

Evaluation of Biofertilizer Application on Soil Physico-Chemical Properties and Plant Growth Parameters: A Review

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Abstract: Sustainable nutrient management has become a major priority in modern agriculture due to the negative environmental consequences associated with excessive use of chemical fertilizers. Continuous application of synthetic fertilizers often results in soil degradation, nutrient imbalance, and declining soil biological activity. Biofertilizers have emerged as an environmentally sound alternative capable of improving soil fertility and crop productivity through natural biological processes. The present review synthesizes available literature on the influence of biofertilizer application on soil physico-chemical properties and plant growth parameters. Different groups of biofertilizers, including nitrogen-fixing bacteria, phosphate-solubilizing microorganisms, potassium-solubilizing bacteria, and mycorrhizal fungi, contribute significantly to nutrient cycling and soil improvement. Biofertilizer application generally enhances soil structure, organic carbon content, nutrient availability, and microbial activity, which in turn improves germination, vegetative growth, physiological performance, and yield. Comparative studies indicate that although chemical fertilizers provide rapid nutrient supply, biofertilizers offer long-term benefits for soil sustainability. However, variability in field performance and formulation challenges remain important constraints. Future research should focus on long-term experiments and development of efficient microbial consortia. Overall, biofertilizers represent an essential component of sustainable soil fertility management and environmentally responsible crop production.

Keywords: Biofertilizers; Soil fertility; Sustainable agriculture; Soil properties; Plant growth parameters; Microbial inoculants

1. Introduction

1.1 Background and Importance

The rapid expansion of modern agriculture has been largely supported by the extensive use of chemical fertilizers, which has contributed significantly to increased crop productivity worldwide. Despite these achievements, the long-term consequences of excessive fertilizer use have become increasingly evident. Continuous application of chemical fertilizers without adequate organic inputs has resulted in declining soil organic matter, nutrient imbalance, soil acidification, and reduced biological activity. These changes have raised serious concerns regarding the sustainability of intensive agricultural systems.

In recent years, sustainable agriculture has gained global attention as an approach aimed at maintaining soil productivity while minimizing environmental degradation. Among various sustainable nutrient management practices, biofertilizers have received considerable interest due to their ability to enhance nutrient availability through biological processes. Beneficial microorganisms associated with plant roots improve soil fertility and support plant growth while reducing dependence on synthetic fertilizers [1], [2].

Biofertilizers not only improve nutrient availability but also contribute to soil restoration by enhancing microbial activity and improving soil structure. Their use is particularly

important in regions where soil fertility has declined due to intensive cultivation.

1.2 Concept and Definition of Biofertilizers

Biofertilizers are preparations containing living microorganisms that enhance nutrient availability to plants when applied to soil or seeds. These microorganisms colonize the rhizosphere or plant tissues and promote plant growth through various biochemical and physiological mechanisms [1]. The beneficial effects of biofertilizers are primarily mediated through plant-microbe interactions. Microorganisms such as nitrogen-fixing bacteria, phosphate-solubilizing bacteria, and mycorrhizal fungi establish close associations with plant roots and improve nutrient uptake efficiency. In addition to nutrient mobilization, many biofertilizers produce growth-promoting substances that stimulate root development and enhance plant vigor [3].

1.3 Rationale for the Review

The increasing global demand for environmentally safe agricultural inputs has stimulated interest in the use of microbial inoculants as alternatives to chemical fertilizers. Although numerous studies have reported beneficial effects of biofertilizers on crop productivity, the results often vary depending on soil conditions, crop species, and climatic factors. Consequently, a comprehensive synthesis of

available research is necessary to better understand the overall effectiveness of biofertilizers.

Particular attention is required to evaluate the influence of biofertilizers on soil physico-chemical properties, since soil quality ultimately determines long-term agricultural sustainability. Many earlier studies have focused primarily on crop yield, while fewer investigations have examined changes in soil properties over extended periods.

1.4 Objectives

The present review was undertaken with the following objectives:

- To evaluate the influence of biofertilizers on soil physico-chemical properties
- To assess the effects of biofertilizers on plant growth parameters
- To compare biofertilizers with chemical fertilizers
- To identify research gaps and future research priorities

2. Methodology

The present review was conducted using a systematic literature survey designed to collect and analyze scientific information related to biofertilizer application and its effects on soil properties and plant growth. Relevant peer-reviewed research articles and review papers published between 2000 and 2024 were considered in order to ensure both historical continuity and inclusion of recent developments.

Scientific databases including Scopus, Web of Science, and Google Scholar were used to identify relevant publications. The literature search was performed using combinations of keywords such as *biofertilizers*, *soil physico-chemical properties*, *plant growth parameters*, *nitrogen fixation*, *phosphate solubilization*, and *sustainable agriculture*. Additional references were obtained by examining citations within selected articles.

Studies were included if they reported experimental or field-based evaluation of biofertilizers on soil properties or plant growth. Only peer-reviewed publications with clearly described methodologies and measurable results were considered. Studies lacking quantitative data or focusing exclusively on chemical fertilizers were excluded.

Relevant information was extracted from each selected study, including type of biofertilizer, crop species, soil characteristics, and measured parameters. Soil properties such as pH, electrical conductivity, organic carbon, and nutrient availability were recorded along with plant growth parameters such as germination, biomass production, and yield.

Although considerable effort was made to include representative studies, variations in soil types, climatic conditions, and experimental designs make direct comparison among studies difficult. Differences in biofertilizer formulations and application methods also influence reported results.

1) Classification and Types of Biofertilizers

Biofertilizers include diverse groups of microorganisms that enhance soil fertility through different biological mechanisms. These microorganisms contribute to nutrient cycling and improve plant growth under a wide range of agricultural conditions.

Nitrogen-fixing biofertilizers represent one of the most widely used groups. Symbiotic bacteria such as *Rhizobium* establish nodules on legume roots and convert atmospheric nitrogen into forms that can be utilized by plants. Non-symbiotic nitrogen-fixing bacteria such as *Azotobacter* and *Azospirillum* also contribute to nitrogen availability and promote plant growth through production of growth-promoting substances [1].

Phosphate-solubilizing microorganisms play an important role in improving phosphorus availability. A large proportion of soil phosphorus exists in insoluble forms that cannot be directly absorbed by plants. Phosphate-solubilizing bacteria convert these forms into soluble phosphate through production of organic acids and enzymes [4].

Certain microorganisms are capable of solubilizing potassium and micronutrients such as zinc. These microorganisms enhance nutrient availability by releasing organic compounds that facilitate mineral dissolution [5].

Mycorrhizal fungi form symbiotic associations with plant roots and improve nutrient uptake, particularly phosphorus. The fungal hyphae extend beyond the root zone and increase the effective surface area for nutrient absorption [6].

Cyanobacteria and algal biofertilizers are especially important in flooded rice ecosystems where they contribute to nitrogen fixation and organic matter accumulation [7].

In recent years, consortium-based biofertilizers containing multiple microbial species have gained attention because they provide complementary functions and often perform better than single-strain inoculants [8].

2) Impact on Soil Physico-Chemical Properties

Biofertilizer application has been shown to influence both physical and chemical properties of soil. Improvements in soil structure are frequently observed following repeated application of microbial inoculants. Enhanced aggregation and reduced bulk density improve soil aeration and water infiltration, resulting in better root growth conditions [9].

Biofertilizers also influence soil chemical properties by enhancing nutrient availability and increasing organic carbon content. Microbial activity contributes to the accumulation of organic matter, which plays a key role in maintaining soil fertility. In many studies, increases in available nitrogen, phosphorus, and potassium have been reported following biofertilizer application [8].

Soil pH and electrical conductivity may also be modified through microbial processes. Production of organic acids during nutrient solubilization often results in slight

reductions in soil pH, which can improve nutrient availability in alkaline soils [5].

Biological properties of soil are particularly responsive to biofertilizer application. Increased microbial biomass, enzyme activity, and soil respiration indicate enhanced biological activity and improved nutrient cycling [3].

3) Mechanisms of Soil Property Modification

The beneficial effects of biofertilizers on soil properties are primarily mediated through biological processes that enhance nutrient cycling and soil structure.

Microorganisms release enzymes and organic acids that convert insoluble nutrients into plant-available forms. These biochemical processes play an important role in maintaining soil fertility under low-input agricultural systems [4].

Biological nitrogen fixation represents one of the most important mechanisms by which biofertilizers improve soil fertility. Nitrogen-fixing bacteria convert atmospheric nitrogen into ammonium, which can be utilized by plants and soil microorganisms [1].

Production of plant growth regulators such as auxins and gibberellins stimulates root development and increases nutrient uptake efficiency [3].

Microbial polysaccharides contribute to soil aggregation and improve soil structural stability. Improved aggregation enhances water retention and reduces soil erosion [6].

4) Effect on Plant Growth Parameters

Biofertilizer application generally improves germination and early seedling growth by enhancing nutrient availability and stimulating root development [3].

Vegetative growth parameters such as plant height, leaf number, leaf area, stem diameter, and root biomass often increase following biofertilizer application. Improved root development enables plants to explore a larger volume of soil for nutrients and water [2].

Physiological parameters such as chlorophyll content and photosynthetic rate are also enhanced due to improved nutrient status. Increased nitrogen availability contributes to higher chlorophyll synthesis and improved photosynthetic efficiency [8].

Yield and yield attributes including grain weight, biomass production, and harvest index generally show positive responses to biofertilizer application, particularly when used in combination with moderate fertilizer inputs [1].

5) Crop-Specific Responses

Different crops respond differently to biofertilizer application depending on their nutrient requirements and root characteristics.

Cereal crops such as wheat and rice often show improved nutrient uptake and yield following biofertilizer application [8].

Leguminous crops show particularly strong responses due to symbiotic nitrogen fixation by *Rhizobium* species [1].

Oilseed crops benefit from improved phosphorus availability through phosphate-solubilizing microorganisms [5].

Horticultural crops often show improvements in growth and fruit quality when biofertilizers are applied [2].

Medicinal plants have also shown improved biomass production and secondary metabolite content following biofertilizer treatment [7].

6) Comparative Evaluation: Biofertilizers vs Chemical Fertilizers

Chemical fertilizers provide nutrients in readily available forms and often produce rapid crop responses. However, long-term dependence on chemical fertilizers may reduce soil biological activity and organic matter content.

Biofertilizers improve soil fertility gradually by enhancing biological processes and nutrient cycling. Although their effects may be slower, they contribute to long-term soil sustainability [3].

Integrated nutrient management combining biofertilizers with chemical fertilizers often produces the best results in terms of productivity and soil health [2].

7) Long-Term Sustainability Aspects

Long-term field experiments indicate that biofertilizer application can maintain or improve soil fertility over extended periods. Increased soil organic carbon and improved nutrient cycling contribute to sustainable crop production [10].

Biofertilizers also reduce dependence on synthetic fertilizers and minimize environmental impacts associated with fertilizer use [11].

8) Constraints and Challenges

Despite their advantages, several factors limit the widespread adoption of biofertilizers. Many biofertilizer products have limited shelf life and require proper storage conditions to maintain microbial viability [12].

Field performance may vary depending on environmental conditions and soil characteristics. Lack of awareness among farmers and inconsistent product quality also represent major challenges.

Research Gaps

Long-term studies evaluating changes in soil physico-chemical properties under biofertilizer application are still limited.

More research is required to understand microbial interactions in different soil environments. Standardized protocols for biofertilizer application are also needed.

3. Future Perspectives

Future research should focus on development of efficient microbial consortia and region-specific biofertilizer formulations.

Modern molecular techniques can improve understanding of plant–microbe interactions and help identify efficient microbial strains.

Integration of biofertilizers with organic amendments will further improve soil fertility and sustainability.

4. Conclusion

The findings summarized in this review clearly indicate that biofertilizers play an important role in improving soil physico-chemical properties and plant growth. By enhancing nutrient availability, improving soil structure, and stimulating microbial activity, biofertilizers contribute significantly to long-term soil fertility.

Although chemical fertilizers remain essential for achieving high crop productivity, their excessive use may compromise soil health. Biofertilizers provide a sustainable alternative that supports environmentally responsible agriculture.

Future research should emphasize long-term field evaluation and development of efficient microbial formulations. Greater policy support and farmer awareness programs will be essential for wider adoption of biofertilizers in sustainable agricultural systems.

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