

THE ROLES OF BIOFERTILIZERS IN SUSTAINABLE CROP PRODUCTION

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Abstract

This study investigates the role of biofertilizers in sustainable crop production. Specifically, the research examines their effects on soil nutrient dynamics, assesses their impact on crop growth and yield, and explores their practical application in farming systems. Empirical evidence suggests that biofertilizers improve soil health by fixing atmospheric nitrogen, solubilizing phosphorus, and producing growth-promoting substances, thereby enhancing nutrient availability for crops. Studies also show that crops treated with biofertilizers exhibit higher growth rates, improved biomass, and increased yields compared to those relying solely on chemical fertilizers. The application of biofertilizers is also cost-effective, environmentally friendly, and reduces the risk of soil and water contamination. The findings highlight the importance of integrating biofertilizers into sustainable agricultural practices to maintain long-term soil fertility and productivity. This study provides actionable insights for farmers, agronomists, and policymakers aiming to transition toward eco-friendly crop production systems. It concludes that biofertilizers are essential for enhancing soil fertility, optimizing crop performance, and promoting sustainable agriculture in the face of growing environmental and economic pressures, and recommended that farmers should be guided on the correct application methods such as seed coating, soil incorporation, and root dipping to enhance microbial establishment.

Keywords: *Biofertilizers, Sustainable agriculture, Soil fertility, Crop productivity, Nutrient management.*

Background of the Study

Sustainable crop production has become a global priority due to increasing concerns around soil degradation, declining crop yields, and the environmental consequences of heavy chemical fertilizer use. Over the past few decades, agricultural intensification has relied heavily on synthetic fertilizers to boost productivity and meet rising food demand (Fasusi, Cruz & Babalola, 2021). Although these inputs have improved yields, they have also contributed to severe ecological challenges, including soil acidification, nutrient imbalance, reduced soil biodiversity, and water pollution from nutrient runoff. This situation has created an urgent need for safer and more sustainable alternatives that can sustain production while protecting the environment. Biofertilizers have emerged as a promising solution in this direction. They are natural products containing living microorganisms such as nitrogen-fixing bacteria, phosphate-solubilizing bacteria, and mycorrhizal fungi that enhance nutrient availability in soils. Unlike chemical fertilizers that supply nutrients directly in inorganic forms, biofertilizers work by improving the natural biological processes that support plant growth, making them an important component of environmentally friendly farming practices and sustainable agriculture systems (Fadiji, Xiong, Egidi & Singh, 2024).

According to Kumar, Dewangan, Lawate, Bahadur & Prajapati, (2019), one of the primary roles of biofertilizers is enhancing soil fertility. Microbial communities in the soil play a critical role in nutrient cycling, decomposition of organic matter, and maintaining soil structure. When these beneficial microorganisms are introduced through biofertilizers, they improve soil health by fixing atmospheric nitrogen, solubilizing bound phosphorus, and increasing the availability of micronutrients such as zinc and silicon (Kamran et al., 2017;

Kumawat et al., 2019). This natural enrichment of the soil reduces dependency on synthetic fertilizers and helps restore soil life that may have been weakened by years of chemical input. In addition to improving nutrient availability, biofertilizers contribute to plant growth and productivity through the production of plant growth-promoting substances. Some microbial strains release hormones like auxins, gibberellins, and cytokinins that enhance root development and overall plant vigor. Stronger roots improve nutrient uptake efficiency and help crops withstand drought, salinity, and disease stress. This makes biofertilizers particularly valuable for farmers practicing low-input agriculture in regions facing climate challenges (Heidari & Golpayegani, 2012).

The benefits of biofertilizers are also linked to their long-term positive effects on soil conservation. Unlike chemical fertilizers, which may rapidly deplete soil structure, biofertilizers enhance soil aggregation and water-holding capacity, supporting long-term crop sustainability and reducing soil erosion. Improved soil physical properties help maintain productivity even under variable climate conditions. Economically, biofertilizers provide cost-effective advantages for smallholder farmers (Bharti et al., 2019). Chemical fertilizers are increasingly expensive and often inaccessible due to global market fluctuations. In contrast, biofertilizers are usually affordable and can sometimes be produced locally using organic waste and microbial cultures. By reducing expenditure on synthetic inputs, farmers can improve profit margins while maintaining or improving crop yields (Torabi, Mokhtarzadeh & Mahlooji, 2012) The growing attention toward climate-smart agriculture and organic farming has further emphasized the importance of biofertilizers. Researchers, agricultural extension services, and policymakers are encouraging farmers to adopt integrated nutrient management systems where biofertilizers complement organic manure and minimal chemical fertilizer use for improved efficiency. This integrated approach has proven effective in improving crop yield stability across diverse environments (Monisha et al., 2023). Global food demand continues to rise due to population growth, changing dietary preferences, and expanding urbanization. To sustain crop productivity, farmers have widely depended on chemical fertilizers to boost soil nutrient availability and increase yields. While these synthetic fertilizers provide short-term benefits, long-term reliance on them has resulted in serious environmental and agronomic consequences such as soil acidification, nutrient leaching, reduced soil microbial diversity, and contamination of water bodies. These soil health challenges threaten the sustainability of agricultural production systems, especially in regions already experiencing declining soil fertility and climate stress (Caputo, 2022). As a result, there is increasing interest in biological alternatives that can improve soil health while sustaining crop productivity. Biofertilizers have been recognized as a potential solution because they supply nutrients through natural biological processes, enhance soil microbial activities, and improve overall soil structure and fertility.

However, despite their documented benefits, the adoption and effective field use of biofertilizers remain limited. In many regions, farmers lack adequate knowledge of how biofertilizers function, how they should be applied, and how they can be integrated with existing soil fertility practices. In other cases, product quality inconsistency, limited extension support, and varying soil conditions have led to mixed results in field performance (Monisha et al., 2023). Although several studies have examined the general benefits of biofertilizers, there is still limited empirical understanding of how biofertilizers specifically influence soil nutrient availability and crop yield performance under real-world farming conditions, especially in low-input or smallholder agricultural systems. Many studies are short-term, and there is insufficient evidence comparing biofertilizers directly with conventional chemical fertilizers over multiple growing seasons (Suryani, Putra & Hidayah, 2020; Naresh et al., 2024). This gap makes it difficult for farmers and policymakers to determine the practical effectiveness and reliability of biofertilizers for sustainable crop production. Therefore, the

study seeks to review literature on specific objectives to: examine the effects of biofertilizers on soil fertility and nutrient availability in sustainable crop production, assess the impact of biofertilizers on crop growth, yield performance, and overall productivity compared to conventional chemical fertilizers, and examine the methods and practices involved in the application of biofertilizers for sustainable crop management.

Effects of Biofertilizers on Soil Fertility and Nutrient Availability in Sustainable Crop Production

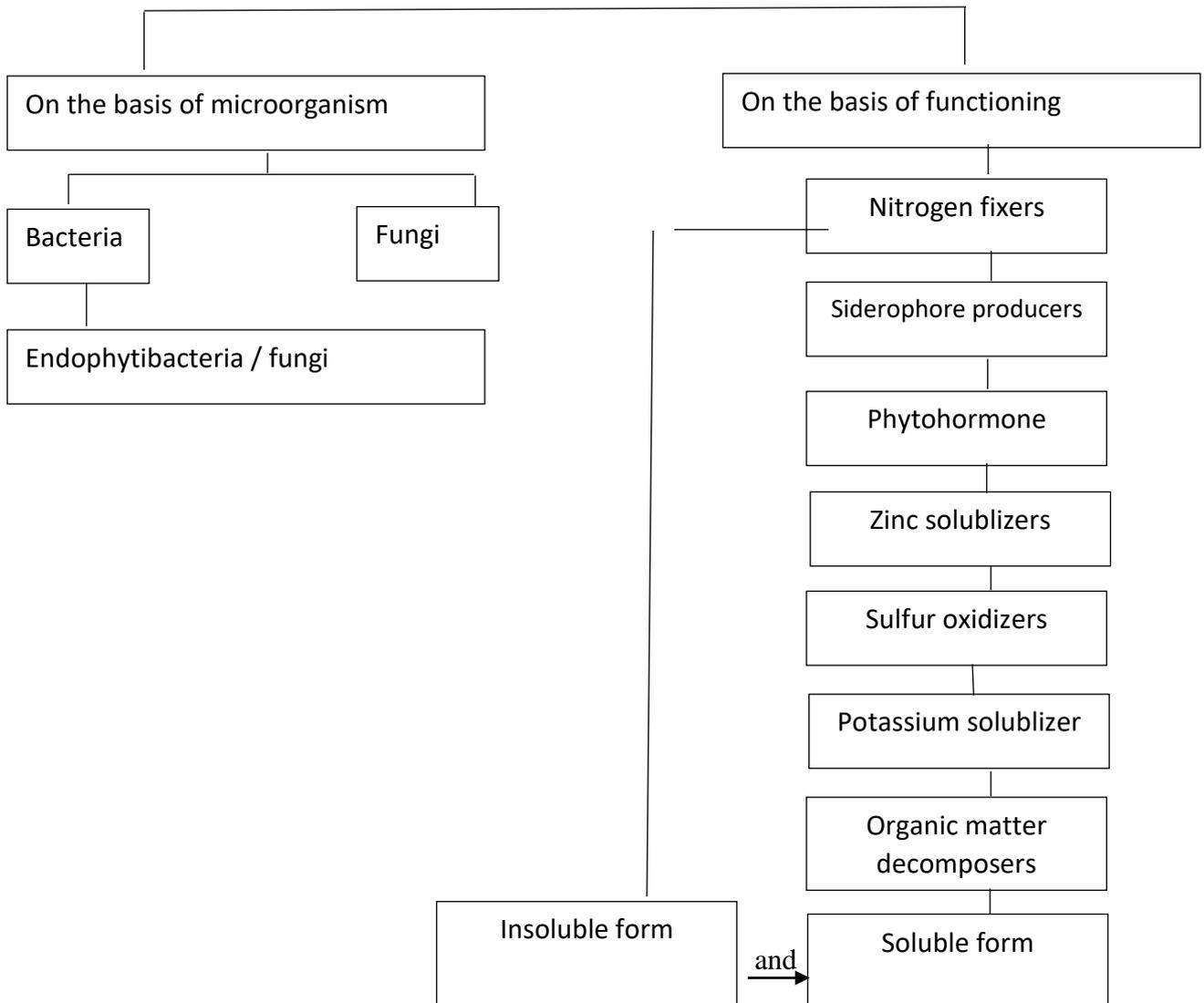
Biofertilizers, including microbial inoculants such as nitrogen-fixers (NFB), phosphate-solubilizing bacteria (PSB), potassium-solubilizing bacteria (KSB), and plant growth-promoting rhizobacteria (PGPR), enhance soil nutrient cycling by converting inaccessible nutrient forms into plant-available forms, increasing microbial biomass, and stimulating enzymatic activities that drive mineralization processes (Fadiji, Xiong, Egidi & Singh, 2024; Fasusi, Cruz & Babalola, 2021). Multiple studies document consistent increases in available nitrogen and phosphorus following biofertilizer application, particularly when formulations combine multiple functional strains (Heidari & Golpayegani, 2012; Kamran et al., 2017). Meta-analyses and reviews report measurable gains in soil organic carbon (SOC) and other fertility indicators after repeated biofertilizer use, suggesting improvements in soil structure, cation exchange capacity, and water-holding capacity that persist beyond a single growing season (Kumar, Dewangan, Lawate, Bahadur & Prajapati, 2019; Kumawat et al., 2019). Experimental studies show that biofertilizers can partially substitute mineral fertilizer inputs by mobilizing native soil phosphorus and fixing atmospheric nitrogen, often allowing a 20–30% reduction in chemical N and P inputs without significant yield loss when management practices are optimized. The effectiveness of this substitution depends strongly on baseline soil fertility, inoculant quality, and crop type; results are most consistent in moderately depleted soils rather than extremely infertile ones (Monisha et al., 2023; Naresh et al., 2024). Biofertilizers also influence the composition of the soil microbial community in ways that enhance nutrient cycling: they increase populations of beneficial bacteria and mycorrhizal fungi, boost enzyme activities such as phosphatases and dehydrogenase, and can suppress opportunistic pathogens, thereby supporting healthier root systems (Fadiji et al., 2024; Fasusi et al., 2021). High-throughput sequencing and field studies confirm these community shifts after inoculation. The effectiveness of biofertilizers for improving soil fertility is context-dependent. Factors such as soil pH, organic matter content, moisture levels, cropping systems, and co-applied fertilizer doses strongly mediate outcomes (Heidari & Golpayegani, 2012; Bharti et al., 2019). Reviews emphasize that integrated approaches—combining biofertilizers with reduced mineral fertilizer rates and organic amendments—provide the most reliable improvements in nutrient status and long-term soil health (Torabi, Mokhtarzadeh & Mahlooji, 2012; Caputo, 2022). Constraints to biofertilizer efficacy remain, including product quality variability, short shelf life, poor field survival of introduced strains, and limited farmer knowledge. To address these challenges, the literature recommends stronger quality control, strain selection tailored to local soils and crops, and extension support to translate promising experimental results into consistent, on-farm soil fertility gains (Suryani, Putra & Hidayah, 2020; Monisha et al., 2023).

Table 1. Contrast between biofertilizer and chemical fertilizer in tabular form

S/N	Biofertilizer	Chemical fertilizer
i.	Biofertilizers fix nutrients, enhances root, revitalize and build soil health.	Chemical fertilizers have short-term positive impacts, which brings about dire consequences like soil depletion and pollution of surface water.
ii.	It improves the environment where they are used	Does not improve the environment over time
iii.	Enhances biodiversity, encourages return by microbes and earthworm.	It does not encourage biodiversity thus discourages microbes and endanger the growth of earthworm.
iv.	Mycorrhizal biofertilizer enable plant growth in extreme soils with low fertility by developing root extensions known as symbiotic roots.	Chemical fertilizer does not
v.	Less expensive than synthetic NPK fertilizer	Very expensive to acquire

Source: Bukagrochem (2024)

Classification of Biofertilizers



Source: Bulkagrochem (2024)

2. Methods and Practices Involved in the Application of Biofertilizers for Sustainable Crop Management

The effectiveness of biofertilizers in improving soil health and crop productivity depends critically on their application. Biofertilizers contain living microorganisms such as *Rhizobium*, *Azotobacter*, *Azospirillum*, phosphate-solubilizing bacteria, and mycorrhizal fungi, which require suitable conditions to survive and colonize plant roots or surrounding soil (Fadiji et al., 2024; Fasusi et al., 2021). Successful application depends on proper handling, protection from direct sunlight, appropriate moisture levels, and alignment with crop type and soil characteristics. Properly applied biofertilizers fix atmospheric nitrogen, solubilize phosphorus, mobilize micronutrients, and enhance root development to improve nutrient uptake. Application methods include seed treatment, soil application, seedling root dipping, foliar spraying, and compost enrichment. Seed treatment is commonly practiced due to its cost-effectiveness, as inoculants adhere to seed surfaces and colonize the rhizosphere immediately after germination (Torabi, Mokhtarzadeh & Mahlooji, 2012). Soil application involves mixing biofertilizers with organic manure or compost to improve microbial survival before incorporation into the soil. Root dipping is particularly useful for vegetables and nursery seedlings, ensuring early establishment of beneficial microbial communities (Monisha et al., 2023). Application method selection depends on the crop, production system, and environmental conditions. For instance, leguminous crops often receive *Rhizobium* inoculants to promote nodulation and nitrogen fixation, whereas cereals and vegetables benefit more from phosphate-solubilizing bacteria or mycorrhizal fungi. Soil pH, temperature, and moisture strongly influence the survival of microbial inoculants, making site-specific management critical (Heidari & Golpayegani, 2012).

Complementary farm practices also support biofertilizer effectiveness. Maintaining adequate soil organic matter, reducing excessive chemical fertilizer use, promoting balanced irrigation, and avoiding harmful pesticides enhance microbial performance. Integrating biofertilizers into broader soil fertility management strategies not only improves crop productivity but also promotes long-term soil sustainability, contributing to environmentally friendly and resource-efficient agricultural systems (Bharti et al., 2019; Fadiji et al., 2024).

Simple Biofertilizer Application Process (Step-by-Step)

1. Seed Treatment Method

- Moisten seeds slightly with clean water.
- Add the biofertilizer powder or slurry to coat the seeds evenly.
- Dry coated seeds in the shade (not direct sun).
- Plant immediately for best results.

2. Soil Application Method

- Mix the biofertilizer with compost or well-decomposed manure.
- Apply the mixture to the field before planting.
- Irrigate lightly to activate microbial growth.

3. Seedling Root Dip Method (for vegetables/nursery crops)

- Prepare a slurry by mixing biofertilizer with water.
- Dip the roots of seedlings into the slurry before transplanting.
- Transplant seedlings into the prepared field.

4. Foliar Spray Method

- Dissolve liquid biofertilizer in water at recommended dilution.
- Spray directly on plant leaves during early morning or late evening.
- Avoid spraying during strong sunlight or rain.

Impact of Biofertilizers on Crop Growth, Yield Performance, and Overall Productivity Compared to Conventional Chemical Fertilizers

A broad body of field trials and reviews indicates that biofertilizers can enhance crop growth metrics such as root biomass, shoot height, and chlorophyll content, as well as yield components including grain weight and fruit number, by improving nutrient uptake and producing phytohormones like auxins (IAA) and gibberellins (Fadji, Xiong, Egidi & Singh, 2024; Heidari & Golpayegani, 2012). Growth and yield improvements are most pronounced when biofertilizers are used alongside judicious mineral fertilizer rates rather than as a sole substitute (Fasusi, Cruz & Babalola, 2021). Meta-analyses report average crop yield increases ranging from approximately 10–40% with appropriate biofertilizer application, though effect sizes vary with crop type, inoculant composition, and environmental conditions. *Bacillus*- and *Rhizobium*-based products often show the most consistent positive effects (Kamran et al., 2017; Kumar, Dewangan, Lawate, Bahadur & Prajapati, 2019). Comparative trials that contrast biofertilizers with full-rate chemical fertilizers often find that chemical fertilizers produce faster early growth responses, but biofertilizer treatments can achieve comparable yields by harvest, especially when combined with reduced mineral inputs. This suggests biofertilizers are most effective as part of integrated nutrient management rather than as one-to-one replacements (Monisha et al., 2023; Naresh et al., 2024). High-quality field experiments demonstrate that combined application of biofertilizers with 50–75% of standard chemical fertilizer rates can maintain or improve yields while reducing costs and environmental impacts, such as nitrogen leaching and greenhouse gas emissions from fertilizer production (Torabi, Mokhtarzadeh & Mahlooji, 2012; Caputo, 2022).

Beyond yields, biofertilizers can improve crop quality traits, including protein content, micronutrient concentration, and shelf life, by enhancing nutrient partitioning and plant health. These benefits have been documented in cereals, legumes, and horticultural crops, adding both market value and nutritional advantages (Fadji et al., 2024; Monisha et al., 2023). Limitations to productivity gains include variability in product performance across sites, failures in production and quality control, and farmers' preference for fast-acting chemical fertilizers to achieve reliable short-term responses. The literature highlights the need for locally adapted field validation, robust regulatory frameworks for inoculant quality, and farmer capacity building to promote confident adoption of integrated fertilizer strategies (Suryani, Putra & Hidayah, 2020; Bharti et al., 2019).

Conclusion

Biofertilizers play a vital role in advancing sustainable crop production by improving soil fertility, enhancing nutrient availability, and supporting crop growth through natural biological processes. Unlike chemical fertilizers, which may degrade soil structure and pollute the environment over time, biofertilizers contribute to long-term soil health by increasing beneficial microbial populations, stimulating enzymatic activity, and improving root development. Their application helps reduce the dependency on costly synthetic inputs, making them especially beneficial to smallholder farmers and communities seeking affordable and environmentally responsible farming solutions. However, the full potential of biofertilizers can only be realized when they are properly applied and integrated into broader soil management strategies. Successful use depends on appropriate selection of microbial strains, awareness of soil and crop characteristics, and correct handling during application. When combined with organic matter and reduced chemical fertilizer use, biofertilizers can significantly improve crop yield and sustainability outcomes. Therefore, promoting farmer awareness, ensuring quality standardization, and strengthening research-extension linkages are essential steps toward enhancing the widespread adoption of biofertilizers for sustainable agriculture.

Recommendations

The following recommendations were made for the study

1. To enhance the effectiveness of biofertilizers in improving soil fertility, agricultural extension services should intensify farmer education programs focused on the role of soil microorganisms in nutrient cycling. Demonstration farms, field days, and farmer training workshops should be used to show practical methods of biofertilizer application and soil improvement practices. This will ensure farmers understand how to maintain soil conditions that support microbial survival and long-term fertility restoration.
2. To ensure successful biofertilizer performance in the field, regulatory bodies should establish strict quality standards for production, packaging, and distribution of microbial inoculants. Farmers should also be guided on the correct application methods such as seed coating, soil incorporation, and root dipping to enhance microbial establishment. Supporting local production units and rural agro-input centers can also improve product availability and reduce cost barriers, promoting wider adoption of biofertilizers in sustainable crop production systems.
3. Farmers should be encouraged to adopt integrated nutrient management practices where biofertilizers are combined with reduced amounts of chemical fertilizers and organic amendments. This balanced approach will support higher and more stable crop yields while minimizing environmental impacts. Policy makers and agricultural agencies should provide incentives, subsidies, or support programs that make biofertilizers affordable and more accessible to smallholder farmers, especially in regions with declining soil fertility.

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