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Review

Importance of Plant Growth-Promoting Microorganisms (PGPMs) in Sustainable Agriculture

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Abstract

Plant growth-promoting microorganisms (PGPMs) have emerged as a critical component of sustainable agriculture, offering a natural alternative to chemical fertilizers and pesticides. These beneficial microbes, including bacteria, fungi, and actinomycetes, enhance plant growth and health through mechanisms such as nutrient solubilization, phytohormone production, and pathogen suppression. This review explores the diverse roles of PGPMs in agriculture, examining their mechanisms of action, practical applications, and the challenges and opportunities associated with their use. The potential of PGPMs to contribute to sustainable farming practices is discussed, with an emphasis on recent research findings and future directions.

Keywords: Plant growth-promoting microorganisms (PGPMs), Sustainable Agriculture, Mechanism of PGPMs and Practical Applications of PGPM.

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Introduction

The increasing global demand for food production, coupled with the need for sustainable agricultural practices, has driven research into alternatives to conventional chemical fertilizers and pesticides [1]. Among these alternatives, plant growth-promoting microorganisms (PGPMs) have garnered significant attention for their ability to enhance plant growth, improve soil fertility, and suppress plant diseases through natural mechanisms. PGPMs, which include a diverse array of bacteria, fungi, and actinomycetes, are capable of establishing beneficial interactions with plants, leading to increased nutrient availability, improved plant health, and enhanced resilience against environmental stresses [2&3].

Recent studies have demonstrated the multifaceted roles of PGPMs in promoting plant growth. These microorganisms contribute to nutrient cycling by solubilizing phosphates, fixing atmospheric nitrogen, and decomposing organic matter, thereby increasing the availability of essential nutrients to plants. For instance, phosphate-solubilizing bacteria such as Pseudomonas and Bacillus spp. release organic acids that mobilize phosphorus, a critical nutrient often limited in soils. Similarly, nitrogen-fixing bacteria like Rhizobium spp. form symbiotic associations with leguminous plants, converting atmospheric nitrogen into a form that plants can assimilate, thus reducing the dependence on synthetic nitrogen fertilizers. In addition to nutrient acquisition, PGPMs produce a range of bioactive compounds, including phytohormones, antibiotics, and siderophores. These compounds play crucial roles in regulating plant growth, enhancing root development, and protecting plants against pathogens. For example, auxins produced by certain PGPMs stimulate root elongation, leading to greater root surface area and improved nutrient and water uptake [4&5]. The application of PGPMs in agriculture is not only beneficial for plant growth but also aligns with the principles of sustainable agriculture. By reducing the reliance on chemical inputs, PGPMs help mitigate the environmental impacts associated with conventional farming practices, such as soil degradation and water pollution. Moreover, the use of PGPMs can enhance soil biodiversity and health, contributing to long-term agricultural sustainability [6].

Despite their potential, the practical application of PGPMs in agriculture faces several challenges, including variability in microbial efficacy due to environmental conditions and the complexities of soil-microbe-plant interactions. As research in this field progresses, understanding these interactions and optimizing the use of PGPMs will be crucial for their successful integration into agricultural systems. This review explores the latest advancements in the understanding and application of PGPMs, highlighting recent findings and discussing future directions for research and development in this promising area of sustainable agriculture.

Types of Plant Growth-Promoting Microorganisms

PGPMs are diverse and include bacteria, fungi, and actinomycetes that colonize plant roots and promote growth. The most studied groups include:

Nitrogen-Fixing Bacteria: These bacteria, such as Rhizobium and Azospirillum, fix atmospheric nitrogen, converting it into ammonia, which plants can use .

Phosphate-Solubilizing Microorganisms: Bacteria like Pseudomonas and Bacillus, and fungi such as Penicillium and Aspergillus, solubilize insoluble phosphate compounds, making phosphorus available to plants [4].

Mycorrhizal Fungi: These fungi, particularly arbuscular mycorrhizal fungi (AMF), form symbiotic relationships with plant roots, enhancing water and nutrient uptake, especially phosphorus.

Biocontrol Agents: PGPMs such as Trichoderma and Bacillus subtilis produce antimicrobial compounds that protect plants from pathogens.

Mechanisms of Plant Growth Promotion

Plant growth-promoting microorganisms (PGPMs) play a significant role in enhancing crop production. These beneficial microbes include bacteria, fungi, and other microorganisms that can positively affect plant growth and health. The effects of PGPMs on crop production can be attributed to several mechanisms, including [3&6]:

1. **Nutrient Solubilization and Uptake:** Plant growth-promoting microorganisms (PGPMs) form symbiotic associations and work with the plant mechanism of plant and enhancing the uptake and transformations of nutrients [7].

   Nitrogen Fixation: Certain PGPMs, such as Rhizobium spp., form symbiotic relationships with leguminous plants, fixing atmospheric nitrogen and converting it into a form that plants can use. This biological nitrogen fixation is crucial for soil fertility, particularly in nitrogen-deficient soils.

   Phosphate Solubilization: Phosphate Solubilizing Bacteria (PSB) like Pseudomonas and Bacillus spp. release organic acids that convert insoluble phosphates into soluble forms, making phosphorus available to plants.

   Potassium and Zinc Solubilization: Similar to phosphorus, certain PGPMs can solubilize potassium and zinc, enhancing their availability to plants.

2. **Production of Plant Growth Regulators:** PGPMs produce Plant Growth Regulators such as indole-3-acetic acid (IAA), gibberellins, and cytokinins, which stimulate plant growth and development. These hormones enhance root growth, nutrient uptake, and overall plant vigor [8].
   Auxins, Cytokinins, and Gibberellins: PGPMs such as Azospirillum and Azotobacter spp. produce phytohormones that promote root elongation, shoot growth, and overall plant development.
   Ethylene Modulation: PGPMs like Pseudomonas spp. can produce enzymes such as ACC deaminase, which lowers plant ethylene levels, helping plants tolerate stress conditions like drought and salinity.
3. **Disease Suppression:** Certain PGPMs, like Trichoderma species, exhibit antagonistic activity against soil-borne pathogens through the production of antibiotics, enzymes, and other antimicrobial compounds. This helps in reducing disease incidence and improving plant health [9].
   Antibiotic Production: Some PGPMs produce antibiotics that inhibit the growth of plant pathogens, providing a natural means of disease control.
   Induced Systemic Resistance (ISR): PGPMs can trigger a plant's immune system, enhancing its ability to resist pathogens and pests [10].
4. **Enhanced Stress Tolerance:** PGPMs can help plants cope with various abiotic stresses such as drought, salinity, and heavy metals. They may do this by improving root architecture, producing stress-related hormones, or by altering the plant's metabolism to better withstand stress conditions [11].
   Abiotic Stress Tolerance: PGPMs improve plant tolerance to abiotic stresses such as drought, salinity, and heavy metal toxicity by various mechanisms, including the production of stress-related enzymes and osmoprotectants.
   Biotic Stress Tolerance: By outcompeting harmful pathogens for nutrients and space, PGPMs protect plants from infections.
5. **Production of Soil Aggregates:** Mycorrhizal fungi form extensive networks of hyphae that bind soil particles together, creating stable soil aggregates. These aggregates improve soil structure, aeration, and water retention, which are essential for healthy root growth [12].
6. **Organic Matter Decomposition:** Many PGPMs play a role in the decomposition of organic matter, breaking down complex organic materials into simpler compounds. This decomposition process enriches the soil with organic nutrients, enhancing soil fertility and structure.
7. **Improvement of Soil Structure and Fertility:** Certain PGPMs, particularly mycorrhizal fungi, can improve soil structure by forming networks that bind soil particles, enhancing soil aeration and water retention. They can also contribute to organic matter decomposition, improving soil fertility.
8. **Enhanced Plant Growth and Yield:** The combined effects of improved nutrient uptake, hormonal stimulation, disease suppression, and stress tolerance generally lead to enhanced plant growth and yield. This can result in better biomass production, increased crop quality, and higher agricultural productivity.

Practical Applications of PGPM in Agriculture

PGPMs are commonly used as biofertilizers, biopesticides, and soil conditioners. They can be applied to crops through seed treatment, soil application, or foliar sprays. The use of PGPMs is part of sustainable agriculture practices, as they reduce dependency on chemical fertilizers and pesticides, thereby lowering environmental impact and promoting soil health [5].

1. **Seed Treatment**
   PGPMs are applied directly to seeds before planting, allowing for early colonization of the rhizosphere. This method is often used for nitrogen-fixing

bacteria and mycorrhizal fungi. The typical application rate ranges from 106 to 108 CFU per seed, depending on the microorganism and crop.

2. **Soil Inoculation**
   PGPMs can be mixed with soil at planting or applied directly to the soil surface. This method is suitable for phosphate-solubilizing bacteria and biocontrol agents. The application rate varies widely, from 106 to 109 CFU per gram of soil, depending on soil conditions and microbial type.
3. **Foliar Application**
   In some cases, PGPMs are applied as a foliar spray to protect plants from aerial pathogens or to promote growth through phytohormone production. The concentration typically ranges from 106 to 108 CFU per milliliter.
4. **Drip Irrigation and Drenching**
   PGPMs can be delivered through irrigation systems, ensuring even distribution in the root zone. This method is particularly useful in greenhouse settings or for high-value crops. The recommended application rate is often specified in terms of CFU per plant or per hectare.

Seed Inoculation **Root Inoculation** **Soil Inoculation**

Fig. 1 Inoculation methods of Plant growth promoting micro-organism [13]

Beneficial roles in agriculture

1. **Reduced Chemical Inputs:** PGPMs improve the efficiency of nutrient uptake by plants, reducing the need for chemical fertilizers. This not only lowers production costs for farmers but also minimizes environmental pollution from fertilizer runoff.

   Cost Savings: By reducing the need for synthetic fertilizers and pesticides, farmers can lower their input costs, leading to higher profitability.

   Environmental Protection: Reduced chemical use minimizes the negative impact on soil health, water quality, and biodiversity.
2. **Sustainable Agriculture:** The use of PGPMs supports sustainable agricultural practices by reducing the reliance on chemical inputs, lowering greenhouse gas emissions, and promoting biodiversity.

   ***Soil Health Improvement*:** PGPMs contribute to soil health by enhancing soil structure, increasing organic matter content, and promoting microbial diversity. Healthy soils are more resilient to erosion, compaction, and other forms of degradation. Carbon Sequestration: Improved plant growth and health lead to greater biomass production, contributing to carbon sequestration and climate change mitigation.

Improved Soil Fertility: By enhancing nutrient availability through nitrogen fixation and phosphate solubilization, PGPMs contribute to improved soil fertility. This leads to healthier plants and higher crop yields.

Enhanced Soil Structure: The production of soil aggregates by mycorrhizal fungi and the decomposition of organic matter by PGPMs improve soil structure. Better soil structure enhances root penetration, water retention, and aeration, promoting robust plant growth.

Soil Amendments: Incorporating PGPMs into soil can improve soil fertility and structure, leading to better root development and nutrient uptake. PGPMs can be included in soil amendments to improve soil structure, fertility, and microbial activity. These amendments support sustainable soil management practices.

Bio-priming: Seeds treated with PGPMs before planting can lead to better germination rates, improved seedling vigor, and enhanced resistance to soil-borne diseases.

Sustainable Soil Management: PGPMs support sustainable soil management by promoting natural processes that maintain soil health. This approach helps in building long-term soil fertility and resilience, crucial for sustainable agriculture.

3. **Enhanced Crop Productivity:** By improving nutrient availability, enhancing root growth, and protecting plants from diseases, PGPMs can lead to significant increases in crop yields. This is especially important in regions with poor soil fertility.

   Yield Increase: The application of PGPMs can lead to significant yield increases, ensuring food security and supporting the growing global population.

   Quality Improvement: Better nutrient availability and plant health result in higher-quality produce, which can command better market prices.

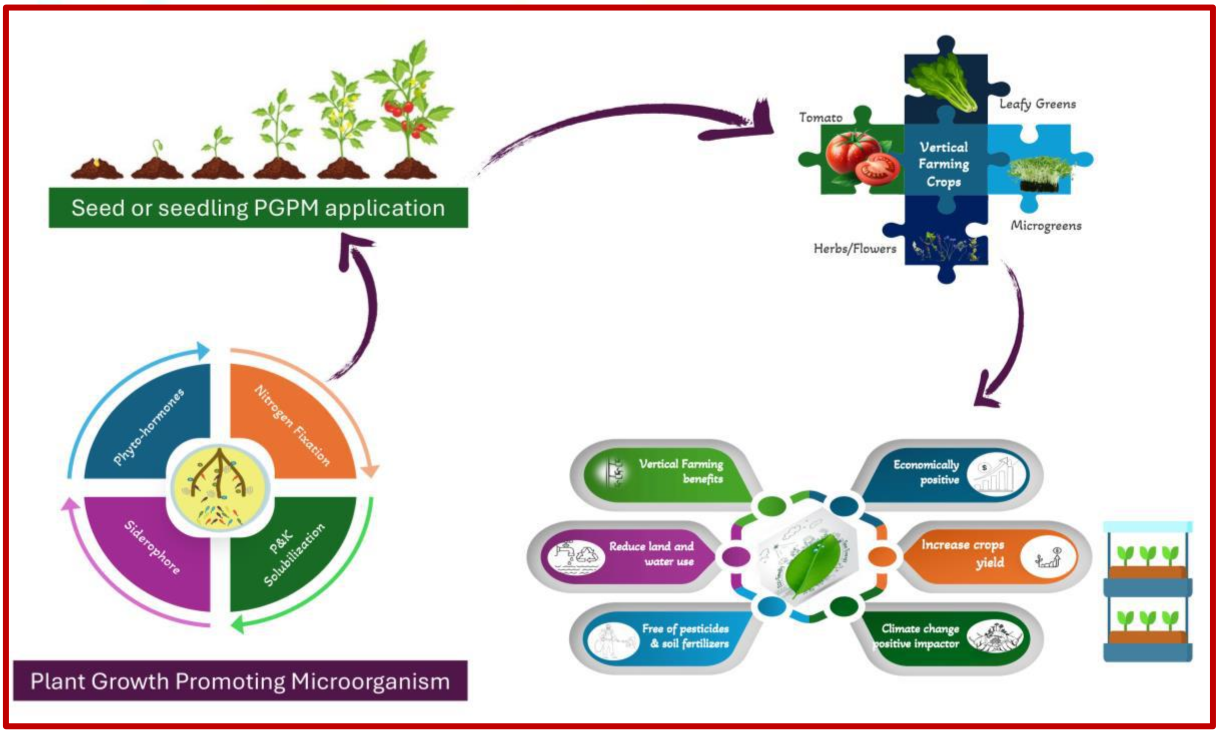

Fig.2 Beneficial roles of Plant growth promoting micro-organism in agriculture [6]

Challenges and Future Directions

PGPMs are typically applied to crops through biofertilizers, biopesticides, and soil amendments. These products can be introduced via seed treatments, soil inoculation, or foliar sprays. However, several challenges need to be addressed for the widespread adoption of PGPMs:

1. **Consistency and Reliability**
   Variability: The performance of PGPMs can vary depending on environmental conditions, soil types, and crop species. More research is needed to understand these interactions and develop reliable application protocols.
2. **Regulatory and Adoption Barriers**
   Regulations: The registration and approval process for biofertilizers and biopesticides can be complex and time-consuming. Streamlining these processes can help in faster adoption of PGPM technologies.
   Farmer Awareness and training: Increasing awareness and education among farmers about the benefits and application methods of PGPMs is crucial for widespread adoption. Extension services and training programs can facilitate this process
3. **Integration with Conventional Practices**
   Compatibility: PGPMs need to be compatible with existing agricultural practices and technologies. Integrating them into conventional farming systems without causing disruptions is key to their success.

Conclusion

Plant growth-promoting microorganisms represent a vital tool in the shift toward sustainable agriculture. By enhancing nutrient availability, promoting plant health, and reducing the need for chemical inputs, PGPMs contribute to increased agricultural productivity and environmental sustainability. However, realizing their full potential requires overcoming challenges related to environmental variability, formulation, and regulation. Continued research and innovation in this field will be essential for advancing sustainable agricultural practices and ensuring food security in a changing world.

References

1. Asghari, B., Khademian, R., and Sedaghati, B. Plant growth promoting rhizobacteria (PGPR) confer drought resistance and stimulate biosynthesis of secondary metabolites in pennyroyal (*Mentha pulegium* L.) under water shortage condition. *Scientia Horticulturae,* 2020, 263: 1–10. [google scholar] [DOI]
2. Bhardwaj, D., Ansari, M.W., Sahoo, R.K., and Tuteja, N. Biofertilizers function as key player in sustainable agriculture by improving soil fertility, plant tolerance and crop productivity. *Microbial Cell Factories,* 2014, 13(1), 66. [google scholar]
3. Khosro, M., and Yousef, S. Bacterial biofertilizers for sustainable crop production: A review. *ARPN Journal of Agricultural and Biological Science,* 2012, 7(5), 307-316. [google scholar]

4. Rodriguez, H., Fraga, R., Gonzalez, T., and Bashan, Y. Genetics of phosphate solubilization and its potential applications for improving plant growth-promoting bacteria. *Plant and Soil,* 2006, 287(1-2): 15-21. [google scholar]
5. Hungria, M., Nogueira, M.A., and Araujo, R.S. Soybean seed co-inoculation with Bradyrhizobium spp. and Azospirillum brasilense: A new biotechnological tool to improve yield and sustainability. *American Journal of Plant Sciences,* 2015, 6(6): 811-817. [google scholar]
6. Dhawi, F. The Role of Plant Growth-Promoting Microorganisms (PGPMs) and Their Feasibility in Hydroponics and Vertical Farming. *Metabolites,* 2023, 13:247. [google scholar] [DOI]
7. Smith, S.E., and Read, D.J. (2008). *Mycorrhizal Symbiosis* (3rd ed.). Academic Press. [google scholar]
8. Spaepen, S., and Vanderleyden, J. Auxin and plant-microbe interactions. *Cold Spring Harbor Perspectives in Biology,* 2011, 3(4): a001438. [google scholar]
9. Harman, G. E. Overview of mechanisms and uses of *Trichoderma* spp. *Phytopathology,* 2006, 96(2): 190-194. [google scholar]
10. Pieterse, C.M., Zamioudis, C., Berendsen, R.L., Weller, D.M., Van Wees, S.C., and Bakker, P.A. Induced systemic resistance by beneficial microbes. *Annual Review of Phytopathology,* 2014, 52: 347-375. [google scholar]
11. Yang, J., Kloepper, J.W., and Ryu, C.M. Rhizosphere bacteria help plants tolerate abiotic stress. *Trends in Plant Science,* 2009, 14(1): 1-4. [google scholar]
12. Rillig, M.C., Wright, S.F., Eviner, V.T., and Tisdall, J.M. Role of arbuscular mycorrhizal fungi in soil aggregation. *Soil Science Society of America Journal,* 2002, 66(2): 1715-1724. [google scholar]
13. Lopes M.J.S., Dias-Filho M.B. and Gurgel E.S.C. Successful Plant Growth-Promoting Microbes: Inoculation Methods and Abiotic Factors. *Frontiers in Sustainable Food Systems,* 2021, 5: 606454. [google scholar] [DOI]