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Biofertilizers & Biostimulants: Sustainable Alternatives for Enhancing Crop Productivity

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The increasing demand for food, declining soil fertility, climate variability, and concerns about the environmental consequences of intensive chemical-input agriculture have created an urgent need for sustainable crop production technologies. Biofertilizers and biostimulants have emerged as promising biological inputs that can complement conventional fertilizers and improve nutrient-use efficiency, crop growth, yield, quality, and resilience to environmental stresses. Biofertilizers mainly consist of beneficial microorganisms such as nitrogen-fixing bacteria, phosphate- and potassium-solubilizing microorganisms, plant growth-promoting rhizobacteria (PGPR), arbuscular mycorrhizal fungi (AMF), cyanobacteria and microbial consortia. Biostimulants stimulate natural physiological and biochemical processes in plants or the rhizosphere and include seaweed extracts, humic and fulvic substances, protein hydrolysates, amino acids, microbial metabolites and chitosan. Evidence indicates that these inputs can improve nutrient acquisition, photosynthesis, root development, antioxidant defence and tolerance to drought, salinity and temperature stress. They should not be regarded as universal replacements for mineral fertilizers, but as important components of integrated nutrient and crop management.

Keywords: Biofertilizers; biostimulants; PGPR; mycorrhiza; seaweed extract; nutrient-use efficiency; soil health; sustainable agriculture; abiotic stress.

Introduction

Modern agriculture has achieved substantial increases in productivity through improved varieties, irrigation, mineral fertilizers, pesticides and mechanization. However, continuous dependence on intensive external inputs can contribute to nutrient imbalance, soil degradation, biodiversity loss and environmental pollution. Agriculture is simultaneously exposed to drought, salinity, heat and irregular rainfall. Sustainable intensification therefore requires technologies that improve productivity while increasing resource-use efficiency and protecting soil health. Biofertilizers and plant biostimulants are increasingly recognized as biological approaches to sustainable crop production. Biofertilizers use beneficial microorganisms to increase nutrient availability and plant nutrient acquisition, whereas biostimulants stimulate natural plant or rhizosphere processes that improve nutrient-use efficiency, crop quality and stress tolerance (Vessey, 2003; Du Jardin, 2015).

Biofertilizers: Concept and Major Groups

Biofertilizers are formulations containing living or metabolically active microorganisms that benefit plants by increasing nutrient availability, improving nutrient uptake or stimulating plant growth. Their mechanisms include biological nitrogen fixation, nutrient solubilization, phytohormone production, siderophore production, improved root development and beneficial plant–microbe interactions (Bhardwaj et al., 2014). Nitrogen-fixing microorganisms such as Rhizobium, Azotobacter and Azospirillum can contribute to crop nitrogen nutrition. Phosphate-solubilizing bacteria and fungi mobilize poorly available phosphorus through organic acids, phosphatases and related biochemical processes. Potassium- and micronutrient-solubilizing microorganisms can increase availability of nutrients held in soil minerals. Plant growth-promoting rhizobacteria (PGPR) are particularly important because they can combine nutrient mobilization with hormonal and physiological effects. Arbuscular mycorrhizal fungi extend the effective soil-exploration zone through external hyphae and can improve phosphorus and water acquisition. Cyanobacteria have special relevance in flooded rice systems because some species fix atmospheric nitrogen and contribute to nutrient cycling.

Plant Biostimulants: Concept and Classification

Plant biostimulants are a diverse group of substances and microorganisms that stimulate plant or rhizosphere processes and improve crop performance. Du Jardin (2015) emphasized that their primary purpose is to stimulate processes related to nutrient-use efficiency, abiotic-stress tolerance and crop quality rather than simply supply nutrients. Important categories include humic and fulvic substances, seaweed and algal extracts, protein hydrolysates and amino acids, microbial biostimulants, Trichoderma, chitosan and selected plant-derived or inorganic substances. Their effects may involve changes in root architecture, nutrient transport, photosynthesis, hormonal signalling, antioxidant activity and water relations.

Major Biostimulants and Their Functions

Seaweed extracts are among the most widely studied biostimulants. They contain polysaccharides, amino acids, minerals, antioxidants and hormone-like compounds that may improve germination, root growth, nutrient uptake, photosynthetic activity and stress tolerance. A recent meta-analysis of 198 studies and 2,021 comparisons reported an average 16.3% increase in crop yield with seaweed-extract biostimulants, although responses varied with crop, formulation, extraction method and application strategy (2026). Humic and fulvic substances can influence soil structure, nutrient availability, root growth and microbial activity. Protein hydrolysates and amino acids may enhance nitrogen metabolism, chlorophyll formation, root development and stress responses. Microbial biostimulants, including PGPR, mycorrhizal fungi and Trichoderma, may simultaneously improve nutrient acquisition and plant defence or stress signalling.

Mechanisms of Action

Biofertilizers and biostimulants operate through multiple interacting mechanisms. Beneficial microorganisms can fix nitrogen, solubilize phosphorus and potassium, produce siderophores and stimulate root development. Biostimulants can modify root architecture and nutrient transport, increasing the efficiency with which plants acquire and use nutrients. Drought, salinity and heat can generate oxidative stress. Biological inputs may stimulate antioxidant enzymes and protective metabolites, helping plants maintain cellular integrity. Beneficial rhizosphere microorganisms can also influence microbial communities, nutrient cycling and biological activity in soil. These mechanisms explain why biological inputs can affect both plant performance and soil processes.

Role in Sustainable Crop Productivity

The contribution of biofertilizers and biostimulants extends beyond yield alone. They can improve nutrient availability, nutrient-use efficiency, root growth, water uptake, crop quality, stress tolerance and biological soil activity. Recent evidence from India indicates that biostimulants can produce meaningful yield responses, although effects differ among crops and products. Their greatest value is likely to occur when they are integrated with balanced fertilization, organic matter management, crop-residue recycling, improved varieties and efficient irrigation. Such integration can reduce unnecessary chemical-input use while maintaining adequate nutrient supply.

Integration with Mineral Fertilizers

Complete replacement of mineral fertilizers is not realistic for all crops because high-yielding crops remove substantial quantities of nutrients from soil. A more practical strategy is integrated nutrient management, combining mineral fertilizers, organic manures, crop residues and biological inputs according to crop demand and soil-test results. In rice-based systems, microbial inoculants may be combined with recommended N, P and K fertilization, organic amendments and residue management. Seaweed, humic or microbial biostimulants may complement these practices by supporting root activity and stress tolerance. Thus, biological inputs should generally be viewed as complementary technologies rather than one-to-one substitutes for fertilizers.

Application Methods and Practical Considerations

Biofertilizers and biostimulants can be applied through seed treatment, seedling/root dipping, soil application, fertigation, foliar spraying or irrigation water. The appropriate method depends on the product, crop and target process. Product quality is critical. Microbial products must contain viable, effective strains at the recommended concentration and remain stable during storage. Compatibility with fungicides, insecticides and fertilizers should be tested before tank mixing. Similarly, biostimulants require attention to active components, formulation quality, dose and timing. Field recommendations should be based on replicated, multi-location trials rather than promotional claims alone.

Constraints and Research Gaps

Field responses can be inconsistent because biological performance is affected by soil type, temperature, moisture, crop genotype, native microbial communities and management. Commercial products may also differ substantially in microbial viability or active ingredients. Dose optimization is necessary because higher rates do not necessarily produce higher yields. Long-term and multi-location studies are required to establish reliable recommendations. Greater attention is also needed to interactions among biofertilizers, biostimulants, mineral fertilizers and pesticides. Standardized product characterization and quality-control systems will be essential for farmer confidence and successful commercialization.

Future Prospects

Future development should move toward crop-, soil- and stress-specific biological solutions. Advances in genomics, metagenomics, metabolomics and high-throughput phenotyping can help identify microorganisms and bioactive compounds associated with specific agronomic functions. Microbial consortia combining nitrogen fixation, phosphorus solubilization, potassium mobilization and stress tolerance may provide broader benefits than single-strain products. Integration of microbial inoculants with seaweed extracts, humic substances, organic amendments and precision nutrient management may create synergistic effects. Algae, agricultural residues and agro-industrial by-products also offer opportunities for circular bioeconomy approaches.

Conclusion

Biofertilizers and biostimulants are important components of the transition toward sustainable and climate-resilient agriculture. Biofertilizers improve crop nutrition primarily through beneficial microorganisms that fix nitrogen, solubilize nutrients, stimulate roots and improve rhizosphere processes. Biostimulants act through broader physiological and biochemical mechanisms, including improved nutrient-use efficiency, photosynthesis, antioxidant defence and abiotic-stress tolerance. The objective should not be to replace every synthetic fertilizer with a biological product, but to reduce unnecessary chemical inputs while increasing the efficiency of every unit of nutrient, water and energy used in crop production. Scientifically validated combinations of biofertilizers, biostimulants, organic resources, mineral fertilizers, improved varieties and precision management can provide a practical pathway toward productive, profitable and environmentally sustainable agriculture.

References

1. Bhardwaj, D., Ansari, M.W., Sahoo, R.K. & Tuteja, N. (2014). Biofertilizers function as key player in sustainable agriculture by improving soil fertility, plant tolerance and crop productivity. *Microbial Cell Factories*, 13, 66.
2. Du Jardin, P. (2015). Plant biostimulants: Definition, concept, main categories and regulation. *Scientia Horticulturae*, 196, 3–14.
3. Rouphael, Y. & Colla, G. (2020). Biostimulants in agriculture. *Frontiers in Plant Science*, 11, 40.
4. Rouphael, Y. & Colla, G. (2020). Toward a sustainable agriculture through plant biostimulants: From experimental data to practical applications. *Agronomy*, 10, 1461.
5. Vessey, J.K. (2003). Plant growth promoting rhizobacteria as biofertilizers. *Plant and Soil,* 255, 571–586.
6. Deepanshi, Rani, A., Kumar, V., Vlaskin, M.S. & Nanda, M. (2026). Microalgae and plant growth promoting rhizobacteria for sustainable agriculture: Biostimulants and biofertilizers to improve soil health and plant stress resilience. *Current Microbiology*, 83, 380.
7. Crop yield responses to seaweed extract-based biostimulants depend on application strategy, formulation, and extraction methods: A meta-analysis. (2026). *Frontiers in Plant Science.*
8. Exploring the potentials of algal derived bio-stimulants and biofertilizers for sustainable agriculture: A review. (2026). *Bioresource Technology Reports*, 33, 102605.