MEDWIN PUBLISHERS
Committed to Create Value for Researchers

Open Access Journal of Agricultural Research
ISSN: 2474-8846

Cultivating Living Soils: Harnessing Biofertilizers and Soil Microbiomes for the Next Generation of Sustainable Crop Production

Berg PVD*

Department of Plant Sciences, Wageningen University & Research, Netherlands

***Corresponding author:** Pieter van den Berg, Department of Plant Sciences, Wageningen University & Research, Netherlands.

Mini Review
Volume 11 Issue 1
Received Date: February 26, 2026
Published Date: March 26, 2026

Abstract

The increasing demand for sustainable agricultural production has accelerated the adoption of environmentally friendly technologies that improve crop productivity while maintaining soil health. Biofertilizers and soil microbiome management have emerged as promising strategies to reduce dependence on synthetic fertilizers and enhance agricultural sustainability. Beneficial microorganisms improve nutrient availability, stimulate plant growth, suppress soil-borne pathogens, and strengthen plant tolerance to environmental stresses. At the same time, advances in microbiome research have improved our understanding of complex plant–microbe interactions that influence soil fertility and crop performance. This mini review summarizes recent developments in biofertilizers and soil microbiome management, highlights their roles in sustainable farming, and discusses current challenges and future research opportunities.

Keywords: Biofertilizers; Soil Microbiome; Sustainable Agriculture; Plant Growth-Promoting Rhizobacteria; Mycorrhiza; Soil Health; Nutrient Management; Agricultural Biotechnology

Introduction

Modern agriculture faces the challenge of increasing crop production while minimizing environmental degradation. Intensive use of chemical fertilizers has significantly improved agricultural productivity over the past several decades; however, excessive fertilizer application has contributed to soil degradation, nutrient imbalance, water pollution, and greenhouse gas emissions. These concerns have encouraged the search for sustainable alternatives that maintain productivity while preserving ecosystem health.

Biofertilizers represent one such alternative by utilizing beneficial microorganisms to improve nutrient availability and plant growth through natural biological processes [1–5]. Simultaneously, advances in soil microbiome research have demonstrated that diverse microbial communities play essential roles in nutrient cycling, disease suppression, and plant resilience [6–11]. Managing these microbial populations has become an important component of sustainable crop production and regenerative agriculture [10,11].

Biofertilizers in Sustainable Agriculture

Biofertilizers are formulations containing beneficial microorganisms that enhance plant growth by improving nutrient availability and soil biological activity [1,12,13]. Unlike chemical fertilizers, biofertilizers promote natural nutrient cycling without causing long-term environmental damage. Common microbial groups include nitrogen-fixing

CC BY

bacteria such as *Rhizobium* and *Azotobacter*, phosphate-solubilizing bacteria, potassium-mobilizing microorganisms, and arbuscular mycorrhizal fungi [1–5].

These microorganisms contribute to crop productivity through multiple mechanisms. They convert atmospheric nitrogen into plant-available forms, solubilize insoluble phosphorus compounds, produce phytohormones that stimulate root development, and improve nutrient uptake efficiency [1–4]. Many microbial inoculants also suppress soil-borne pathogens through competition, antimicrobial metabolite production, and induction of plant defense responses [4,7–9].

The adoption of biofertilizers has increased because they reduce dependence on synthetic fertilizers, lower production costs, and contribute to environmentally sustainable farming systems [3,13].

Soil Microbiome Management

The soil microbiome consists of bacteria, fungi, archaea, algae, and other microorganisms that interact with plant roots and surrounding soil. These microbial communities influence nutrient cycling, organic matter decomposition, soil structure, and plant health [6–10]. Healthy and diverse microbial populations contribute to resilient agricultural ecosystems capable of maintaining productivity under changing environmental conditions [6,11,12].

Recent advances in high-throughput sequencing and metagenomic technologies have revealed the remarkable diversity of soil microorganisms and their functional importance [9,10,14–18]. Researchers now recognize that effective crop management should consider not only plant genetics but also the biological processes occurring within the rhizosphere [7,8,10].

Management practices such as crop rotation, reduced tillage, cover cropping, organic amendments, and microbial inoculation can enhance microbial diversity and improve soil ecosystem functions [6,12,16]. These approaches support nutrient availability while increasing resistance to pests, diseases, drought, and other environmental stresses [10,17,18].

Recent Advances and Future Perspectives

Agricultural biotechnology has accelerated the development of next-generation biofertilizers with improved stability, longer shelf life, and greater field performance [13,14,19,20]. Multi-strain microbial consortia are being investigated because they often provide broader functional benefits than individual microbial species [16,18,20]. Artificial intelligence, remote sensing, and precision agriculture are also being integrated into microbiome research to optimize microbial applications according to crop requirements and soil conditions [10,11,20].

Emerging technologies such as metagenomics, metabolomics, and transcriptomics continue to improve understanding of plant–microbe interactions [9,10,17]. These tools will facilitate the design of customized microbial products tailored to specific crops, environments, and farming systems [10,16].

Despite these advances, several challenges remain. The performance of biofertilizers may vary under different climatic and soil conditions, and standardization of production, quality control, and field evaluation requires further attention [13,20]. Greater collaboration among researchers, industry, extension agencies, and farmers will be essential to accelerate commercialization and large-scale adoption [4,20].

Conclusion

Biofertilizers and soil microbiome management represent complementary strategies for achieving sustainable agricultural production. Beneficial microorganisms enhance nutrient availability, improve soil fertility, strengthen plant health, and reduce dependence on chemical fertilizers. Advances in microbiome science are providing new opportunities to develop biologically based crop management systems that improve productivity while protecting environmental resources. Continued research integrating microbial biotechnology, precision agriculture, and systems biology will further enhance the practical application of these technologies. Promoting the adoption of biofertilizers and effective microbiome management will play an important role in ensuring sustainable crop production, healthy soils, and long-term global food security.

References

1. Vessey JK (2003) Plant growth promoting rhizobacteria as biofertilizers. Plant Soil 255: 571–586.

2. Bhattacharyya PN, Jha DK (2012) Plant growth-promoting rhizobacteria (PGPR): emergence in agriculture. World J Microbiol Biotechnol 28: 1327–1350.

3. Adesemoye AO, Kloepper JW (2009) Plant–microbes interactions in enhanced fertilizer-use efficiency. Appl Microbiol Biotechnol 85: 1–12.

4. Backer R, Rokem JS, Ilangumaran G, Lamont J, Praslickova D, et al. (2018) Plant growth-promoting rhizobacteria: context, mechanisms of action, and roadmap to

Copyright© Berg PVD.

commercialization of biostimulants for sustainable agriculture. Front Plant Sci 9: 1473.

5. Smith SE, Read DJ (2008) Mycorrhizal Symbiosis. 3rd ed., Academic Press.

6. van der Heijden MGA, Bardgett RD, van Straalen NM (2008) The unseen majority: soil microbes as drivers of plant diversity and productivity in terrestrial ecosystems. Ecol Lett 11(3): 296–310.

7. Berendsen RL, Pieterse CMJ, Bakker PAHM (2012) The rhizosphere microbiome and plant health. Trends Plant Sci 17(8): 478–486.

8. Mendes R, Garbeva P, Raaijmakers JM (2013) The rhizosphere microbiome: significance of plant beneficial, plant pathogenic, and human pathogenic microorganisms. FEMS Microbiol Rev 37(5): 634–663.

9. Compant S, Samad A, Faist H, Sessitsch A (2019) A review on the plant microbiome: ecology, functions, and emerging trends in microbial application. J Adv Res 19: 29–37.

10. Trivedi P, Leach JE, Tringe SG, Sa T, Singh BK (2020) Plant–microbiome interactions: from community assembly to plant health. Nat Rev Microbiol 18: 607–621.

11. Singh BK, Trivedi P (2017) Microbiome and the future for food and nutrient security. Trends Microbiol 25(10): 758–768.

12. Gupta VVSR, Germida JJ (2015) Soil aggregation: influence on microbial biomass and implications for sustainable agriculture. Appl Soil Ecol 94: 1–7.

13. Mącik M, Gryta A, Frąc M (2020) Biofertilizers in agriculture: an overview on concepts, strategies and effects on soil microorganisms. Adv Agron 162: 31–87.

14. Rouphael Y, Colla G (2020) Biostimulants in agriculture. Front Plant Sci 11: 40.

15. Alori ET, Babalola OO (2018) Microbial inoculants for improving crop quality and human health in Africa. Front Microbiol 9: 2213.

16. Toju H, Peay KG, Yamamichi M, Narisawa K, Hiruma K, et al. (2018) Core microbiomes for sustainable agroecosystems. Nat Plants 4: 247–257.

17. Jansson JK, Hofmockel KS (2020) Soil microbiomes and climate change. Nat Rev Microbiol 18: 35–46.

18. Banerjee S, Schlaeppi K, van der Heijden MGA (2018) Keystone taxa as drivers of microbiome structure and functioning. Nat Rev Microbiol 16: 567–576.

19. Ojuederie OB, Olanrewaju OS, Babalola OO (2019) Plant growth-promoting rhizobacteria, mycorrhizal fungi, and sustainable agriculture: a review. Front Microbiol 10: 2079.

20. Rodríguez AMD, Cota FIP, Chávez LAC, Ortega LFG, Alvarado MIE, et al. (2025) Microbial Inoculants in Sustainable Agriculture: Advancements, Challenges, and Future Directions. Plants (Basel) 14(2): 191.

Copyright© Berg PVD.