability of plants to acquire nutrients from soil.

The Government of India defines biofertilizers as microbial products that help make nutrients present in soil and the atmosphere available to plants. ICAR has reported that biofertilizers can improve crop yields by approximately 10–25% and supplement chemical fertilizers, particularly nitrogen and phosphorus fertilizers, by approximately 20–25% in many cases when used appropriately (Press Information Bureau [PIB], 2023).

These figures should be interpreted as reported potential outcomes rather than guaranteed responses across all crops, soil types, climates, and microbial formulations.

2.2 Classification of Biofertilizers

Biofertilizers may be classified according to their microbial composition, nutrient-mobilizing mechanisms, and intended agricultural application.

Table 1 ***Major Categories of Biofertilizers and Their Functions***

Category	Representative Microorganisms	Principal Mechanism	Agricultural Significance
Nitrogen-fixing biofertilizers	Rhizobium, Bradyrhizobium	Symbiotic nitrogen fixation	Improves nitrogen nutrition of legumes
Associative nitrogen fixers	Azospirillum	Associative nitrogen fixation and root stimulation	Supports cereals, grasses, and other crops

Free-living nitrogen fixers	Azotobacter	Atmospheric nitrogen fixation	Improves nitrogen availability in non-leguminous crops
Phosphate-solubilizing bacteria (PSB)	Bacillus, Pseudomonas	Organic acid production and mineral phosphate solubilization	Improves phosphorus availability
Phosphate-solubilizing fungi	Aspergillus, Penicillium	Acidification and phosphatase activity	Mobilizes certain soil phosphorus pools
Potassium-mobilizing microorganisms	Selected Bacillus and other bacterial strains	Mineral weathering and potassium release	Improves potassium availability
Zinc-solubilizing microorganisms	Selected Bacillus, Pseudomonas	Solubilization of zinc compounds	Supports micronutrient nutrition
Arbuscular mycorrhizal fungi (AMF)	Rhizophagus and related genera	Hyphal nutrient acquisition	Enhances phosphorus and micronutrient uptake
Acetobacter	Acetobacter diazotrophicus	Associative/endophytic nitrogen fixation	Particularly relevant to sugarcane
Cyanobacterial biofertilizers	Anabaena, Nostoc	Biological nitrogen fixation	Useful in rice-based systems
Azolla-based biofertilizers	Azolla–Anabaena association	Nitrogen fixation and biomass incorporation	Supports rice cultivation

Source: Adapted from FAO (2005), PIB (2023), and established microbial nutrient-management literature.

The Government of India has notified several categories of biofertilizers under the Fertiliser (Inorganic, Organic or Mixed) (Control) Order, 1985, including Rhizobium, Azotobacter, Azospirillum, phosphate-solubilizing microorganisms, mycorrhizal biofertilizers, potassium-mobilizing biofertilizers, zinc-solubilizing biofertilizers, and microbial consortia (PIB, 2023).

2.3 Mechanisms of Action of Biofertilizers

Biofertilizers improve plant nutrition through several interrelated mechanisms.

2.3.1 Biological Nitrogen Fixation

Atmospheric nitrogen (N_2) is abundant but cannot be directly utilized by most plants. Certain microorganisms convert atmospheric nitrogen into ammonia through the nitrogenase enzyme complex.

The general reaction is: $N_2 + 8H^+ + 8e^- \rightarrow 2NH_3 + H_2$

The ammonia produced is subsequently incorporated into microbial and plant nitrogen metabolism. Biological nitrogen fixation occurs through symbiotic associations (particularly between Rhizobium and leguminous plants), associative relationships between microorganisms and plant roots, free-living nitrogen-fixing microorganisms in soil, and cyanobacteria in aquatic and rice-based agroecosystems.

Rhizobium inoculation is particularly important for pulses such as chickpea, pigeon pea, lentil, soybean, and green gram. Inoculation with compatible and efficient rhizobial strains can improve nodulation, nitrogen fixation, plant growth, and yield. However, the magnitude of response depends on strain compatibility, soil nitrogen status, phosphorus availability, moisture, and environmental conditions.

2.3.2 Phosphate Solubilization and Mobilization

Phosphorus is essential for ATP production, nucleic acid synthesis, membrane formation, and energy transfer in plants. Although many Indian soils contain substantial total phosphorus, only a fraction is immediately available to plants because phosphorus can become immobilized through adsorption, precipitation, or incorporation into organic compounds.

Phosphate-solubilizing microorganisms improve phosphorus availability through production of organic acids, release of protons and acidification, chelation of calcium, iron, and aluminium, production of phosphatases and phytases, and mineralization of organic phosphorus. The effectiveness of phosphate-solubilizing microorganisms depends on the chemical composition of the soil, the type of phosphorus compound, microbial survival, and the availability of carbon sources.

2.3.3 Potassium Mobilization

Potassium is required for enzyme activation, osmotic regulation, stomatal functioning, and carbohydrate transport. A considerable quantity of potassium occurs in soil minerals, including feldspars and micas, but is not immediately available to plants. Certain microorganisms can enhance potassium release through mineral weathering, organic acid production, and the modification of mineral surfaces. Potassium-mobilizing microorganisms therefore have potential to improve potassium availability in soils where the mineral potassium reserves are present but poorly accessible.

2.3.4 Production of Plant Growth-Promoting Substances

Several beneficial microorganisms produce compounds that influence plant growth and root development. These include indole-3-acetic acid (IAA), gibberellin-like compounds, cytokinins, siderophores, ACC deaminase, and other metabolites involved in plant–microbe interactions.

IAA-producing microorganisms may stimulate lateral root formation and root-hair development, increasing the effective surface area for nutrient uptake. Siderophores bind iron and may improve iron acquisition by microorganisms and plants under certain conditions. ACC deaminase-producing bacteria can reduce the accumulation of stress-associated ethylene in plants, thereby potentially improving root growth under environmental stress.

2.3.5 Enhancement of Soil Microbial Interactions

Biofertilizers can influence the composition and activity of the rhizosphere microbiome. The rhizosphere is the soil region influenced by root exudates, microbial colonization, and plant–microbe interactions. Beneficial microbial populations may improve nutrient mineralization, root development, soil aggregation, plant tolerance to certain stresses, and competition against selected soilborne pathogens.

However, successful establishment of inoculated microorganisms is not guaranteed. Indigenous microbial populations, soil pH, moisture, temperature, crop species, and inoculant quality can influence their performance.

3. Concept, Classification, and Significance of Organic Fertilizers

3.1 Definition of Organic Fertilizers

Organic fertilizers are nutrient-containing materials derived primarily from plant, animal, or other biological sources that are applied to agricultural soils to supply nutrients and/or improve soil properties. They include farmyard manure (FYM), compost, vermicompost, green manure, poultry manure, oil cakes, biogas slurry and digestate, crop residues and other decomposed organic materials, and permitted organic nutrient formulations.

Organic fertilizers are important because they contribute to both nutrient supply and soil organic matter management. Unlike many highly soluble mineral fertilizers, nutrients in organic materials are frequently released gradually through microbial decomposition and mineralization. The release rate depends on the material's carbon-to-nitrogen ratio (C:N ratio), lignin content, moisture, temperature, microbial activity, and soil conditions.

Organic fertilizers should therefore be considered both nutrient resources and components of soil fertility management.

3.2 Classification of Organic Fertilizers

Table 2 ***Major Organic Fertilizers and Their Agricultural Significance***

Organic Fertilizer	**Source**	**Important Characteristics**	**Major Agricultural Applications**
Farmyard manure	Cattle dung, urine, bedding materials	Supplies organic carbon and multiple nutrients	Field crops, horticulture, soil improvement
Compost	Decomposed crop residues and organic wastes	Stabilized organic matter and nutrients	General soil fertility management
Vermicompost	Organic materials processed by earthworms	Fine, biologically processed organic material	Horticulture, nurseries, vegetables
Green manure	Leguminous and non-leguminous crops	Adds biomass and organic matter; legumes may fix nitrogen	Rice-based systems, rotations
Poultry manure	Poultry litter and excreta	Relatively nutrient-rich; requires appropriate handling	Cereals, vegetables, horticultural crops
Oil cakes	Neem, groundnut, castor, mustard and other oilseeds	Supplies nutrients and organic compounds	Field crops, horticulture
Biogas slurry	Anaerobic digestion of organic wastes	Contains nutrients and residual organic matter	Crop production and nutrient recycling
Crop residues	Straw, stalks, leaves, roots	Adds carbon and supports nutrient cycling	Conservation agriculture and soil organic matter management
Press mud	Sugar industry by-product	Organic matter and nutrients	Sugarcane and other crops
City compost	Segregated biodegradable municipal waste	Recycles urban organic resources	Agricultural and horticultural soils, subject to quality standards

Source: Adapted from FAO (2005), FAO (2017), and relevant Indian organic fertilizer standards.

3.3 Farmyard Manure

Farmyard manure is one of the oldest and most widely used organic fertilizers in India. It generally consists of cattle dung, urine, bedding materials, and partially decomposed organic matter. FYM contributes to soil fertility by supplying nitrogen, phosphorus, potassium, and secondary nutrients; increasing soil organic carbon; improving soil aggregation and structural stability; increasing water-holding capacity; supporting microbial biomass and activity; and improving nutrient retention in sandy and low-organic-matter soils.

The nutrient composition of FYM varies considerably depending on livestock species, feeding practices, bedding materials, storage conditions, and degree of decomposition. Poor storage and unmanaged manure heaps can result in nitrogen losses through volatilization, leaching, and runoff. Consequently, proper collection, storage, and application are important for maximizing its fertilizer value.

3.4 Compost

Compost is produced through the controlled biological decomposition of organic materials under predominantly aerobic conditions. Composting converts biodegradable wastes into a relatively stable organic amendment. Common composting materials include crop residues, animal manures, leaves and plant biomass, vegetable and fruit wastes, and selected biodegradable agro-industrial wastes.

Compost improves soil fertility by supplying nutrients and contributing to soil organic matter. Its major advantages include waste recycling, reduced dependence on external nutrient inputs, improved soil structure, and increased biological activity. However, compost quality is determined by feedstock composition, maturity, nutrient concentration, salinity, and contamination. Immature compost may cause temporary nitrogen immobilization, oxygen depletion, phytotoxicity, or poor crop establishment.

3.5 Vermicompost

Vermicomposting involves the biological processing of organic materials by earthworms and associated microorganisms. Earthworms fragment organic materials and increase their contact with microorganisms. Their digestive processes and casts can influence nutrient transformations and organic matter characteristics.

Vermicompost is frequently used in vegetable production, nurseries, horticulture, and organic farming. Its potential benefits include improved soil aggregation, increased microbial activity, improved nutrient availability, enhanced root growth, improved soil moisture retention, and recycling of organic wastes. Nevertheless, vermicompost should not be regarded as a universally concentrated fertilizer. Its nutrient composition varies according to feedstock and processing conditions, and the amount required for field-scale nutrient supply may be substantial.

3.6 Green Manuring

Green manuring involves growing a crop specifically to incorporate its biomass into the soil. Important green manure crops in India include Sesbania aculeata (dhaincha), Sesbania rostrata, Crotalaria juncea (sunn hemp), cowpea, and other locally adapted leguminous crops.

Green manuring is particularly important in rice-based systems and other cropping systems where the interval between crops permits biomass production. Leguminous green manure crops can contribute biologically fixed nitrogen, while their incorporated biomass supplies organic carbon and supports microbial nutrient cycling. Green manuring may also improve soil aggregation, biological activity, and nutrient retention. The effectiveness of green manuring depends on biomass production, nitrogen fixation, incorporation timing, decomposition, and subsequent crop nutrient demand.

4. Role of Biofertilizers and Organic Fertilizers in Soil Fertility

Soil fertility is the capacity of soil to provide essential nutrients in adequate quantities and suitable proportions for plant growth. Soil fertility is closely related to soil health, but the two concepts are not identical. Soil fertility primarily concerns nutrient availability and the ability of soil to support plant nutrition. Soil health is a broader concept encompassing physical, chemical, and biological properties that sustain ecosystem functions.

Biofertilizers and organic fertilizers influence soil fertility through complementary mechanisms.

4.1 Improvement of Soil Physical Properties

Organic fertilizers contribute to soil organic matter, which plays a critical role in the formation and stabilization of soil aggregates. Stable aggregates improve pore continuity, aeration, infiltration, and root penetration. The addition of organic matter can also reduce bulk density in some soils, improve soil structure, increase water infiltration, reduce surface crusting, improve water-holding capacity, and reduce susceptibility to erosion.

These benefits are particularly important in coarse-textured soils, degraded agricultural lands, and soils with low organic carbon. However, the magnitude of improvement depends on the type and quantity of organic material, soil texture, climatic conditions, and duration of application.

Biofertilizers contribute indirectly to soil physical properties through increased root growth, microbial biomass, extracellular polymer production, and improved rhizosphere aggregation. Microbial extracellular polymeric substances (EPS), fungal hyphae, root exudates, and organic matter contribute to the formation of soil aggregates. Arbuscular mycorrhizal fungi can influence soil aggregation through hyphal networks and associated biochemical processes.

4.2 Improvement of Soil Chemical Properties

4.2.1 Increase in Soil Organic Carbon

Soil organic carbon (SOC) is an important indicator of soil quality and long-term agricultural sustainability. Organic amendments contribute carbon through the addition of plant residues, manure, compost, and other biologically derived materials. Some of the added carbon is decomposed and released as carbon dioxide, while a fraction may be stabilized through interactions with minerals and soil aggregates. The resulting changes in SOC depend on quantity and quality of organic inputs, soil texture and mineralogy, temperature and moisture, tillage intensity, cropping system, and duration of management. Long-term organic matter management is therefore essential for maintaining soil carbon stocks.

4.2.2 Improvement of Cation Exchange Capacity

Cation exchange capacity (CEC) represents the ability of soil to retain and exchange positively charged ions. Humified organic matter contains functional groups, including carboxyl and phenolic groups, that contribute to CEC. An increase in organic matter can improve the retention of nutrients such as potassium, calcium, magnesium, and ammonium. This effect is particularly important in sandy soils, where nutrient retention is frequently limited.

4.2.3 Nutrient Mineralization

Organic fertilizers contain nutrients in both organic and inorganic forms. Microorganisms decompose organic compounds and release nutrients through mineralization. For example, organic nitrogen is converted to ammonium and subsequently to nitrate. The rate of mineralization depends on temperature, moisture, substrate quality, microbial activity, and the C:N ratio. A high C:N ratio may cause temporary

nitrogen immobilization, whereas materials with a relatively low C:N ratio may release nitrogen more rapidly. This distinction is important for synchronizing nutrient release with crop demand.

4.2.4 Improved Micronutrient Availability

Organic matter can influence the availability of iron, zinc, copper, and manganese through complexation, chelation, and changes in soil chemical conditions. Organic ligands may increase the mobility of certain micronutrients and improve their availability to plants. However, the response is soil-specific. Organic matter may also immobilize certain nutrients under particular conditions.

4.3 Improvement of Soil Biological Properties

Soil microorganisms are essential for nutrient cycling, organic matter decomposition, and soil ecosystem functioning. Organic fertilizers provide carbon substrates that support microbial growth and activity. Their application may increase microbial biomass carbon, microbial biomass nitrogen, soil respiration, enzyme activity, functional diversity of soil microorganisms, and nutrient mineralization rates.

Important soil enzymes include dehydrogenase (indicator of microbial oxidative activity), urease (catalyses urea hydrolysis), phosphatase (releases phosphate from organic phosphorus compounds), β-glucosidase (involved in carbon cycling), and arylsulfatase (involved in sulfur mineralization). Enzyme activity is influenced by soil temperature, moisture, substrate availability, microbial populations, and management practices.

The combined application of organic amendments and biofertilizers may create favorable conditions for microbial activity and nutrient transformations. Recent reviews emphasize the potential synergy between organic amendments and microbial inoculants for maintaining soil fertility and agricultural sustainability (Tayade et al., 2024).

4.4 Improvement of Nutrient-Use Efficiency

Nutrient-use efficiency (NUE) describes how effectively crops utilize nutrients supplied through fertilizers, soil reserves, and other sources. Biofertilizers may improve NUE through nutrient mobilization, root development, and improved plant nutrient acquisition. Organic fertilizers may improve NUE through gradual nutrient release, increased nutrient retention, improved soil water relations, enhanced root development, and reduced nutrient losses under appropriate management.

However, organic nutrient sources do not automatically guarantee high NUE. Poorly synchronized nutrient release, excessive application, or inadequate management can result in nutrient losses. An integrated approach that combines organic amendments, biofertilizers, crop rotations, soil testing, and appropriate nutrient application is therefore essential.

Table 3 ***Comparative Contribution of Biofertilizers and Organic Fertilizers to Soil Fertility***

Soil Fertility Component	Biofertilizers	Organic Fertilizers
Nitrogen availability	Biological nitrogen fixation and N-related microbial processes	Nitrogen supply through mineralization
Phosphorus availability	Solubilization and mobilization	Organic phosphorus supply and mineralization
Potassium availability	Mobilization of mineral potassium	Potassium supply through organic materials
Soil organic carbon	Indirect contribution through roots and microbial biomass	Direct addition of organic carbon

Soil structure	Microbial EPS, root stimulation, fungal hyphae	Aggregation, organic matter addition
Water-holding capacity	Indirect effects through root and microbial processes	Improved soil organic matter and structure
Microbial biomass	Introduction or stimulation of beneficial microorganisms	Carbon and nutrient supply to microbial populations
Micronutrient availability	Solubilization and mobilization	Nutrient supply and organic complexation
Nutrient retention	Improved plant acquisition and selected microbial processes	Increased organic matter and cation exchange capacity
Long-term soil fertility	Biological nutrient cycling	Organic matter maintenance and nutrient recycling

5. Synergistic Role of Biofertilizers and Organic Fertilizers

The combined application of biofertilizers and organic fertilizers is an important strategy for improving soil fertility and crop productivity. Organic fertilizers provide carbon substrates, nutrients, and a favorable habitat for microorganisms. Biofertilizers, in turn, can enhance nutrient transformations and plant nutrient acquisition. This interaction can be described as a soil fertility management cycle.

5.1 Organic Resource materials as Carriers and Substrates for Microorganisms

Organic Resource materials may provide favorable conditions for the survival and activity of beneficial microorganisms. Organic Resource materials can supply carbon sources, nitrogen and other nutrients, moisture-retaining substrates, microsites for microbial colonization, and organic compounds involved in microbial metabolism. Nevertheless, the effect of an Organic Resource materials on an inoculant depends on its quality, maturity, salinity, pH, and compatibility with the microbial strain. For example, highly saline or incompletely decomposed organic materials may adversely affect microbial survival and crop establishment.

5.2 Improved Phosphorus Availability through Integrated Application

Phosphorus is often a limiting nutrient in Indian agricultural soils. The combined application of compost or FYM with phosphate-solubilizing microorganisms may improve phosphorus availability through complementary mechanisms. Organic matter may influence phosphorus adsorption and complexation, while phosphate-solubilizing microorganisms release organic acids and phosphatases. Mycorrhizal fungi can further improve phosphorus acquisition by extending the effective nutrient-absorbing area of plant roots. This combination is particularly relevant to crops with substantial phosphorus requirements.

5.3 Improved Biological Nitrogen Management

The integration of leguminous green manure, Rhizobium inoculation, and organic nutrient recycling can improve nitrogen management. The process involves establishment of a compatible nitrogen-fixing microorganism, formation of root nodules, biological fixation of atmospheric nitrogen, production of nitrogen-rich biomass, incorporation of residues or green manure, mineralization and release of nitrogen, and uptake by subsequent crops. This approach is particularly useful in cereal–legume rotations and integrated organic farming systems.

5.4 Integration with Mineral Fertilizers

Biofertilizers and organic fertilizers may also be used in integrated nutrient management (INM) systems that include mineral fertilizers. INM aims to supply nutrients through a combination of organic, biological,

and inorganic sources while maintaining soil fertility and crop productivity. This approach is especially relevant during the transition from conventional agriculture to organic farming. The use of biofertilizers and organic amendments alongside mineral fertilizers can improve nutrient-use efficiency and potentially reduce excessive fertilizer application. However, the appropriate nutrient substitution rate must be determined through crop-specific and soil-specific studies.

Recent research emphasizes the potential benefits of combining microbial inoculants and organic amendments rather than relying on either input independently (Tayade et al., 2024).

6. Significance of Biofertilizers and Organic Fertilizers in Promoting Organic Farming in India

6.1 Organic Farming: Concept and Principles

Organic farming is an agricultural production system that emphasizes ecological processes, biological nutrient cycling, soil health, biodiversity, and the responsible management of natural resources. Organic farming does not simply involve the replacement of chemical fertilizers with organic fertilizers. It requires a broader transformation of agricultural management involving soil organic matter management, crop rotation and diversification, biological pest management, nutrient recycling, conservation of biodiversity, prevention of prohibited input use, maintenance of soil fertility, and appropriate certification and traceability.

Biofertilizers and organic fertilizers are essential components of this system because they support biological nutrient management and the recycling of organic resources. NSOP describes organic agriculture as a production system that emphasizes the preservation and regeneration of soil, sound plant nutrition, and environmentally responsible agricultural management.

6.2 Reducing Dependence on External Nutrient Inputs

Organic farming systems seek to minimize dependence on synthetic inputs by utilizing locally available resources and biological processes. Biofertilizers can reduce dependence on certain external nutrient inputs by improving nutrient acquisition and supporting biological nitrogen fixation. Organic fertilizers can recycle nutrients from livestock manure, crop residues, green manure crops, compostable agricultural wastes, and selected agro-industrial by-products. This approach can improve nutrient self-sufficiency, particularly in mixed crop–livestock farming systems.

However, organic farming does not eliminate the need for nutrient budgeting. Nutrients removed through harvested products must be replenished through organic inputs, biological fixation, permitted external inputs, or other nutrient sources.

6.3 Recycling Agricultural and Urban Organic Wastes

India generates substantial quantities of agricultural residues, livestock manure, and biodegradable organic wastes. The conversion of these resources into compost, vermicompost, and other permitted organic fertilizers can contribute to circular nutrient management. The benefits include recycling nutrients that would otherwise be lost, reducing the environmental burden associated with unmanaged organic wastes, improving soil organic matter, supporting rural employment and entrepreneurship, and reducing dependence on certain external nutrient inputs.

The FAO has emphasized that organic manures are important not only as nutrient sources but also for improving soil physical and chemical properties and enhancing the efficiency of mineral fertilizers when used in complementary nutrient management systems (FAO, 2005).

6.4 Supporting Small and Marginal Farmers

Small and marginal farmers constitute a major proportion of India's agricultural population. Biofertilizers and organic fertilizers can provide opportunities for reducing input costs and improving resource-use efficiency, particularly where locally available organic materials can be utilized. Potential benefits include lower expenditure on selected external inputs, improved soil fertility, better utilization of livestock resources, increased recycling of crop residues, opportunities for local production of compost and biofertilizers, and development of farmer groups and producer organizations.

Nevertheless, organic farming may involve additional labor requirements, certification costs, and marketing challenges. The economic benefits depend on crop selection, input availability, market access, and the transition period.

6.5 Improving the Sustainability of Indian Agriculture

The application of biofertilizers and organic fertilizers may contribute to sustainable agriculture through improved soil fertility, increased biological activity, reduced nutrient losses under appropriate management, better soil water retention, greater resilience to certain environmental stresses, improved recycling of nutrients, and reduced dependence on selected synthetic inputs. These benefits are particularly relevant in degraded soils, low-organic-carbon regions, and farming systems where nutrient imbalances have developed.

However, sustainable agriculture requires more than the use of organic inputs. Soil conservation, water management, crop diversification, balanced nutrient application, and integrated pest management remain essential.

7. Status of Organic Farming in India: Facts and Figures

India has emerged as a major producer of organic agricultural commodities. According to APEDA, India ranked second globally in terms of organic agricultural land and first in terms of the total number of organic producers, based on the FiBL and IFOAM Yearbook 2024.

7.1 Organic Certification under NPOP

The National Programme for Organic Production is implemented by APEDA under the Ministry of Commerce and Industry, Government of India. NPOP provides standards for organic production, accreditation of certification bodies, inspection, certification, and the use of the India Organic logo.

Table 4 ***India's Organic Farming Statistics Under NPOP***

Indicator	2023–2024	2024–2025
Certified organic cultivated area	1.71 million ha	2.25 million ha
Cultivated area under conversion	2.76 million ha	1.71 million ha
Total certified cultivated area, including conversion	4.48 million ha	3.97 million ha
Wild-harvest collection area	2.85 million ha	2.26 million ha
Certified organic farm production	3.23 million MT	4.39 million MT
Farm production under conversion	0.32 million MT	0.31 million MT
Organic export quantity	0.261 million MT	0.368 million MT
Organic export value	₹4,007.91 crore	₹5,394.32 crore

Source: APEDA (2024, 2025). Production values represent commercial output for sale and should not be interpreted as total physical production from all certified farms.

The figures indicate that certified organic cultivated area increased from approximately 1.71 million hectares in 2023–2024 to 2.25 million hectares in 2024–2025. Organic farm production under NPOP also increased from approximately 3.23 million tonnes to 4.39 million tonnes. The reduction in the total area under certification, including conversion, between these two reporting years should not automatically be interpreted as a decline in organic farming. Certification coverage, conversion status, and reporting methods influence the reported figures.

7.2 State-Wise Distribution of Organic Farming

Organic farming is distributed across different agroclimatic regions of India. Madhya Pradesh, Maharashtra, Rajasthan, Gujarat, Odisha, and other states have substantial areas under organic certification.

Table 5 ***Leading Indian States in Certified Organic Cultivated Area Under NPOP, 2024–2025***

State	Certified Organic Area (ha)	Area Under Conversion (ha)	Total Area (ha)
Madhya Pradesh	670,425.55	343,030.67	1,013,456.22
Maharashtra	526,628.63	439,916.08	966,544.71
Rajasthan	303,761.56	247,987.99	551,749.55
Gujarat	192,940.85	244,092.15	437,033.00
Odisha	93,537.36	106,574.70	200,112.07
Sikkim	75,451.57	258.83	75,710.40
Uttarakhand	56,009.91	38,414.86	94,424.76
Uttar Pradesh	51,045.63	18,022.95	69,068.57
Karnataka	32,236.69	21,394.92	53,631.61
Meghalaya	20,100.10	9,575.04	29,675.13

Source: APEDA (2025). Figures refer to cultivated farm area registered under NPOP, not wild-harvest collection area.

Madhya Pradesh and Maharashtra together account for a substantial proportion of India's certified organic cultivated area. Sikkim is particularly significant because it became India's first fully organic state in 2016. The organic farming experience of Sikkim demonstrates the importance of coordinated government policy, farmer training, input management, certification, and market development. However, the suitability of organic farming practices varies across agroclimatic regions, cropping systems, and farm resource conditions.

7.3 Organic Production and Exports

Organic production in India includes cereals, millets, pulses, oilseeds, spices, fruits, vegetables, tea, coffee, medicinal plants, and processed agricultural products. APEDA reported the following for 2024–2025: certified organic farm production approximately 4.39 million tonnes; organic farm production under conversion approximately 0.31 million tonnes; organic export quantity approximately 368,155 tonnes; organic export value approximately ₹5,394.32 crore; and organic export realization approximately US$665.97 million. The major export destinations include the United States, the European Union, Great Britain, Canada, Australia, Switzerland, and other international markets (APEDA, 2025).

The development of reliable organic nutrient management is essential for maintaining certification compliance, product quality, and long-term production sustainability.

8. Government Initiatives for Promoting Organic and Biological Nutrient Management in India

The Government of India has introduced several programmes to promote organic farming, natural farming, soil health, and biological nutrient management. Following are the details government of India Initiatives for Promoting Organic and Biological Nutrient Management:

8.1 Paramparagat Krishi Vikas Yojana (PKVY)

PKVY is a centrally sponsored scheme under the broader framework of the National Mission for Sustainable Agriculture. The scheme promotes cluster-based organic farming, farmer capacity building, organic input management, certification, and marketing. Under PKVY, assistance of ₹31,500 per hectare over three years has been provided for the promotion of organic farming. This includes ₹15,000 per hectare through Direct Benefit Transfer to farmers for on-farm and off-farm organic inputs, according to the Government of India's reported scheme provisions (PIB, 2025).

The scheme can support the adoption of compost and vermicompost, farmyard manure, biofertilizers, green manure crops, and other permitted organic inputs. PKVY is particularly important for supporting the transition toward organic farming among farmer clusters.

8.2 Mission Organic Value Chain Development for North Eastern Region (MOVCDNER)

MOVCDNER is an important initiative for promoting organic farming in the northeastern states of India. The programme focuses on the development of organic value chains, farmer organizations, production clusters, processing, certification, and marketing. The scheme provides assistance of ₹46,500 per hectare over three years for relevant organic farming activities, including support for organic inputs and farmer organizations. The reported assistance includes ₹32,500 per hectare for on-farm and off-farm organic inputs, with ₹15,000 per hectare provided through DBT to farmers (PIB, 2025).

The programme is particularly relevant to the northeastern region because of its diverse agroecological conditions, traditional farming practices, and opportunities for organic production.

8.3 National Mission on Natural Farming (NMNF)

The National Mission on Natural Farming emphasizes the promotion of natural farming practices that rely on biological processes, locally available resources, and ecological management. Natural farming and organic farming are related but distinct approaches. Natural farming generally emphasizes the use of locally available biological resources and ecological processes, while organic farming may include a broader range of permitted external organic inputs and formal certification requirements.

The NMNF provides an opportunity to promote biological nutrient cycling, soil organic matter management, microbial activity, crop diversification, natural resource conservation, and farmer training and demonstration. The development of reliable biofertilizer technologies and quality organic inputs can complement natural farming programmes where their use is consistent with the applicable production standards.

8.4 PM-PRANAM

The PM-PRANAM initiative aims to encourage states and union territories to reduce excessive dependence on chemical fertilizers and promote balanced nutrient management. The programme encourages the adoption of integrated nutrient management practices and the use of organic and biofertilizers to maintain soil fertility and sustainable agricultural productivity (PIB, 2025).

8.5 Soil Health Card Scheme

The Soil Health Card Scheme provides information on soil nutrient status and recommendations for nutrient management. Soil testing is important for determining soil pH, electrical conductivity, organic carbon, available nitrogen, available phosphorus, available potassium, and selected secondary and micronutrients. The use of soil test information can improve the effectiveness of organic fertilizers and biofertilizers by identifying nutrient deficiencies, pH constraints, and the need for specific amendments.

8.6 National Programme for Organic Production (NPOP)

NPOP provides the regulatory and certification framework for organic production in India. The programme is implemented by APEDA and includes standards for organic production, certification, accreditation, and traceability. NPOP is important for export-oriented organic production and the maintenance of certification integrity.

8.7 Participatory Guarantee System for India (PGS-India)

PGS-India is a participatory organic quality assurance system designed primarily for domestic organic production. It emphasizes farmer participation, peer review, local knowledge, group responsibility, and community-based verification. PGS-India can facilitate organic certification among small and marginal farmers who may face difficulties accessing third-party certification systems.

Table 6 ***Major Indian Initiatives and Their Relevance to Biological Nutrient Management***

Programme	**Primary Objective**	**Relevance to Biofertilizers and Organic Fertilizers**
PKVY	Promotion of organic farming	Support for organic inputs and cluster-based farming
MOVCDNER	Organic value-chain development in the Northeast	Organic input support, certification, and market development
NMNF	Promotion of natural farming	Biological nutrient management and resource recycling
PM-PRANAM	Reduction of excessive chemical fertilizer use	Encourages INM and biological nutrient sources
Soil Health Card Scheme	Soil fertility assessment	Supports soil-test-based nutrient management
NPOP	Organic certification and export standards	Ensures compliance with organic production requirements including usage of suitable inputs like biofertilizers and organic fertilizers
PGS-India	Participatory domestic organic certification	

9. Quality Control and Regulatory Framework for Biofertilizers and Organic Fertilizers in India

The effectiveness of biofertilizers and organic fertilizers depends not only on their application but also on their quality. Poor-quality products may contain inadequate nutrient concentrations, low microbial viability, contaminants, or unsuitable formulations.

9.1 Fertiliser (Inorganic, Organic or Mixed) (Control) Order, 1985

The Fertiliser (Inorganic, Organic or Mixed) (Control) Order, 1985, commonly referred to as the FCO, provides the regulatory framework for fertilizer quality in India. The FCO includes specifications for

notified biofertilizers and organic fertilizers, as well as provisions relating to fertilizer manufacture, sale, quality, and compliance. The Government of India has published updated FCO reference materials through the National Centre for Organic and Natural Farming (NCONF, 2023).

9.2 Quality Parameters of Biofertilizers

Important quality parameters include identity of the microbial strain, viable cell count, microbial purity, absence of specified contaminants, appropriate pH, packaging and labeling, and efficiency characteristics/compatibility with the intended crop and application method. Microbial viability is particularly important because biofertilizers depend on living microorganisms. The presence of an appropriate microbial species alone does not guarantee effectiveness. The strain must be viable, sufficiently abundant, compatible with the crop, and capable of functioning under the target soil conditions.

9.3 Quality Parameters of Organic Fertilizers

Important quality parameters include organic carbon content, moisture content, nutrient concentration, C:N ratio, pH, electrical conductivity, maturity and stability, heavy metal concentrations, pathogen contamination free, and physical characteristics. Organic fertilizers produced from municipal wastes, sewage-derived materials, or industrial by-products require particularly careful quality control. Contaminants may accumulate in soil if contaminated organic materials are repeatedly applied.

9.4 Importance of Quality Assurance

Quality assurance is essential for maintaining farmer confidence, ensuring predictable nutrient supply, preventing contamination, supporting certification compliance, improving field performance, facilitating commercial development, and strengthening the credibility of organic farming. The development of reliable testing protocols, reference standards, microbial culture collections, and quality control laboratories is therefore a major priority for the expansion of biological nutrient management.

10. Limitations and Challenges in the Adoption of Biofertilizers and Organic Fertilizers

Despite their substantial potential, biofertilizers and organic fertilizers face several technical, economic, and institutional challenges.

10.1 Variability in Nutrient Composition

Organic fertilizers differ considerably in nutrient concentration. The composition of FYM, compost, vermicompost, poultry manure, and other materials depends on the source, processing method, storage conditions, and maturity. Consequently, nutrient application rates should be based on nutrient analysis rather than volume or weight alone.

10.2 Slow Nutrient Release

Organic fertilizers often release nutrients gradually. This can be advantageous for maintaining long-term soil fertility, but nutrient release may not always coincide with crop demand. Crops with high nutrient requirements during early growth stages may experience temporary nutrient limitations if organic materials mineralize too slowly.

10.3 Microbial Survival and Field Performance

Biofertilizer performance depends on the survival and establishment of inoculated microorganisms. Important limiting factors include high soil temperature, moisture stress, soil acidity or alkalinity, salinity, incompatible pesticides, poor storage conditions, low inoculant quality, and competition from indigenous microorganisms. The effectiveness of microbial inoculants can therefore vary substantially between locations and seasons.

10.4 Availability of Organic Resources

The quantity of organic materials available to farmers is often limited. Crop residues may be used for livestock feed, fuel, construction, or other purposes. Similarly, livestock manure may not be adequately collected or stored. Organic farming systems therefore require effective resource budgeting and recycling strategies.

10.5 Labor and Transportation Costs

Organic fertilizers are often bulky and may require substantial labor for collection, transport, processing, and field application. These costs can be particularly significant for small and marginal farmers. The development of decentralized composting facilities, farmer cooperatives, and local organic input enterprises may help reduce these constraints.

10.6 Transition Period and Yield Variability

During conversion from conventional to organic farming, soil nutrient supply and crop productivity may change. The transition period can involve reduced availability of rapidly soluble nutrients, changes in soil microbial populations, increased labor requirements, need for new crop rotations, temporary yield variability, and certification and marketing challenges. The economic viability of organic farming depends on appropriate transition planning, crop selection, nutrient management, and market access.

10.7 Risk of Nutrient Losses

Organic fertilizers are not inherently free from environmental risks. Excessive manure or compost application can contribute to nitrogen leaching, phosphorus runoff, ammonia volatilization, greenhouse gas emissions, salinity accumulation, and nutrient imbalances. Organic fertilizers should therefore be applied according to crop nutrient requirements and soil nutrient status.

10.8 Need for Reliable Scientific Evidence

Although many studies demonstrate beneficial effects of biofertilizers and organic fertilizers, the magnitude of their effects is highly variable. Research findings should not be generalized across all crops and soil types. The development of region-specific recommendations requires long-term field experiments, multi-location trials, and economic evaluation.

11. Future Research Priorities and Recommendations

The wider adoption of biofertilizers and organic fertilizers in India requires a combination of scientific innovation, institutional support, and farmer-centered implementation.

11.1 Development of Efficient Microbial Consortia

Research should focus on developing microbial consortia containing compatible microorganisms with complementary functions. Potential combinations include nitrogen-fixing microorganisms with phosphate-solubilizing bacteria, phosphate-solubilizing bacteria with mycorrhizal fungi, potassium-mobilizing microorganisms with plant growth-promoting rhizobacteria, and microbial consortia compatible with compost and other organic amendments. The compatibility of different microorganisms must be evaluated before commercial formulation.

11.2 Development of Region-Specific Biofertilizers

India's agroclimatic diversity requires biofertilizer technologies adapted to local conditions. Research priorities should include acid-tolerant microbial strains for acidic soils, salt-tolerant microorganisms for saline soils, drought-adapted microbial strains, crop-specific nitrogen-fixing microorganisms, microbial consortia for northeastern Indian agroecosystems, and biofertilizers compatible with locally available

organic materials. The selection of locally adapted microbial strains may improve survival and field performance.

11.3 Strengthening Organic Fertilizer Production

Organic fertilizer production should be strengthened through decentralized composting facilities, improved composting methods, quality testing and certification, scientific management of livestock manure, crop-residue recycling, appropriate use of agro-industrial by-products, and farmer producer organizations and cooperatives. The establishment of local organic fertilizer production units may reduce transportation costs and improve access to quality inputs.

11.4 Long-Term Soil Fertility Experiments

Long-term field experiments are essential for evaluating the cumulative effects of organic fertilizers and biofertilizers. Important research parameters include soil organic carbon, soil microbial biomass, soil enzyme activity, available nitrogen, phosphorus, and potassium, micronutrient availability, soil aggregation, bulk density, water-holding capacity, crop productivity, nutrient-use efficiency, greenhouse gas emissions, and farm profitability. Long-term studies should compare organic farming, integrated nutrient management, and conventional nutrient management systems under similar agroclimatic conditions.

11.5 Improving Farmer Training and Extension

Farmer training is essential for ensuring the correct use of biofertilizers and organic fertilizers. Training programmes should emphasize identification of suitable biofertilizers, seed treatment and root dipping, appropriate inoculant application methods, storage and handling, compost preparation, organic fertilizer quality assessment, soil testing, nutrient budgeting, organic certification, and market development. Demonstration plots and farmer field schools can improve awareness and adoption.

11.6 Digital Monitoring and Organic Nutrient Management

Digital technologies can improve organic farming management through soil fertility mapping, organic input databases, crop nutrient requirement assessment, certification traceability, farmer advisory systems, monitoring of soil organic carbon, and digital records of organic input application. Integration of soil testing, remote sensing, and farm-level nutrient records may improve the efficiency of organic nutrient management.

11.7 Strengthening Research and Extension Institutions

Research institutions, agricultural universities, ICAR institutes, NCONF, regional centres, state agricultural departments, and farmer organizations should collaborate to develop reliable organic nutrient management technologies. The establishment of regional biofertilizer testing facilities, demonstration farms, and organic input production units would support technology transfer. Greater coordination between research institutions and organic farming certification agencies is also necessary to ensure that recommended inputs comply with applicable standards.

12. Discussion

Biofertilizers and organic fertilizers represent complementary technologies for maintaining soil fertility and supporting sustainable agricultural production. Their significance extends beyond the direct supply of plant nutrients. Biofertilizers influence nutrient availability through microbial processes, while organic fertilizers contribute nutrients, organic carbon, and improvements in soil structure and biological activity. The combined application of these inputs can improve nutrient cycling, support beneficial microbial populations, and contribute to the development of more resilient agricultural systems.

Nevertheless, their effectiveness depends on several interacting factors. First, nutrient availability must be synchronized with crop demand. Organic fertilizers may release nutrients slowly, while biofertilizers depend on microbial activity and survival. Therefore, neither input can be expected to provide uniform nutrient supply under all conditions.

Second, organic farming requires effective nutrient budgeting. Although biological nitrogen fixation and organic nutrient recycling can contribute substantially to nutrient supply, harvested crops continuously remove nutrients from agricultural soils. Nutrient replacement must therefore be planned carefully.

Third, the economic benefits of organic farming depend on input availability, labor costs, certification, market access, and crop selection.

Fourth, the quality of organic fertilizers and biofertilizers is essential for their effectiveness. The use of poor-quality microbial inoculants or contaminated organic materials may reduce productivity and create environmental risks.

India's organic farming sector has expanded considerably, and official certification data indicate growing production and export activity. However, the future of organic farming will depend not merely on increasing certified area but also on maintaining soil fertility, improving farmer profitability, and ensuring the sustainability of agricultural production.

The most appropriate approach is therefore a scientifically grounded, region-specific, and integrated strategy that combines biological nutrient management, organic resource recycling, soil testing, crop diversification, and effective quality control.

13. Conclusion

Biofertilizers and organic fertilizers are important components of sustainable soil fertility management and organic farming in India. Biofertilizers improve nutrient availability through biological nitrogen fixation, phosphorus solubilization, potassium mobilization, micronutrient mobilization, and plant growth-promoting mechanisms. Organic fertilizers supply nutrients and organic carbon while improving soil structure, water-holding capacity, nutrient retention, and microbial activity.

Their combined application can enhance nutrient cycling, improve soil fertility, and contribute to the long-term sustainability of agricultural production. The significance of these inputs is particularly important in India, where intensive agricultural production, soil fertility degradation, nutrient imbalances, and the need for sustainable resource management have increased the demand for alternative and complementary nutrient management strategies.

Government initiatives such as PKVY, MOVCDNER, NMNF, PM-PRANAM, NPOP, and PGS-India provide important institutional support for organic farming and biological nutrient management. However, biofertilizers and organic fertilizers should not be considered universal substitutes for mineral fertilizers. Their effectiveness depends on microbial quality, nutrient composition, soil properties, crop requirements, climate, and management practices.

A sustainable transition toward organic farming requires the integration of biological nutrient management with soil testing, nutrient budgeting, organic resource recycling, crop diversification, and appropriate quality assurance. Future research should prioritize efficient microbial consortia, region-specific biofertilizers, long-term soil fertility experiments, improved organic fertilizer production, and farmer-centered extension systems.

Ultimately, the successful promotion of organic farming in India depends on maintaining soil fertility while ensuring crop productivity, farmer profitability, environmental sustainability, and the long-term resilience of agricultural ecosystems.

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