

Review

Agricultural Bio-Inputs as a Pillar of Sustainable Agribusiness: Agronomic Performance, Economic Viability, and Business Challenges

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Abstract

Agricultural bio-inputs offer a promising tool for enhancing the sustainability of modern farming systems and decreasing reliance on synthetic agrochemicals. We review agronomic performance, environmental benefits, economic viability and commercialization concerns of agricultural bio-inputs including biofertilizers, biostimulants, microbial inoculants and biopesticides. A systematized critical narrative review approach was used to synthesize evidence from peer-reviewed literature and institutional reports published during 2014-2024. The reviewed evidence suggests that bio-inputs can improve nutrient-use efficiency, increase soil microbial activity, support crop productivity and increase resilience to environmental stresses, while contributing to reduced environmental impacts. Their performance is however influenced by type of crops, environmental conditions, management practices and quality of product. The review also identifies several barriers to wider adoption, including regulatory uncertainty, inconsistent field performance, limited farmer awareness, and commercialization constraints. Notwithstanding these challenges, the increasing demand for sustainable agricultural methods provides promising opportunities for innovation and market expansion in the bio-input segment. The findings underscore the need for supportive policy frameworks, harmonized regulations, ongoing investment in research and greater cooperation among researchers, industry stakeholders and policy makers to enable the effective integration of bio-inputs into sustainable and economically viable agricultural systems.

Keywords: Bio-inputs; sustainable agriculture; microbial inoculants; sustainable agribusiness; green entrepreneurship; bioeconomy; regenerative agriculture

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1. Introduction

The extensive use of chemical fertilizers and pesticides has facilitated a sustained increase in crop yields through more intensive fertilizer application. Global fertilizer use rose from 46.3 million tons in 1965 to 137.18 million tons in 2001, 200.57 million tons in 2020, and is expected to exceed

206 million tons in 2024 [1–3]. Application rates rose from 90 to 113 kg ha⁻¹ between 2002 and 2022, with a global average of 129 kg ha⁻¹ in 2020 [4–6]. Nitrogen fertilizers account for approximately 57% of total use [3,5]. Despite increased production volumes, efficiency gains have not progressed proportionally.

While this model delivers short-term productivity gains, it generates significant environmental and economic externalities. Gaytancıoğlu & Yılmaz indicate that the unbalanced application of plant nutrients (69.2%) and limited soil analysis practices increase production costs and environmental risks [7]. Excessive fertilizer application causes nitrous oxide emissions, chemical and biological soil deterioration, microbial disruption, and water contamination, which affect ecosystems and human health [8–10]. Moreover, the instability of agrochemical pricing raises the risks for manufacturers and uncertainties over profitability [11,12].

Therefore, agricultural bio-inputs have become more and more important as complementary or alternative tools in more sustainable production systems. Biofertilizers and bioproducts from microbial and plant origins may improve the functionality of the soil and mitigate biotic and abiotic stresses [13–15]. This transition has been hastened by the rise in fertilizer costs, tightening environmental regulations and pressures on global food security [16–18]. Nevertheless, agronomic efficacy is still context-specific and is influenced by soil-climate interactions, technology design and management practices [15,19].

Bio-inputs can contribute to decrease production costs by up to 35% of total expenditure, stimulate local value chains and green innovation [20–21] with economic benefits. However, adoption requires agro-industrial capacity, clear regulatory structures, technical expertise, and a competitive position [11,22]. Technoeconomic evaluations suggest that microalgal bio-inputs and plant growth-promoting rhizobacteria are promising biosustainable technologies, but their scalability is reliant on efficient production systems, appropriate regulation and structurally viable business models [15,18–19,23].

Therefore, bioproducts should not be considered direct substitutes for conventional inputs, but rather technical alternatives that represent a balance between productivity and environmental sustainability, taking into account cost and operational complexity. This critical review evaluates their agronomic effectiveness and the associated economic and institutional constraints to discern the structural conditions that define their contribution to sustainable agribusiness.

2. Review Methodology

The objective of this study was to integrate interdisciplinary evidence and identify trends, knowledge gaps, and structural constraints in the agronomic, economic, and business dimensions of agricultural bio-

inputs through a systematized critical narrative review [24–25].

Supplemented by targeted searches in ScienceDirect, PubMed, and Google Scholar, a structured literature search was conducted in Scopus and Web of Science for publications between January 2022 and March 2026. The search was conducted using combined keywords for biofertilizers, bioproducts, microbial inoculants, agronomic performance, nutrient use efficiency, market dynamics, scalability, regulation, and bioeconomy.

The initial screening and database consolidation resulted in 220 records. After removal of non-peer-reviewed material and duplicates, full-text assessment was conducted using predefined inclusion criteria: (i) peer-reviewed journal articles; (ii) empirical field or greenhouse studies, systematic reviews, meta-analyses, or technoeconomic assessments; (iii) explicit methodological description; and (iv) relevance to at least one analytical dimension (agronomic performance, economic feasibility, or institutional and regulatory analysis).

Following eligibility assessment, the final analytical corpus comprised 140 peer-reviewed articles, distributed across agronomic, economic, and institutional dimensions. Furthermore, 35 institutional reports (FAO, OECD, governmental agencies, CGIAR, and related bodies) were exclusively incorporated to contextualize policy frameworks and market dynamics [26–28]. However, they were not incorporated into the core analytical synthesis. The analytical corpus was restricted to descriptive contextual reference and did not include market intelligence reports or technical press sources.

A thematic comparative approach was employed to analyze the retained literature, which enabled the identification of structural conditions, variability patterns, and convergences that influence the integration of bio-inputs into sustainable agribusiness systems.

3. Agricultural Bio-Inputs: Concept and Classification

3.1. Definition of agricultural bio-inputs

A group of agricultural bio-inputs includes biostimulants, biopesticides, biosurfactants, biofertilizers, phytohormones, and microbial inoculants. These inputs can be derived from microbes, plant extracts, organic matter, or natural substances. Their purpose is to improve crop growth, nutrition, and health, increase soil fertility, and balance the biological complex [29–30].

From a regulatory perspective, bio-inputs are primarily classified as biofertilizers, biostimulants, and

microbial inoculants. These products also include seeds, plant and animal nutrition products, biocontrol agents, and biotechnology products with active ingredients of biological origin. Different regulations consider them as instruments to dispense with chemical inputs and for the sustainability of agricultural systems, although the definitions and scopes differ from one institution to another [31–33].

3.2 Differences between bio-inputs and conventional fertilizers

For decades, chemical fertilizers have been essential in agriculture, supplying crops with necessary nutrients in a very short period. The overuse of chemical fertilizers leads to soil degradation, nutritional imbalance, water pollution

and has adverse effects on ecosystems and human health [34–36].

In contrast, bio-inputs improve soil fertility and nitrogen use efficiency in plants through biological processes. Well managed systems can maintain competitive yields [37–39]. This functional difference is a disadvantage in that bio-inputs deliver results in a slow manner, unlike conventional fertilizers which are fast acting. They are greatly affected by environmental factors, crop management practices, microbial activity and interaction of production systems. The comparative characteristics of bio-inputs and conventional fertilizers, including their composition, mechanisms of action, environmental impacts, performance, costs, and application methods, are summarized in Table 1.

Table 1. Comparative characteristics of bio-inputs and conventional fertilizers

Appearance	Bio-inputs	Conventional Fertilizers	References
Composition	Live microorganisms, inoculants, plant extracts, organic residues; naturally contain macro- and micronutrients	Industrially refined inorganic chemicals; mainly N, P, K	[29,33,37]
Mechanism of action	Fix nutrients (N, P, K), solubilize minerals, promote microbial symbiosis, stimulate plant growth and microbiota.	They provide nutrients immediately and evenly; they do not interact with microbiota or promote natural fertility.	[34,38–39]
Impact on the ground	Improves structure, increases natural fertility, maintains biological balance	Soil degradation, loss of natural fertility, accumulation of toxic substances	[35–36]
Environmental impact	Low pollution, promotes sustainability and biodiversity	Runoff causes eutrophication and damage to aquatic ecosystems	[34–35]
Performance and efficiency	Competitive yields, but slower to release nutrients; effectiveness depends on environmental conditions and microbial compatibility	Fast-acting nutrients; immediate results, but increasing dependence	[37,39]
Costs	Generally, more economical, efficient use of nutrients	More expensive due to industrial production and non-renewable resources	[37]
Shelf life / nutrient density	Lower nutrient density, short shelf life	High nutrient density, extended shelf life	[37]
Application	Seed treatment or field application; gradual and natural	Direct application to soil or fertigation; rapid absorption	[37]

3.3. Classification of agricultural bio-inputs

3.3.1. Biofertilizers

Biofertilizers, sometimes referred to as inoculants, bioinoculants, or bioformulations, consist of a swarm of beneficial microorganisms that inhabit the rhizosphere or the interior of plant tissues. They can be single-strain or mixtures, as long as they are beneficial to the rhizosphere or endosphere and to plant reproduction [17,40].

Several studies we have cited indicate that biofertilizers do indeed help crops achieve higher levels of nutrient absorption, suppress diseases, and make their defenses more resilient to biotic and abiotic stresses,

including pathogens, and especially to external environmental variations [16,41]. These products are composed almost exclusively of bacteria that, in addition to being biodegradable and non-polluting, enrich the soil and improve soil fertility [42–43].

3.3.2. Biostimulants

Biostimulants are chemical substances or bacteria applied to plants or the rhizosphere that improve certain physiological processes in plants. This enhances nutrient use, abiotic stress management, and crop quality, regardless of the crop's nutritional content [44–45].

These products consist of microorganisms, plant extracts, algae, and other organic substances. These may include degradation products of organic materials, low molecular weight molecules, polysaccharides, metabolites of inorganic chemicals, and microbial assemblages [46]. At the plant level, these compounds alter gene expression, metabolize and synthesize certain phytohormones, and mitigate oxidative stress. This results in beneficial effects on yields, quality, and the use of water and fertilizers [19,47].

3.3.3. Microbial inoculants

Microbial inoculants are bio-inputs based on beneficial microorganisms, particularly plant growth-promoting microorganisms (PGPM/PGPR). They are a novel approach for agriculture [48–49]. These inoculants improve soil–plant interaction through biological nitrogen fixation, nutrient solubilization, and the synthesis of phytohormones, siderophores, and antimicrobial enzymes [50]. They are an alternative to chemical fertilizers because they help maintain bacterial balance in the soil, which increases crop resilience and productivity [51].

3.3.4. Seaweed extracts, amino acids, and humic substances

People utilize natural biostimulants like seaweed extracts, amino acids, and humic substances a lot because they help plants grow better, produce more, and handle stress better. Seaweed extracts are rich in bioactive phytochemicals, such as polysaccharides, betaines, phenols, carotenoids, vitamins, minerals, and phytohormones. These molecules help plants get the nutrients they need and stay strong [52–53].

Amino acids, obtained from animal or plant protein hydrolysates, enhance photosynthesis, nitrogen uptake, and above-ground biomass [54–55]. Humic compounds, particularly fulvic acids, function as natural chelating agents that enhance the uptake of micronutrients and promote soil fertility [56–57].

4. Agronomic Impact of Bio-inputs

4.1. Productivity and yield performance

Biostimulants applied alone or in combination with conventional fertilization have been shown to improve crop productivity and even exceed mineral fertilization in some cases [58]. The use of foliar biostimulants and root fertilization in wheat led to an increase in yield of 55%; however, the responses depended on the genotype, the fertilizer, and the management.

Biostimulants, both microbial and non-microbial, improve maize grain yield, especially when combined with mineral fertilization. However, a large variation exists among the production systems [59–60]. Microbial inoculation, in addition to practices such as cover crops, is a large component of yield variation in field studies, which highlights the systemic nature of bio-input performance [61].

Use of plant growth-promoting rhizobacteria like *Bacillus subtilis* and *Azospirillum brasilense* in combination with NPK fertilization has been reported to increase the nutritional efficiency and yields under favorable soil and climate conditions [62–64]. Similarly, positive effects have been observed on potatoes, strawberries, and fruit orchards using macroalgal extracts, mycorrhizae, compost and bioorganic fertilizers, but these responses vary depending upon location and stage of growth [65–67].

Overall, these studies demonstrate that the primary function of bio-inputs is as supplements to integrated nutrient management systems rather than as substitutes for synthetic fertilizers [68].

4.2. Resource use efficiency and root functionality

Through mechanisms such as biological nitrogen fixation, phosphorus solubilization, stimulation of soil enzymatic activity, and enhanced photosynthetic performance, bio-inputs improve nutrient assimilation and utilization [69–70]. In field and horticultural systems, their use—independently or alongside reduced mineral fertilization—has increased plant tissue concentrations of N, P, K, Ca, Zn, and Fe while sustaining yield and quality [71–73].

These improvements are closely linked to modifications in root architecture. In crops such as lettuce, wheat, maize, and tomato, microbial consortia and PGPR promote auxin- and gibberellin-mediated root branching and elongation, thereby increasing root biomass and fine-root formation [74–78]. Bacterial–mycorrhizal co-inoculation enhances nutrient efficiency, but its efficacy is contingent upon agronomic management, water availability, and soil type [73,79–80].

It is true that many studies are site-specific and of limited scale, but there are studies that have documented positive responses, even under stress from lack of water and nutrients, suggesting that bio-inputs can increase nutrient efficiency in different production contexts [81–84].

4.3. Stress tolerance and soil functional resilience

Under biotic and abiotic stress conditions, mineral fertilizers may not fully translate into productivity increases. Bio-inputs trigger complex physiological responses, including activation of the antioxidant defense system and modulation of primary and secondary metabolic pathways, thereby improving resilience to stress [46,85–86].

Seaweed extracts and plant-derived compounds have enhanced nitrogen assimilation and growth in the presence of water, salinity, and thermal stress [87–89]. However, performance is not universally consistent and remains influenced by agronomic management [90–91]. Bibliometric analyses emphasize formulation heterogeneity and environmental variability as major barriers to standardization [92–93].

When combined with organic amendments, bio-input integration enhances biological and biochemical functionality at the soil level by increasing microbial activity, organic carbon, nutrient cycling, and network stability [38,94–96]. Although there have been reports of enhancements in nitrogen efficiency and resilience, sustained benefits necessitate appropriate management [97–99]. Reviews consistently link the use of bio-inputs to improved soil physical properties, carbon sequestration, and long-term agroecosystem resilience [100–101].

5. Bio-inputs as a Basis for Agricultural Ventures

5.1. Entrepreneurial emergence and competitive landscape

The expansion of startups using bio-inputs reflects a broader shift towards more sustainable and knowledge-integrated agri-food systems. This has been driven by both economic and environmental constraints on agrochemical use models and by the increasing demand for lower-impact solutions. Startups like KM ZERO and MicroIN have developed microencapsulation technologies that improve product stability and reduce costs, two of the main barriers to adoption [102]. Similarly, research by Bioomix and Agrobiomics on biological alternatives that promote resilience to climate change and reduce dependence on chemicals has been funded [103,104].

Maintaining a strong market position, on the other hand, requires consistently delivering replicable agronomic performance in real-world field scenarios, which are influenced by variations in soil, climate, and system management. At the same time, the field of biological inputs has also been invaded by large transnational corporations, such as Bayer, Corteva, and Syngenta, leading to greater market concentration, vertical

integration, and increased pressure on the competitiveness of biological producers and entrepreneurs [105,106].

5.2. Scalability, innovation, and production models

Particularly in the case of biofertilizers and microbial and microalgal biostimulants, bio-input production has significant scalability potential due to recent advances in bioprocess engineering, formulation standardization, and circular economy techniques [107, 101]. However, technical scalability does not always translate into agronomic scalability, as a product's effectiveness depends on inoculum quality, environmental conditions, and management practices.

For successful scaling up, agronomic validation for the region, the existence of standardized quality protocols, and congruence between production infrastructure and conventional agricultural practices are required [108]. For continued commercial expansion, effective public policy design, a robust regulatory framework, and investments in research and innovation are essential [109]. Experiences in Brazil and other contexts show that scaling up can be achieved through industrial or decentralized models, each with its own trade-offs in terms of cost structure, quality control, and producer confidence [110, 111, 19].

Technological innovations such as metagenomics, gene editing, nanoencapsulation, and advanced formulation have improved microbial strain selection and product stability, and reduced variability in complex applications [15]. The integration of biostimulants with nanotechnology promotes improvements in plant nutrition and food quality within the circular economy, although this involves high development costs and complex regulatory requirements [112]. In Latin America, innovative formulations of commercially viable bio-inputs have reduced production costs when combined with agronomic validation and technology transfer strategies [113,114]. Biocontrol agents, in particular, improve soil-plant interactions and nitrogen use efficiency, thereby enhancing productivity and environmental sustainability [50,115,116].

5.3. Market dynamics, costs, and structural barriers

Over the past five years, the bio-inputs market in Latin America has experienced substantial growth, accompanied by increasing investment in agroecology, bioeconomy, and regenerative agriculture [117,118]. International institutions such as the World Bank, the IDB, and IFAD have incorporated bio-inputs into their agricultural development projects, resulting in reduced financial risk and greater incentives for their implementation [18].

Internationally, the bio-input markets (biostimulants, biocontrol agents, and biofertilizers) are growing between 12% and 15% annually. Given the current regulatory pressures and evolving demand, these markets are projected to be valued at between US\$6 billion and US\$29 billion by 2030 [119–124].

Despite this growth, high development, registration, certification, and marketing costs continue to restrict market entry. Over the medium term, the costs of production and acquisition may be 20–30% higher than for conventional chemical inputs, especially where technical assistance is required [123, 125]. In addition, the special storage and transportation needs and short shelf life of live products reduce competitiveness, particularly in regions with limited infrastructure [125].

A major impediment to uptake is a mistrust from producers, often coming from a perceived superiority of chemical inputs, inconsistent field results, and a lack of validated local technical information [126]. Regulatory ambiguity limited technological standards, and the high cost of advanced technologies further raise barriers to entry for new businesses [127]. This implies that market growth does not necessarily mean that everyone will use it. The bioeconomy must be consistent with economic viability and environmental sustainability through increased public investment, harmonization of regulations, reinforcement of extension systems, and promotion of public-private collaboration [128].

6. Business Models Associated with Bio-inputs

6.1. Industrial versus decentralized production models

Bio-input production industry can be either industrial or decentralized (local/community-based). Legislation controlling and requiring quality control and standardization of formulations has allowed industrial models to achieve economies of scale, certification, global reach and distribution, and even the contracting of new and/or big agro-industrial players [129, 113, 130, 110]. However, the large scale of industrial production usually constrains adapting production to the diversity of local agronomic conditions.

Decentralized models, such as biofactories and community-based systems, tend to reduce dependencies on external inputs, optimize the use of resources, and enhance territorial autonomy. Local operating systems and community banks are examples of entities that simultaneously promote rural development, family farming, and ecosystem sustainability [131–133]. Although their systems tend to improve flexibility and adaptation to

the context, they present limitations regarding quality control, scalability, and market penetration.

Therefore, the choice between industrial and local production is a structural dilemma that pits control and standardization against flexibility and adaptation to the context.

6.2. Direct commercialization and cooperative integration

Direct sales to producers involve marketing of the product, but also giving technical support, training, and assistance to make producers feel more confident in adopting new technologies, in line with farmers' behavior and perceptions of risk [134]. These tactics generally involve digital platforms, private extension services, and distributors that serve as technology advisors and offer management packages that are tailored [135–138].

Partnerships with agricultural cooperatives are another important model. Cooperatives improve connectivity, input availability, training, and financial services, as well as marketing for farmers, which, in turn, increases the adoption of sustainable technologies [139,140]. They increase collective bargaining, information exchange and technology integration, which increases sustainability, productivity, food security, and, at the same time, reduces poverty in the supply chain [141,142]. International organizations emphasize their role in facilitating the attainment of economies of scale and the adherence to sustainability standards by smallholders [143–146].

However, both direct and cooperative models depend on institutional capacity, governance quality, and the availability of technical services. Direct commercialization increases operating costs and limits scalability in heterogeneous markets, while cooperative effectiveness varies according to internal organization and social cohesion.

6.3. Service integration and circular bioeconomy models

Integrated service models reduce the uncertainty associated with bio-input performance by integrating product provision, technical assistance, digital tools, and participatory extension systems within Agricultural Innovation Systems (AIS) [147]. Evidence indicates that smallholders experience increased productivity, resilience, and adoption when they have access to technological bundles, advisory services, and training simultaneously [148,149]. However, these models need continued funding and may rely on public support or blended funding sources [150].

At the same time, circular bioeconomy systems use agricultural and agro-industrial by-products to produce biofertilizers and other bioproducts, thus closing nutrient cycles and reducing environmental consequences [151, 18]. Initiatives in Latin America have demonstrated that productivity, carbon sequestration, and rural entrepreneurship may be reconciled through territorial coordination, technical availability, and public-private partnerships [152, 153]. The policy frameworks of the European Union and national governments are gradually including bio-inputs and food processing waste as crucial elements for territorial development and sustainable innovation [154–156].

7. Limitations and Structural Challenges for Bio-input Adoption

7.1. Agronomic variability and standardization constraints

Although bio-inputs enhance yield, nutrient efficiency, and stress tolerance, their effectiveness remains highly context-dependent. Performance varies according to product formulation, soil and climate conditions, crop genotype, and management practices [157–159]. Reviews consistently highlight heterogeneity in results under both controlled and field conditions, complicating standardization and reducing producer confidence [15,84].

Additional constraints include limited shelf life, environmental sensitivity, formulation specificity for different latitudes, and higher operational complexity, all of which increase commercialization challenges [160–162]. These factors reinforce uncertainty and slow adoption in heterogeneous production systems.

7.2. Regulatory Fragmentation and Institutional Gaps

The growth of the industry, in contrast to the uncertainty in the regulatory sector, demonstrates a lack of confidence and investment in the industry. Regulated biological inputs, such as agrochemicals, exhibit unclear and/or inconsistent coverage and criteria in the regulation of biofertilizers and biostimulants, especially in the US and some organic certification systems [163,164].

Standards in quality control, validation protocols, and digital traceability integration systems increase implementation costs, despite the combination of control and validation within the system, and the digital traceability of quality control across quality control, engineering, and the system, and the cost control of quality in medicine, not biology, engineering, and medicine [165–167]. The lack of regulatory harmonization is a widely

recognized obstacle in the literature to the integration of sectoral regulation [48,168,169,11].

7.3. Behavioral barriers, capacity gaps, and structural competition

The risk that producers assume significantly impacts how they implement new strategies. Although farmers have shown certain levels of knowledge about environmental problems and have shown a willingness to pay more for sustainable inputs, their inclination towards the use of industrial fertilizers, which they perceive as safer, more concentrated and faster [170]; As they say, “distrust stems from a lack of agronomic data, poor technical communication, locally validated agronomic data, and disparate commercial data” [171].

Training and capacity building have proven to have a significant impact on adoption, especially among smallholder farmers [140,172,173]. However, evidence suggests that implementation time, the time it takes for results to become visible, and the short timeframe for extension results have been linked to low adoption rates [134,174,138]. Therefore, technical support must be complemented by financial incentives [175,176,11].

In addition to behavioral factors, structural market concentration faces further constraints. Large agrochemical corporations, such as Bayer, BASF, Corteva, Syngenta, FMC, UPL, Yara, and The Mosaic Group, have entered the bio-inputs sector through mergers and acquisitions and currently control approximately 80% of the global biopesticide market [106,177]. Their financial capacity, control of distribution logistics, patent ownership, and ongoing subsidies for chemical fertilizer production create competitive asymmetries that limit market entry opportunities for smaller companies [178,179,22,180–181].

8. Future Opportunities and Emerging Trends

8.1 Regenerative integration and technological convergence

Biostimulation, and in some cases bio-inoculation, contribute to regenerative agriculture because they help implement and/or improve conservation agriculture practices [48,84], which generally reduce the use of chemical inputs. However, its contribution to biological and/or regenerative systems depends on the existence of adequate methodologies and long-term research in the context of adaptive management of systems, particularly in systems with high environmental variability and organic integration [182,183].

The convergence of bio-inputs with circular bioeconomy strategies, omic tools, and supportive public

policies especially in Latin America and Brazil acts as an enabling condition for expansion, though not a guarantee of ecological sustainability [165,184–186].

Customization strategies represent another promising frontier. Formulations that combine microbial consortia, biosurfactants, natural polymers, and multi-omics approaches at the soil and crop levels allow for adjustments to increase nutritional efficiency and stress tolerance [187,188]. Advances in Argentina, Brazil, and Mexico show how biotechnology, combined with government programs and private investment, can enhance local adaptation [113,189,184]. However, tailored solutions require greater investment in R&D, higher regulatory approval costs, and specialized technical capabilities, which limit their dissemination beyond industry niches [190].

8.2 Digitalization, market expansion, and governance

Digitalization and traceability technologies such as blockchain, IoT, sensors, QR systems, and precision agriculture are becoming more significant to improve transparency, certification, and value differentiation along agri-food chains [191–193]. In addition to certification, pilot studies have demonstrated that traceability can allow bio-inputs to obtain and strengthen their market positioning [67, 194]. However, interoperability difficulties, implementation costs, gaps in standardization, and the digital divide are still major impediments for small and medium producers [195–199].

Markets are expected to continue to increase in sustainable agriculture. The bio-inputs industry increased from USD 10.6 billion in 2021 to USD 12.7 billion in 2023 and is expected to reach USD 29 billion in 2030 [200–202]. Organic agriculture products, USD 15.1 billion in 2024, may reach USD 43.58 billion by 2032. Sustainable input markets USD 31.90 billion or more [181, 203–204]. By 2034, biostimulants could be worth 11.2 billion USD alone [202]. Especially Brazil and Mexico exhibit high regional dynamics (around 21% and >12% CAGR, respectively), driven by regulatory reforms and export pressures [129, 205].

However, market expansion does not guaranty efficient agronomic integration. Adoption depends on legislative clarity, technical uniformity, agronomic validation and economic models capable of accommodating biological diversity [206–207].

Public policy therefore becomes central. International evidence indicates that financing, institutional coordination, market creation, and technical assistance are essential for translating green innovation into economic and environmental impact [208–209]. Sustainability-

oriented clustering strategies emphasize biomass valorization, territorial development, and value-chain strengthening [210–211]. Bibliometric analyses further highlight that regulatory incentives, green finance, and academia–industry collaboration enhance scalability and SDG contributions when governance capacity and regional technical expertise are present [212]. At the territorial level, integrated financing, advisory services, and governance programs foster rural green entrepreneurship and job creation [213].

9. Conclusions

The use of bio-inputs as part of agricultural production systems presents itself as a high-potential strategy for achieving more sustainable and agronomically viable agriculture. Trials have shown that the use of microbial inoculants, biofertilizers, and biostimulants, among others, contributes to increased yields, improved nutrient utilization, enhanced tolerance to biotic and abiotic stress, and improved soil health. Under certain conditions, yields can equal or surpass those of conventional biofertilization. However, these results are conditional, not automatic, and depend on the combination of crop and soil species, climate, product formulation, and the proper integration of agroecosystem management.

Agricultural bio-inputs represent a significant business opportunity from an economic perspective in a context of new environmental restrictions, variable input prices, and increasing demand for more sustainable goods. The several forms of production and marketing (industrial production, biorefineries, cooperative networks, and integrated service models) illustrate the dynamism of this industry. However, its medium and long-term success depends on the management of agronomic variability, regulatory compliance, and the creation of confidence with producers through technical support and validation.

The market has grown without a commensurate sectoral take-off in terms of the number of enterprises, especially in the case of bioinputs. As for the adoption of bio-inputs, the growth of the market has presented several limitations, among other reasons, due to the lack of results in the adoption of bio-inputs in agriculture, standardization, regulatory inconsistencies, and a knowledge gap, which in turn overvalues competitors who enrich their structures thanks to subsidies.

Bio-inputs should not be seen merely as another input; rather, they should be viewed as part of the transformations that need to occur in the agro-industry, as the argument is that it is a more complex system. The

successful integration of these into the bioeconomy and regenerative systems requires, among other things, (i) robust agronomic validations, (ii) clear and flexible regulations for the product in question, (iii) business models incorporating advisory and training services, (iv) public policies that generate and protect innovation, and (v) governance systems integrating environmental, social, and economic considerations.

The role of bioproducts in the agro-industry of the future will ultimately depend not only on their biological effectiveness but also on the coordinated interaction of scientific knowledge, institutional capability, market structure, and territorial administration. Only through this incorporation can bioproducts move from emergent alternatives to structural elements of regenerative agriculture systems.

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References

- Food and Agriculture Organization of the United Nations (FAO). Statistical Yearbook: World Food and Agriculture 2022; FAO: Rome, Italy, 2022. <https://doi.org/10.4060/cc2211en>
- M. S. Deshmukh, Tanaji N. Ghagare, Dada. R. Nanaware, Kavita. S. Vadrale, Santosh. S. Sutar, (2023), Synthetic Agricultural Inputs and Its Impact on Foodgrains and Human Health, J, Biotechnology and Bioprocessing, 4(2); DOI:10.31579/2766-2314/100
- Sasu, D.D. Global fertilizer consumption from 1965 to 2024, by nutrient. Statista, 2025. Available online: <https://www.statista.com/statistics/438967/fertilizer-consumption-globally-by-nutrient/> (accessed on 10 December 2025).
- Atlas pestycydów. Fakty na temat toksycznych substancji chemicznych w rolnictwie; Fundacja im. Heinricha Bölla w Warszawie; Polski Klub Ekologiczny Koło w Gliwicach; Koalicja Żywa Ziemia: Warsaw, Poland, 2024. Available online: https://pl.boell.org/sites/default/files/2024-02/atlas-pestycydow-2024_1.pdf (accessed on 1 January 2026).
- Food and Agriculture Organization of the United Nations (FAO). Inorganic fertilizers—2002–2022. FAOSTAT Analytical Brief No. 90; FAO: Rome, Italy, 2024. <https://doi.org/10.4060/cd1485en>
- Struciński, P. Pesticide residues in fruits and vegetables—facts and myths. Available online: <https://ncez.pzh.gov.pl/abc-zywienia/zasady-zdrowego-zywienia/pozostalosci-pestycydow-w-owocach-i-warzywach-fakty-i-mity/> (accessed on 1 January 2026).
- Gaytancıoğlu, O.; Yılmaz, F. Sustainable paddy farming in Edirne: Evaluating the impacts of excessive fertilizer and pesticide use. Sustainability 2024, 16, 7814. <https://doi.org/10.3390/su16177814>
- Paudel, J. Fertile grounds: Navigating the environmental impact of fertilizer consumption. Eur. Rev. Agric. Econ. 2025, 52, 617–643. <https://doi.org/10.1093/erae/jbaf033>
- Adebanjo-Aina, O.; Oludoye, O. Impact of nitrogen fertiliser usage in agriculture on water quality. Pollutants 2025, 5, 21. <https://doi.org/10.3390/pollutants5030021>
- Bhanushankar, B.A.; Moni, M.; Srivastava, S.; Nagpal, H.; Kawatra, R. Impacts of agricultural chemicals (chemical fertilizers and pesticides) on human health and environmental sustainability: An illustrated case study of Nathupur and Seoli Village in Sonipat District, Haryana State. Indian J. Agric. Res. 2025, 59, 1491–1501. <https://doi.org/10.18805/IJARe.A-6432>
- Silva, J.C.F.; Machado, K.L.G.; Silva, A.F.S.; Dias, R.; Bodnar, V.R.; Vieira, W.O.; Moreno-Pizani, M.A.; Ramos, J.D.; Pauli, I.; Costa, L.C. Challenges and opportunities for new frontiers and technologies to guarantee food production. Sustainability 2025, 17, 3792. <https://doi.org/10.3390/su17093792>
- Abay, K.A.; Chamberlin, J.; Chivenge, P.; Spielman, D.J. Fertilizer, soil health, and economic shocks: A synthesis of recent evidence. Food Policy 2025, 133, 102892. <https://doi.org/10.1016/j.foodpol.2025.102892>
- Gupta, A.; Saharan, B.S.; Sadh, P.K.; Duhan, J.S. Green to green: Harnessing bio-fertilizers for sustainable pulse production and food security. Discover Plants 2024, 1, 73. <https://doi.org/10.1007/s44372-024-00079-y>
- Jiang, Y.; Yue, Y.; Wang, Z.; Lu, C.; Yin, Z.; Li, Y.; Ding, X. Plant biostimulant as an environmentally friendly alternative to modern agriculture. J. Agric. Food Chem. 2024, 72, 5107–5121. <https://doi.org/10.1021/acs.jafc.3c09074>
- Shahzad, M.; Hayat, R.; Mujtaba, G.; Ur Rehman, W.; Shahzad, M.N. Biofertilizers in sustainable agriculture: Mechanisms, applications, and future prospects. Discover Agriculture 2025, 3, 224. <https://doi.org/10.1007/s44279-025-00318-0>
- Daniel, A.I.; Fadaka, A.O.; Gokul, A.; Bakare, O.O.; Aina, O.; Fisher, S.; Burt, A.F.; Mavumengwana, V.; Keyster, M.; Klein, A. Biofertilizer: The future of food security and food safety. Microorganisms 2022, 10, 1220. <https://doi.org/10.3390/microorganisms10061220>

17. Ibáñez, A.; Garrido-Chamorro, S.; Vasco-Cárdenas, M.F.; Barreiro, C. From lab to field: Biofertilizers in the 21st century. *Horticulturae* 2023, 9, 1306. <https://doi.org/10.3390/horticulturae9121306>
18. Food and Agriculture Organization of the United Nations (FAO) Investment Centre. The potential of bioinputs for greener agrifood systems in Latin America and the Caribbean. FAO, 2025. Available online: <https://www.fao.org/investment-centre/latest/news/detail/the-potential-of-bioinputs-for-greener-agrifood-systems-in-latin-america-and-the-caribbean/en> (accessed on 02 January 2025).
19. Meena, D.C.; Borthal, P.S.; Kumara, T.M.K. Biostimulants for sustainable development of agriculture: A bibliometric content analysis. *Discover Agriculture* 2025, 3, 2. <https://doi.org/10.1007/s44279-024-00149-5>
20. Bullor, L.; Braude, H.; Monzón, J.; Cotes Prado, A.M.; Casavola, V.; Carbajal Morón, N.; Risopoulous, J. Bioinsumos: Oportunidades de inversión en América Latina (Direcciones de inversión No. 9); Food and Agriculture Organization of the United Nations: Rome, Italy, 2023. <https://doi.org/10.4060/cc9060es>
21. Fiocco, D.; Ganesan, V.; Mokodsi, A.L.; Alesso, F.; Gryscek, O. Global farmer insights 2024. McKinsey & Company, 2024. Available online: <https://www.mckinsey.com/industries/agriculture/our-insights/global-farmer-insights-2024> (accessed on 5 January 2026).
22. Mac Clay, P.; Bort, G.; Feeney, R.; Sellare, J. Industrial dynamics and business strategies in the emergence of agricultural biological inputs. *Bus. Strategy Environ.* 2025, 34, 6472–6487. <https://doi.org/10.1002/bse.4314>
23. Gama, R.C.N.; Castro, J.S.; Marangon, B.B.; Jesus Junior, M.M.; Ribeiro, V.J.; Silva, J.; Calijuri, M.L. Microalgae bioinputs as disruptive technology for a sustainable agriculture: A systematic and bibliometric review. *J. Environ. Chem. Eng.* 2025, 13, 116034. <https://doi.org/10.1016/j.jece.2025.116034>
24. Ahmad, M.N. Narrative literature reviews in scientific research: Pros and cons. *Jordan J. Agric. Sci.* 2025, 21, 1–4. <https://doi.org/10.35516/jjas.v21i1.4143>
25. Salvador Oliván, J.A.; Marco Cuenca, G.; Arquero Avilés, R. La reproducibilidad de las estrategias de búsqueda en revisiones sistemáticas publicadas en revistas españolas de Biblioteconomía y Documentación. *Ibersid* 2023, 17, 129–137. <https://doi.org/10.54886/ibersid.v17i1.4892>
26. Guerrero-Villegas, W.; Rosero-Rosero, M.; Layana-Bajana, E.-M.; Villares-Villafuerte, H. Circular agriculture models: A systematic review of academic contributions. *Sustainability* 2025, 17, 7146. <https://doi.org/10.3390/su17157146>
27. Amoah, J.; Ngmensoa, G.; Annan, R.A. Global evidence on nature-positive agricultural practices and their socio-economic and ecological impacts: A systematic review. *Front. Sustain. Food Syst.* 2025, 9, 1723693. <https://doi.org/10.3389/fsufs.2025.1723693>
28. Almeida, B.P.; Pavão, L.F.S.; de Farias, M.S.; Nicolodi, N.M.; Petry, M.T.; Leal, M.M.; Coradi, P.C.; de Souza, V.L.; Queirós, M.S.; Furtado, G.F.; Tres, M.V.; Zabot, G.L. Agricultural biomass as a resource for biomaterials, biofertilizers, and bioproducts: A systematic review. *Agrochemicals* 2025, 4, 23. <https://doi.org/10.3390/agrochemicals4040023>
29. da Silva, J.M.; Dalbon, V.A.; Alves, A.C.; Ataíde, C.B.; dos Santos, T.M.C.; Costa, M.E.L.; Montaldo, Y.C. Bioinputs in sustainable agriculture: Benefits, challenges, and pathways for resilient farming systems. *Asian J. Res. Crop Sci.* 2025, 10, 85–97. <https://doi.org/10.9734/ajrcs/2025/v10i2354>
30. Rosales-Castillo, R.; Velázquez-de Lucio, B.S.; Hernández-Domínguez, E.M.; Álvarez-Cervantes, J. Bio-inputs: An alternative to achieve sustainable agriculture. *Terra Latinoam.* 2025, 43, e2045. <https://doi.org/10.28940/terra.v43i.2045>
31. Ministério da Agricultura, Pecuária e Abastecimento. Bioinputs—Aumentando a biodiversidade brasileira (Programa Nacional de Bioinsumos); Gobierno Federal de Brasil: Brasília, Brazil, 2022. Available online: <https://www.gov.br/agricultura/pt-br/assuntos/inovacao/bioinsumos/nacional-bioinputs-program> (accessed on 5 January 2026).
32. Ministerio de Agricultura, Ganadería y Alimentación (MAGA). ¿Qué son los bioinsumos en la agricultura? Gobierno de la República de Guatemala, 2025. Available online: <https://guatemala.gob.gt/que-son-los-bioinsumos-en-la-agricultura/> (accessed on 6 January 2025).
33. Vermelho, A.B.; Macrae, A.; Neves Junior, A.; Domingos, L.T.S.; de Souza, J.E.; Piazentim Borsari, A.C.; Souza de Oliveira, S.; von der Weid, I.; Veillard, P.; Zilli, J.E. Microbial bioinputs in Brazilian agriculture. *J. Integr. Agric.* 2026, 25, 402–423. <https://doi.org/10.1016/j.jia.2025.09.013>
34. Admin. Biofertilizantes vs fertilizantes químicos: Perspectiva ambiental. TMK Compostador-Noticias, 2024. Available online: <https://es.tmkhb.com/biofertilizantes-vs-chemical-fertilizers-environmental-perspective/> (accessed on 9 January 2026).
35. Jana, B.; Chattopadhyay, R.; Das, R.; Kanthal, S. Bio-fertilizer: An alternative to chemical fertilizer in agriculture. *Int. J. Res. Agron.* 2024, 7, 144–149. <https://doi.org/10.33545/2618060X.2024.v7.i4c.539>
36. Krishna, N.R.; Manasa, K.; Abinandhan, S.; Janawad, K.; Sivasangari, K.J. Biofertilizers: A sustainable alternative to chemical fertilizers for enhanced crop productivity. *Agric. Food E-Newsl.* 2025, 7, 70752. Available online: https://www.researchgate.net/publication/390887066_Biofertilizers_A_Sustainable_Alternative_to_Chemical_Fertilizers_for_Enhanced_Crop_Productivity (accessed on 9 January 2026).
37. Khillar, S. Difference between biofertilizer and chemical fertilizer. Difference Between Similar Terms and Objects, 2022. Available online: <https://www.differencebetween.net/technology/difference-between-biofertilizer-and-chemical-fertilizer/> (accessed on 9 January 2026).
38. Patel, K.K.; Pandey, A.K.; Baheliya, A.K.; Singh, V.; Yadav, R.; Pandey, S.; Adesh; Yadav, V. A comparative study of the effects of biofertilizers and chemical fertilizers on soil physical and biological properties under chickpea crop (*Cicer arietinum* L.). *Int. J. Environ. Clim. Chang.* 2024, 14, 72–80. <https://doi.org/10.9734/IJECC/2024/v14i34020>
39. Ximena, J. Comparative study of biofertilizers and chemical fertilizers on plant growth performance. *QITP Int. J. Fertil.* 2026, 6, 1–6. Available online: [https://qitpress.com/articles/QITP-IJF-IJF/VOLUME_6_ISSUE_1/QITP-IJF_06_01_001.pdf](https://qitpress.com/articles/QITP-IJF/VOLUME_6_ISSUE_1/QITP-IJF_06_01_001.pdf) (accessed on 9 January 2026).
40. Himabindu, K.; Goutami, N. El futuro del uso de biofertilizantes en la agricultura segura. *J. Exp. Agric. Int.* 2024, 46, 255–263. <https://doi.org/10.9734/jeai/2024/v46i72580>
41. Vignesh, M.; Gowshika, R.; Deepa, M.; Delisiya Jose, R.; Dhanya Priyadharshini, S.; Jayashree, P.L.; Kanmani, P.S.; Sutha Sri, S.; Akshai, T.J.; Hariram, S.; Sreehari, S. Role of microbial biofertilizers in enhancing vegetable crop productivity and stress tolerance. *Int. J. Hortic. Food Sci.* 2025, 7, 99–106. <https://doi.org/10.33545/26631067.2025.v7.i6b.326>
42. Keerthan, P.; Ashoka, P.; Singh, V.; Bhargavi, R.; Pujitha, N.; Anusha, T.; Hima Bindu, T.P.L. The role of biofertilizers in soil health

- improvement and sustainable farming: A comprehensive review. *Arch. Curr. Res. Int.* 2025, 25, 163–179. <https://doi.org/10.9734/acri/2025/v25i51196>
43. Ammar, E.E.; Rady, H.A.; Khattab, A.M.; Amer, M.H.; Mohamed, S.A.; Elodamy, N.I.; Al-Farga, A.; Aioub, A.A.A. A comprehensive overview of eco-friendly bio-fertilizers extracted from living organisms. *Environ. Sci. Pollut. Res.* 2023, 30, 113119–113137. <https://doi.org/10.1007/s11356-023-30260-x>
 44. Lu, Q.; Jin, L.; Tong, C.; Liu, F.; Huang, B.; Zhang, D. Research progress on the growth-promoting effect of plant biostimulants on crops. *Phyton* 2024, 93, 661–679. <https://doi.org/10.32604/phyton.2024.049733>
 45. Ciriello, M.; Fusco, G.M.; Woodrow, P.; Carillo, P.; Roupheal, Y. Unravelling the nexus of plant response to non-microbial biostimulants under stress conditions. *Plant Stress* 2024, 11, 100421. <https://doi.org/10.1016/j.stress.2024.100421>
 46. Boutahiri, S.; Benrkia, R.; Tembeni, B.; Idowu, O.E.; Olatunji, O.J. Effect of biostimulants on the chemical profile of food crops under normal and abiotic stress conditions. *Curr. Plant Biol.* 2024, 40, 100410. <https://doi.org/10.1016/j.cpb.2024.100410>
 47. Zulfiqar, F.; Moosa, A.; Ali, H.M.; Bermejo, N.F.; Munné-Bosch, S. Biostimulants: A sufficiently effective tool for sustainable agriculture in the era of climate change? *Plant Physiol. Biochem.* 2024, 211, 108699. <https://doi.org/10.1016/j.plaphy.2024.108699>
 48. Díaz-Rodríguez, A.M.; Parra Cota, F.I.; Cira Chávez, L.A.; García Ortega, L.F.; Estrada Alvarado, M.I.; Santoyo, G.; de los Santos-Villalobos, S. Microbial inoculants in sustainable agriculture: Advancements, challenges, and future directions. *Plants* 2025, 14, 191. <https://doi.org/10.3390/plants14020191>
 49. Pareek, M.; Kathayat, V.; Joshi, B. Greening the fields: Microbial inoculants as catalysts for sustainable agriculture. *Int. Res. Adv. Microbiol. Biotechnol.* 2025, review paper ID 2024.03.2. <https://doi.org/10.46402/2024.03.2>
 50. dos Reis, G.A.; Martínez-Burgos, W.J.; Pozzan, R.; Pastrana Puche, Y.; Ocán-Torres, D.; Mota, P.Q.F.; Rodrigues, C.; Serra, J.L.; Scapini, T.; Karp, S.G.; Soccol, C.R. Comprehensive review of microbial inoculants: Agricultural applications, technology trends in patents, and regulatory frameworks. *Sustainability* 2024, 16, 8720. <https://doi.org/10.3390/su16198720>
 51. He, S.; Zhang, Y.; Yang, X.; Li, Q.; Li, C.; Yao, T. Effects of microbial inoculants combined with chemical fertilizer on growth and soil nutrient dynamics of Timothy (*Phleum pratense* L.). *Agronomy* 2024, 14, 1016. <https://doi.org/10.3390/agronomy14051016>
 52. Mughunth, R.J.; Velmurugan, S.; Mohanakshmi, M.; Vanitha, K. A review of seaweed extract's potential as a biostimulant to enhance growth and mitigate stress in horticulture crops. *Sci. Hortic.* 2024, 334, 113312. <https://doi.org/10.1016/j.scienta.2024.113312>
 53. Kisvarga, S.; Horotán, K.; Hamar-Farkas, D.; Orlóci, L. Effects of humic acids, seaweed extract and *Equisetum arvense* L. extracts on morphological, histological and physiological parameters of the ornamental plant *Ocimum basilicum* Rokokó. *Horticulturae* 2024, 10, 1231. <https://doi.org/10.3390/horticulturae10111231>
 54. Sun, W.; Shahrajabian, M.H.; Kuang, Y.; Wang, N. Amino acids biostimulants and protein hydrolysates in agricultural sciences. *Plants* 2024, 13, 210. <https://doi.org/10.3390/plants13020210>
 55. Atero-Calvo, S.; Navarro-León, E.; Polo, J.; Ruiz, J.M. Physiological efficacy of the amino acid-based biostimulants Pepton 85/16, Pepton origin, and Nutriterra in lettuce grown under optimal and reduced synthetic nitrogen fertilization. *Front. Plant Sci.* 2025, 16, 1645768. <https://doi.org/10.3389/fpls.2025.1645768>
 56. Ali, E.F.; Al-Yasi, H.M.; Issa, A.A.; Hessini, K.; Hassan, F.A.S. Ginger extract and fulvic acid foliar applications as novel practical approaches to improve the growth and productivity of Damask rose. *Plants* 2022, 11, 412. <https://doi.org/10.3390/plants11030412>
 57. Hello Nature. About biostimulants: Use and benefits of biostimulants. Biostimulant.com, 2020. Available online: <https://www.biostimulant.com/biostimulant-101/> (accessed on 9 January 2026).
 58. Fasani, E.; Franceschi, C.; Furini, A.; DalCorso, G. Effect of biostimulants combined with fertilization on yield and nutritional value of wheat crops. *BMC Plant Biol.* 2025, 25, 736. <https://doi.org/10.1186/s12870-025-06804-3>
 59. Ocwa, A.; Mohammed, S.; Mousavi, S.M.N.; Illés, Á.; Bojtor, C.; Ragán, P.; Rátonyi, T.; Harsányi, E. Maize grain yield and quality improvement through biostimulant application: A systematic review. *J. Soil Sci. Plant Nutr.* 2024, 24, 1609–1649. <https://doi.org/10.1007/s42729-024-01687-z>
 60. Saldivar-Villarroel, J.; Cruz-Martinez, R.V. Impacto de bioestimulantes y ácido húmico en el rendimiento del maíz híbrido (*Zea mays* L.): Evidencias desde el Valle de Ica, Perú. *AgroScience Research* 2024, 2, 73–77. <https://doi.org/10.17268/agrosci.2024.008>
 61. Lahijanjan, S.; Schmidt, J.; Feuerstein, U.; Polle, A. Effects of cover crops and microbial inoculants in different farming systems on soil microbial communities and yield of maize. *Biol. Fertil. Soils* 2025, 61, 1165–1182. <https://doi.org/10.1007/s00374-025-01929-x>
 62. Muhammad, H.; Ijaz, M.; Sattar, A.; Ul-Allah, S.; Sher, A.; Asif, M.; Dilshad, M.; Mahmood, K.; Riaz, M.W.; Zaheer, M.S.; Rizwan, M.; Manoharadas, S. Synergistic effects of PGPRs and fertilizer amendments on improving the yield and productivity of canola (*Brassica napus* L.). *BMC Plant Biol.* 2025, 25, 50. <https://doi.org/10.1186/s12870-025-06062-3>
 63. Galindo, F.S.; Pagliari, P.H.; da Silva, E.C.; de Lima, B.H.; Fernandes, G.C.; Thiengo, C.C.; Bernardes, J.V.S.; Jalal, A.; Oliveira, C.E.S.; Vilela, L.S.; Junior, E.F.; Nogueira, T.A.R.; do Nascimento, V.; Teixeira Filho, M.C.M.; Galindo, J.L. Impact of nitrogen fertilizer sustainability on corn crop yield: The role of beneficial microbial inoculation interactions. *BMC Plant Biol.* 2024, 24, 268. <https://doi.org/10.1186/s12870-024-04971-3>
 64. Pradhan, S.; Mitra, N.G.; Sahu, R.K. Microbial consortia enhance wheat productivity, plant nutrition and soil fertility in Vertisols of Central India. *Front. Sustain. Food Syst.* 2026, 9, 1699269. <https://doi.org/10.3389/fsufs.2025.1699269>
 65. El-Abeid, S.E.; Elshewy, E.S.; Ahmed, A.Y. Bio-stimulants for plant growth promotion and sustainable management of *Rhizoctonia solani* causing black scurf of potato tubers. *BMC Plant Biol.* 2025, 25, 1695. <https://doi.org/10.1186/s12870-025-07689-y>
 66. Thakur, P.; Kumar, P.; Sharma, C.L.; Sharma, U.; Sharma, N.; Ladon, T. Ameliorating potential effects of natural biological formulations and biostimulants on plant health and quality attributes in coriander-fenugreek intercropped strawberry (*Fragaria* × *ananassa* Duch.). *BMC Plant Biol.* 2025, 25, 164. <https://doi.org/10.1186/s12870-025-06184-8>
 67. Gonçalves, B.; Santos, M.; Silva, V.; Rodrigues, A.; Oliveira, I.; Lopes, T.; Sujeeth, N.; Guinan, K.J. Biostimulants in fruit crop production: Impacts on growth, yield, and fruit quality. *Horticulturae* 2025, 11, 1452. <https://doi.org/10.3390/horticulturae11121452>

68. Pandey, K.; Saharan, B.S. Soil microbiomes: A promising strategy for boosting crop yield and advancing sustainable agriculture. *Discover Agriculture* 2025, 3, 54. <https://doi.org/10.1007/s44279-025-00208-5>
69. Karunakaran, A.; Fathima, Y.; Singh, P.; Beniwal, R.; Singh, J.; Ramakrishna, W. Next-generation biofertilizers: Nanoparticle-coated plant growth-promoting bacteria biofertilizers for enhancing nutrient uptake and wheat growth. *Agriculture* 2024, 14, 517. <https://doi.org/10.3390/agriculture14040517>
70. Zhang, X.; Zhang, L.; Liu, J.; Shen, Z.; Liu, Z.; Gu, H.; Hu, X.; Yu, Z.; Li, Y.; Jin, J.; Wang, G. Biofertilizers enhance soil fertility and crop yields through microbial community modulation. *Agronomy* 2025, 15, 1572. <https://doi.org/10.3390/agronomy15071572>
71. Demir, H.; Sönmez, İ.; Uçan, U.; Akgün, İ.H. Biofertilizers improve plant growth, yield, and mineral concentration of lettuce and broccoli. *Agronomy* 2023, 13, 2031. <https://doi.org/10.3390/agronomy13082031>
72. Uçar, G.; Şimşek, M.; Topçu, V.; Öktüren Asrı, F.; Ertürk, M.E.; Çelik, İ. Synergistic effects of biofertilizers and chemical fertilizers on yield and nutritional quality of greenhouse-grown lettuce. *Hortis* 2025, 42, 80–87. <https://doi.org/10.16882/Hortis.1716339>
73. Nabati, J.; Nezami, A.; Yousefi, A.; Oskoueian, E.; Oskoueian, A.; Ahmadi-Lahijani, M.J. Biofertilizers containing plant growth promoting rhizobacteria enhance nutrient uptake and improve growth and yield of chickpea plants in an arid environment. *Sci. Rep.* 2025, 15, 8331. <https://doi.org/10.1038/s41598-025-93070-w>
74. Giri, S.; Virk, V. Root-driven hormones and plant growth-promoting rhizobacteria as natural biostimulants for sustainable crop growth. *Discover Plants* 2025, 2, 360. <https://doi.org/10.1007/s44372-025-00390-2>
75. Montesdeoca-Flores, D.; Alfayate-Casañas, C.; Hernández-Bolaños, E.; Hernández-González, M.; Estupiñán-Afonso, Z.; Abreu-Acosta, N. Effect of biofertilizers and rhizospheric bacteria on growth and root ultrastructure of lettuce. *Hortic. Environ. Biotechnol.* 2024, 65, 15–28. <https://doi.org/10.1007/s13580-023-00545-8>
76. Rafique, M.; Naveed, M.; Mumtaz, M.Z.; Niaz, A.; Alamri, S.; Siddiqui, M.H.; Waheed, M.Q.; Ali, Z.; Naman, A.; ur Rehman, S.; Brtnicky, M.; Mustafa, A. Unlocking the potential of biofilm-forming plant growth-promoting rhizobacteria for growth and yield enhancement in wheat (*Triticum aestivum* L.). *Sci. Rep.* 2024, 14, 15546. <https://doi.org/10.1038/s41598-024-66562-4>
77. Dias, A.C.; Alves, G.C.; Rodrigues da Silva, T.F.; Reis, V.M. Inoculation effects of growth-promoting bacteria on corn root architecture: Influence of nitrogen levels, bacterial populations, and plant genotypes. *Rev. Bras. Ciênc. Solo* 2023, 47, e0230059. <https://doi.org/10.36783/18069657rbc20230059>
78. Rondinel Huanaco, B.T.; Quispe-Medina, E.R.; Garcia-Blásquez Morote, C.; Quispe-Tenorio, J.A.; Velásquez Mantari, J.; Paitamala Campos, O.; Díaz Morales, L.A.; Matsusaka Quiliano, D.C. Efectos sinérgicos de bioinoculantes microbianos en el desarrollo radicular de variedades de maíz morado (*Zea mays* L.). *Rev. Investig. Agroprod. Sustentable* 2025, 6, 59–68. <https://doi.org/10.25127/agrops.20252.1088>
79. Zapata-Sifuentes, G.; Sariñana-Aldaco, O.; Lara-Reimers, E.A.; Torres-Rodríguez, J.A.; Zuñiga-Serrano, A.; Preciado-Rangel, P. Efecto bioestimulante de rizobacterias benéficas sobre el rendimiento y compuestos bioactivos de pepino. *Rev. Mex. Cienc. Agríc.* 2025, 16, e3948. <https://doi.org/10.29312/remexca.v16i3.3948>
80. Dzvene, A.R.; Chidzuza, C. Application of biofertilizers for enhancing beneficial microbiomes in push–pull cropping systems: A review. *Bacteria* 2024, 3, 271–286. <https://doi.org/10.3390/bacteria3040018>
81. Mousavi, S.M.; Tadayon, M.S.; Shahabi Far, J. Integrated application of foliar biostimulants and biofertilizers improves wheat resilience, nutrient uptake, and yield under deficit irrigation in semi-arid regions. *Agric. Water Manag.* 2025, 322, 109958. <https://doi.org/10.1016/j.agwat.2025.109958>
82. Bayram, C.A.; Murmu, K. Biostimulants as a sustainable strategy for enhancing vegetable production: A literature review. *Int. J. Agric. Environ. Food Sci.* 2025, 9, 216–227. <https://doi.org/10.31015/2025.si.8>
83. Quille, P.; Kacprzyk, J.; O’Connell, S.; Ng, C.K.Y. Reducing fertiliser inputs: Plant biostimulants as an emerging strategy to improve nutrient use efficiency. *Discover Sustainability* 2025, 6, 128. <https://doi.org/10.1007/s43621-025-00910-w>
84. Arinaitwe, U.; Yabwalo, D.N.; Hangamaisho, A. Unlocking the potential of biostimulants: A review of classification, mode of action, formulations, efficacy, mechanisms, and recommendations for sustainable intensification. *Int. J. Plant Biol.* 2025, 16, 122. <https://doi.org/10.3390/ijpb16040122>
85. Di Sario, L.; Boeri, P.; Matus, J.T.; Pizzio, G.A. Plant biostimulants to enhance abiotic stress resilience in crops. *Int. J. Mol. Sci.* 2025, 26, 1129. <https://doi.org/10.3390/ijms26031129>
86. Martínez-Lorente, S.E.; Martí-Guillén, J.M.; Pedreño, M.Á.; Almagro, L.; Sabater-Jara, A.B. Higher plant-derived biostimulants: Mechanisms of action and their role in mitigating plant abiotic stress. *Antioxidants* 2024, 13, 318. <https://doi.org/10.3390/antiox13030318>
87. Sarango, Y.; Chenche, O. Efecto de bioestimulantes foliares en la tolerancia al estrés abiótico en cultivos de *Raphanus sativus*. *Reincisol* 2024, 3, 4420–4442. [https://doi.org/10.59282/reincisol.V3\(6\)4420-4442](https://doi.org/10.59282/reincisol.V3(6)4420-4442)
88. Ntanasi, T.; Karavidas, I.; Spyrou, G.P.; Giannothanas, E.; Aliferis, K.A.; Saitanis, C.; Fotopoulos, V.; Sabatino, L.; Savvas, D.; Ntatsi, G. Plant biostimulants enhance tomato resilience to salinity stress: Insights from two Greek landraces. *Plants* 2024, 13, 1404. <https://doi.org/10.3390/plants13101404>
89. Espinosa-Aguilar, M.A.; Mocha-Cuenca, B.J.; Rosales-Curipoma, D.E.; Clavijo-Narvaez, K.E. The role of seaweed extracts as biostimulants to mitigate biotic and abiotic stress in crops. *Multidiscip. Lat. Am. J.* 2025, 3, 659–673. <https://doi.org/10.62131/MLAJ-V3-N2-039>
90. Raza, Q.-U.-A.; Rehim, A.; Bashir, M.A.; Raza, H.M.A.; Aon, M.; Geng, Y.; Moustafa, M.; Alshaharni, M.O.; Ali, H.; Lucas, R.S. Identifying the abilities of biostimulants to improve vegetable production compared with conventional fertilizer. *Front. Sustain. Food Syst.* 2024, 8, 1345259. <https://doi.org/10.3389/fsufs.2024.1345259>
91. Ikiz, B.; Yildiz Dasgan, H.; Balik, S.; Aldiyab, A.; Gruda, N.S. Improved salt stress resilience, growth, and quality of soilless basil through biostimulant application. *Sci. Rep.* 2025, 15, 35522. <https://doi.org/10.1038/s41598-025-19670-8>
92. Kadoglidou, K.I.; Anthimidou, E.; Krommydas, K.; Papa, E.; Karapatzak, E.; Tsiveli, N.; Irakli, M.; Mellidou, I.; Xanthopoulou, A.; Kalivas, A. Effect of biostimulants on drought tolerance of greenhouse-grown tomato. *Horticulturae* 2025, 11, 601. <https://doi.org/10.3390/horticulturae11060601>
93. Liaqat, W.; Altaf, M.T.; Jan, M.F.; Maqbool, A.; Ali, A.; Barutçular, C.; Baloch, F.S.; Rahimi, M. Bibliometric and systematic review of biostimulant research under drought stress. *Plant Stress* 2026, 19, 101177. <https://doi.org/10.1016/j.stress.2025.101177>
94. Adam, S.; Mohd Nor, M.N.; Hani, N.W.; Boll Kassim, N.Q.; Othman, N.M.I.; Abu Sari, N.; Alias, M.L. Effects of integrating biofertilizers

- with chemical fertilizers on soil physico-chemical properties and oil palm yield. *Malays. J. Soil Sci.* 2025, 29, 417–426.
95. Matondang, R.R.; Ustiatik, R.; Febiona, S.; Kurniawan, S. Fertilizer changes soil bacterial community and soil quality in coffee agroforestry systems. *J. Ecol. Eng.* 2025, 26, 180–190. <https://doi.org/10.12911/22998993/205821>
 96. Li, Z.; Sui, X.; Li, M.; Yu, Z.; Lv, P.; Wang, L.; Zhang, J.; Li, W. Reduced chemical fertilizer combined with organic fertilizer alters soil microbial community and enhances microbial diversity of *Acanthopanax senticosus* cultivation. *Microorganisms* 2025, 13, 2709. <https://doi.org/10.3390/microorganisms13122709>
 97. Hussain, A.; Iqbal, Z.; Sabir, A.; Alhomaidi, E.; Ahmad, M. Comparative impact of bio-organic and inorganic fertilizer application on soil health, grain quality and yield stability in nutrient deficient regions. *EGUsphere* 2025, preprint. <https://doi.org/10.5194/egusphere-2025-4852>
 98. Zhao, J.; Di, C.; Li, B.; Zhang, T.; Liu, Y.; Sun, F.; Dong, Q.; Duan, J.; Zheng, W.; Li, D. Impact of organic fertilizer substitution on soil quality and microbial diversity in maize ecosystems. *Res. Square* 2025, preprint. <https://doi.org/10.21203/rs.3.rs-8033838/v1>
 99. Malal, H.; Garcia, J.A.; Marrs, A.; Ait Hamza, M.; Emerson, C.; Nocco, M.; Lakhtar, H.; Lazcano, C. Organic and inorganic fertilizers modulate the response of the soil microbiome to salinity stress. *Front. Microbiol.* 2025, 16, 1551586. <https://doi.org/10.3389/fmicb.2025.1551586>
 100. Ghimirey, V.; Chaurasia, J.; Acharya, N.; Dhungana, R.; Chaurasiya, S. Biofertilizers: A sustainable strategy for enhancing physical, chemical, and biological properties of soil. *Innovations in Agriculture* 2024, 7, 1–11. <https://doi.org/10.3897/ia.2024.128697>
 101. Ntsomboh Ntsefong, G.; Gabriel, M.S.T.; Namuene, K.S.; Melanie, D.T.C.; Kingsley, T.M. Biofertilizers: An integrated approach to improving soil fertility, plant nutrition, forest and environmental sustainability. *Open Access Libr. J.* 2025, 12, e13141. <https://doi.org/10.4236/oalib.1113141>
 102. Equipo Redagícola. La startup mexicana MicroIN recibe premio a la sostenibilidad por transformar la formulación de los bioinsumos. *Redagícola* 2025. Available online: <https://redagricola.com/la-startup-mexicana-microin-recibe-premio-a-la-sostenibilidad-por-transformar-la-formulacion-de-los-bioinsumos/> (accessed on 10 January 2026).
 103. De Marzo, S. Danish biotech Bioomix raises €6.3 million to make agriculture more sustainable with microbial solutions. *EU-Startups* 2023. Available online: <https://www.eu-startups.com/2023/10/danish-biotech-bioomix-raises-e6-3-million-to-make-agriculture-more-sustainable-with-microbial-solutions/> (accessed on 10 January 2026).
 104. Laoun, J. Agrobiomics raises \$4M to advance microbial solutions for agriculture. *Vestbee* 2024. Available online: <https://www.vestbee.com/insights/articles/agrobiomics-raises-4-m> (accessed on 10 January 2026).
 105. Strategic Market Research. Biofertilizers market by product type, crop type, microorganism, and region, 2024–2030 (Report No. 36949584); Strategic Market Research, 2025. Available online: <https://www.strategicmarketresearch.com/market-report/biofertilizers-market> (accessed on 13 January 2026).
 106. GRAIN. Corporate bioinputs: Agribusiness's new toxic trap. *GRAIN* 2024. Available online: <https://grain.org/en/article/7175-corporate-bioinputs-agribusiness-s-new-toxic-trap> (accessed on 13 January 2026).
 107. Miranda, A.M.; Hernandez-Tenorio, F.; Villalta, F.; Vargas, G.J.; Sáez, A.A. Advances in the development of biofertilizers and biostimulants from microalgae. *Biology* 2024, 13, 199. <https://doi.org/10.3390/biology13030199>
 108. Palacios-López, L.A. El uso de biofertilizantes en la agricultura moderna: sus avances, desafíos y perspectivas. *Multidiscip. Collab. J.* 2023, 1, 52–64. <https://doi.org/10.70881/mcj/v1/n2/16>
 109. Aramendis, R.; Mondaini, A.; Rodríguez, A. Bioinsumos de uso agrícola: situación y perspectivas en América Latina y el Caribe (Documentos de Proyectos LC/TS.2023/149); Comisión Económica para América Latina y el Caribe (CEPAL): Santiago, Chile, 2023.
 110. Minare, R.; Ferreira, B.W.; Rolim, G.S.; Seibert, J.B.; Diosti, P.F.R.; Fontana, D.C.; Bellini, M.R.; Silva, F.R.; Oliveira, J.R.; Coutinho, C.R.; Figueiredo, F.R.A.; Neto, E.P.S.; Duarte, F.R.M.; Lira, A.G.; Maia, A.V.P.; Okura, M.H.; Monnerat, R.; Tavares de Castro, M.; Montalvão, S.C.L. Producción de bioinsumos agrícolas avanza con nueva ley. *Revista Cultivar* 2025. Available online: <https://revistacultivar-es.com/articulos/Producci%C3%B3n-de-bioinsumos-en-la-finca-avanza-con-nueva-ley> (accessed on 13 January 2026).
 111. Eureka. Biofertilizers Impact in Resilient Crop Production Platforms. 2025. Available online: <https://eureka.patsnap.com/report-research-on-biofertilizers-impact-in-resilient-crop-production-platforms> (accessed on 14 January 2026).
 112. Magnabosco, P.; Masi, A.; Shukla, R.; Bansal, V.; Carletti, P. Advancing the impact of plant biostimulants to sustainable agriculture through nanotechnologies. *Chem. Biol. Technol. Agric.* 2023, 10, 117. <https://doi.org/10.1186/s40538-023-00491-8>
 113. da Silva Medina, G.; Rotondo, R.; Rodríguez, G.R. Innovations in agricultural bio-inputs: Commercial products developed in Argentina and Brazil. *Sustainability* 2024, 16, 2763. <https://doi.org/10.3390/su16072763>
 114. Ferreyra-Suarez, D.; García-Depraect, O.; Castro-Muñoz, R. A review on fungal-based biopesticides and biofertilizers production. *Ecotoxicol. Environ. Saf.* 2024, 283, 116945. <https://doi.org/10.1016/j.ecoenv.2024.116945>
 115. Herrero, J.; Ramírez, A.; Díaz-Santos, E.; Torres-Cortés, G. Biofertilizers for enhanced nitrogen use efficiency: Mechanisms, innovations, and challenges. *Preprints* 2025, preprint. <https://doi.org/10.20944/preprints202510.2490.v1>
 116. Ullah, Q.; Haider, W.; Waqar, M.; Athiqah, M.Y.N.; Maysaroh, U.; Sajjad, N.; Khomphet, T.; Ageru, T.A. Innovative biotechnological approaches in agriculture: From biopesticides against insect pests to flavor enhancement in crops. *J. Agric. Food Res.* 2025, 24, 102369. <https://doi.org/10.1016/j.jafr.2025.102369>
 117. Abbud, J.; Cechin, A. Bioinsumos para agricultura no Brasil: por que o alternativo não se torna dominante? *Braz. J. Political Econ.* 2026, 46, e263739. <https://doi.org/10.1590/0101-31572026-3739>
 118. Bulut, M.; Filik, G. The future of innovative agriculture: Bioeconomy and sustainable agriculture. *Turk. J. Agric.-Food Sci. Technol.* 2024, 12, 1110–1119. <https://doi.org/10.24925/turjaf.v12i6.1110-1119.6793>
 119. Food and Agriculture Organization of the United Nations (FAO). Destacan el uso de bioinsumos para aumentar la productividad y sostenibilidad de la agricultura. 2024. Available online: <https://www.fao.org> (accessed on 14 January 2026).
 120. AgroLatam. Biológicos para una agricultura sustentable: mercado global. 2025. Available online: <https://www.agrolatam.com/tecnologia-latam/biologicos->

- agricultura-sustentable-mercado-global/ (accessed on 14 January 2026).
121. Sawal, J. Bio-based biopesticides market size, share & 2034 growth trends report; Emergen Research, 2025. Available online: <https://www.emergenresearch.com/industry-report/bio-based-biopesticides-market> (accessed on 14 January 2026).
 122. Biologicals Latam. El tamaño del mercado de bioinsumos superaría los US\$29 mil millones en 2034. 2025. Available online: <https://biologicalslatam.com/en/el-tamano-del-mercado-de-bioinsumos-superaria-los-us29-mil-millones-en-2034/> (accessed on 14 January 2026).
 123. Global Growth Insights. Agricultural biologicals market report; Global Growth Insights, 2025. Available online: <https://www.globalgrowthinsights.com/market-reports/agricultural-biologicals-market-108107> (accessed on 16 January 2026).
 124. Informes de Expertos. Mercado de biopesticidas: análisis y proyecciones. 2025. Available online: <https://www.informesdeexpertos.com/informes/mercado-de-biopesticidas> (accessed on 16 January 2026).
 125. Mali, S. Agricultural biologicals market analysis 2026 (8th ed., Report ID: CMR524665); Athenaeum Market Research, 2025. Available online: <https://www.cognitivemarketresearch.com/agricultural-biological-market-report> (accessed on 16 January 2026).
 126. Market.us. Global agricultural biologicals market size, share analysis report by crop-type, by product, by application, by region and companies: Industry segment outlook, market assessment, competition scenario, trends, and forecast 2025–2034 (Report ID: 155651); Market.us, 2025. Available online: <https://market.us/report/agricultural-biologicals-market/> (accessed on 16 January 2026).
 127. Escaleras Medina, J.C.; Baque Mite, R.F. Innovaciones en la producción de frutas, flores y cultivos tropicales: Uso de bioinsumos y tecnologías emergentes. *Cienc. Soc. Hum.* 2025, 12. <https://doi.org/10.69639/arandu.v12i1.716>
 128. Ghorbani Pashakolaie, V.; Gonella, S.; Muhith, I.B. Integrating modern bioeconomy into macroeconomics: A comprehensive review of impacts and interactions. *Biotechnol. Rep.* 2025, 102125. <https://doi.org/10.1016/j.biteb.2025.102125>
 129. Mano, A.; Samora, R. Brazil's bioinputs market boasts four times global average growth, research shows. Reuters 2024. Available online: <https://www.reuters.com/markets/commodities/brazils-bioinputs-market-boasts-four-times-global-average-growth-research-shows-2024-06-25/> (accessed on 16 January 2026).
 130. González Vidal, X. Bioinsumos despegan de la mano de universidades y centros de investigación. *Redagícola* 2024. Available online: <https://redagricola.com/bioinsumos-despegan-de-la-mano-de-universidades-y-centros-de-investigacion/> (accessed on 16 January 2026).
 131. CIRAD. The biofactory boom in Latin America. 2024. Available online: <https://www.cirad.fr/en/cirad-news/news/2024/the-biofactory-boom-in-latin-america> (accessed on 17 January 2026).
 132. Vargas Padilla, M.F.; Ocampo Montesino, J.D.; Canónigo Zapardiel, K.J.; Ortiz Puello, K.M. Producción de bioinsumos para mejorar la productividad agrícola de pequeños agricultores en el municipio de Plato, Magdalena. Diploma thesis, Universidad Nacional Abierta y a Distancia, Colombia, 2024.
 133. Espina, P. Biofábricas: innovación agroecológica que regenera el suelo y promueve los cultivos saludables. INDAP 2025. Available online: <https://www.indap.gob.cl/noticias/biofabricas-innovacion-agroecologica-que-regenera-el-suelo-y-promueve-los-cultivos/> (accessed on 17 January 2026).
 134. Ataei, P.; Karimi, H.; Klöckner, C.A.; Es'haghi, S.R.; Zarei, R. The promotion of biofertilizer application on farms: Farmers' intentional processes. *Environ. Technol. Innov.* 2022, 28, 102722. <https://doi.org/10.1016/j.eti.2022.102722>
 135. Goulet, F.; Ortega Landa, R.; Buenrostro, F.; Fonteyne, S. Can agrodealers be agents of sustainability transitions in agriculture? Reflections based on the expansion of biological inputs in Mexico. *J. Rural Stud.* 2025, 120, 103838. <https://doi.org/10.1016/j.jrurstud.2025.103838>
 136. PW Consulting. Global biofertilizer products market research report 2026: Forecast to 2032; PW Consulting, 2026. Available online: <https://pmarketresearch.com/worldwide-biofertilizer-product-market-research-2024-by-type-application-participants-and-countries-forecast-to-2030/> (accessed on 18 January 2026).
 137. Munthali, N.; Leeuwis, C.; van Paassen, A.; Lie, R.; Asare, R.; van Lammeren, R.; Schut, M. Innovation intermediation in a digital age: Comparing public and private new-ICT platforms for agricultural extension in Ghana. *NJAS Wagening. J. Life Sci.* 2018, 86, 64–76. <https://doi.org/10.1016/j.njas.2018.05.001>
 138. AgriBrasilis. Agrochemical update Brazil & Latin America: Pesticides, fertilizers. 2023. Available online: <http://agribrasilis.com/2023/10/25/bioinputs-market/> (accessed on 18 January 2026).
 139. Chen, C.; Peng, R.; Ye, F.; Liao, W. The role of cooperative membership in promoting agricultural green production technologies among rice farmers in rural China. *Sci. Rep.* 2025, 15, 31044. <https://doi.org/10.1038/s41598-025-09181-x>
 140. Liu, Y.; Shi, R.; Peng, Y.; Wang, W.; Fu, X. Impacts of technology training provided by agricultural cooperatives on farmers' adoption of biopesticides in China. *Agriculture* 2022, 12, 316. <https://doi.org/10.3390/agriculture12030316>
 141. Kalogiannidis, S.; Karafolas, S.; Chatzitheodoridis, F. The key role of cooperatives in sustainable agriculture and agrifood security: Evidence from Greece. *Sustainability* 2024, 16, 7202. <https://doi.org/10.3390/su16167202>
 142. Sánchez-Navarro, J.L.; Arcas-Lario, N.; Bijman, J.; Hernández-Espallardo, M. The role of agricultural cooperatives in mitigating opportunism in the context of complying with sustainability requirements: Empirical evidence from Spain. *Agric. Food Econ.* 2024, 12, 40. <https://doi.org/10.1186/s40100-024-00332-8>
 143. Food and Agriculture Organization of the United Nations (FAO). FAO signs agreement with the International Cooperative Alliance to strengthen joint cooperation. 2024. Available online: <https://www.fao.org/americas/news/news-detail/alianza-cooperativa-internacional/en> (accessed on 18 January 2026).
 144. Food and Agriculture Organization of the United Nations (FAO). FAO impulsa agenda regional para fortalecer el papel de las cooperativas en el desarrollo productivo y territorial. 2025. Available online: <https://www.fao.org/americas/news/news-detail/fortalecer-cooperativas/en> (accessed on 19 January 2026).
 145. Food and Agriculture Organization of the United Nations (FAO). Cinco aspectos claves sobre la importancia de las cooperativas para el bienestar de la población y el desarrollo sostenible. 2025. Available online: <https://www.fao.org/paraguay/noticias/detail-events/fr/c/1732197/> (accessed on 19 January 2026).

146. International Cooperative Alliance (ICA). FAO event looks at the role of cooperatives in driving responsible sourcing and sustainability-driven trade requirements. 2023. Available online: <https://ica.coop/en/newsroom/news/fao-event-looks-role-cooperatives-driving-responsible-sourcing-and-sustainability> (accessed on 19 January 2026).
147. Food and Agriculture Organization of the United Nations (FAO). Agricultural Innovation Systems (AIS)—research and extension systems. 2026. Available online: <https://www.fao.org/research-extension-systems/ais/en/> (accessed on 19 January 2026).
148. Mukherjee, S.; Padaria, R.N.; Burman, R.R.; Velayudhan, P.K.; Mahra, G.S.; Aditya, K.; Sahu, S.; Saini, S.; Mallick, S.; Quader, S.W.; Shrivani, K.; Ghosh, B.; Bhat, A.G. Global trends in ICT-based extension and advisory services in agriculture: A bibliometric analysis. *Front. Sustain. Food Syst.* **2025**, *9*, 1430336. <https://doi.org/10.3389/fsufs.2025.1430336>
149. Tayang, W.; Lalruatfeli, P.C.; Hnialum, M.; Sahoo, B.K. Agricultural extension and advisory services: Enhancing access to knowledge and technologies for sustainable agriculture. In *Advances in Agronomy*; Kadam, S.R.; Yosung, L.; Chishi, H.M.; Malemngambi, T.; Sushma, S.H.A., Eds.; Bigfoot Publications (OPC) Pvt. Ltd., 2023; Vol. 2, pp. Chapter 18. ISBN Print Book- 978-81-19201-41-9
150. Inter-American Institute for Cooperation on Agriculture (IICA). Más de 550 participantes se reúnen en la primera edición de un curso sobre tecnologías sostenibles para la agricultura con bioinsumos. 2025. Available online: <https://iica.int/es/noticias/convocados-por-el-iica-mas-de-550-participantes-se-reunen-en-primera-edicion-de-curso-sobre-tecnologias-sostenibles-para-la-agricultura-con-bioinsumos/> (accessed on 19 January 2026).
151. Srivastava, R.K.; Sarangi, P.K.; Shadangi, K.P.; Sasmal, S.; Gupta, V.K.; Govarthanan, M.; Sahoo, U.K.; Subudhi, S. Biorefineries development from agricultural byproducts: Value addition and circular bioeconomy. *Sustain. Chem. Pharm.* **2023**, *32*, 100970. <https://doi.org/10.1016/j.scp.2023.100970>
152. Medina Morales, P.; Morales Ibarra, M.; González Monterrubio, C. Bioinsumos y bioeconomía circular contra el cambio climático: Alianza para la productividad, regeneración de suelos y captura de carbono en la agricultura de México, Biofábrica Siglo XXI. *C3-Bioeconomy* **2024**, *5*, 125–142. <https://doi.org/10.21071/c3b.vi5.17771>
153. Ministerio de Ganadería, Agricultura y Pesca (MGAP). Uruguay aprobó el Plan Nacional de Bioinsumos: un paso estratégico para la sostenibilidad agropecuaria. 2025. Available online: <https://www.gub.uy/ministerio-ganaderia-agricultura-pesca/comunicacion/noticias/uruguay-aprobo-plan-nacional-bioinsumos-paso-estrategico-para-sostenibilidad> (accessed on 19 January 2026).
154. Bahman, M.; Kumar, P.; Sankhyan, N.K.; Kashyap, M. Valorization of agricultural wastes: A circular economy approach. *Biol. Forum—Int. J.* **2025**, *17*, 84–89. <https://doi.org/10.65041/BiologicalForum.2025.17.3.14>
155. La Moncloa. Planas: “La bioeconomía circular permitirá una producción agroalimentaria más eficiente, competitiva y sostenible.” 2025. Available online: <https://www.lamoncloa.gob.es/serviciosdeprensa/notasprensa/agricultura/paginas/2025/180125-planas-bioeconomia-circular.aspx> (accessed on 19 January 2026).
156. ceiA3 – Campus de Excelencia Internacional Agroalimentario. Una oportunidad en la bioeconomía circular: valorización sostenible de subproductos orgánicos. 2025. Available online: <https://www.ceia3.es/es/noticias/una-oportunidad-en-la-bioeconomia-circular-valorizacion-sostenible-de-subproductos-organicos/> (accessed on 19 January 2026).
157. Mannino, G. Plant-biostimulants interaction: Scientific trends, markets dynamics, and real-world implication. *J. Plant Interact.* **2025**, *20*, 2572668. <https://doi.org/10.1080/17429145.2025.2572668>
158. Li, J.; Van Gerrewey, T.; Geelen, D. A meta-analysis of biostimulant yield effectiveness in field trials. *Front. Plant Sci.* **2022**, *13*, 836702. <https://doi.org/10.3389/fpls.2022.836702>
159. Costa, D.; Walsh, É.; Dieli, C.; O'Halloran, O.; Awan, Z.A.; Gargan, A.; Landeta-Manzano, B.; Priyadarshini, A.; Foley, L.; Gaffney, M.T.; Walsh, L. Impact of biostimulant use in agricultural crops (strawberries, leafy greens and mushrooms) under different horticultural cropping systems: A systematic review. *Ann. Appl. Biol.* **2025**. <https://doi.org/10.1111/aab.70021>
160. Mahmoudi, M.; Asbai, Z.; Foughal, T.; Mabicka Obame, R.G.; Ognalaga, M.; Malounghou Bounangnan, J.D.; Bahlaouan, B.; Boutaleb, N. Biofertilizers for sustainable and environment-friendly agriculture. *Nat. Built Soc. Environ. Health* **2025**, *1*. <https://doi.org/10.63095/NBSEH.25.934721>
161. Ertürk, Y.; Kutlu, M. A potential alternative in sustainable horticulture: Microalgae. *Int. J. Agric. Environ. Food Sci.* **2025**, *9*, 358–377. <https://doi.org/10.31015/2025.si.35>
162. Jha, S.; Singh, D. Innovations in biofertilizer formulations: Nanotechnology, biostimulants, and sustainable delivery systems. *Int. J. Creat. Res. Thoughts* **2025**, *13*. Available on: <https://ijcrt.org/viewpaperforall.php?paper=IJCRT2506525> (accessed on 19 January 2026).
163. Santos, F.; Melkani, S.; Oliveira-Paiva, C.; Bini, D.; Pavuluri, K.; Gatiboni, L.; Mahmud, A.; Torres, M.; McLamore, E.; Bhadha, J.H. Biofertilizer use in the United States: Definition, regulation, and prospects. *Appl. Microbiol. Biotechnol.* **2024**, *108*, 511. <https://doi.org/10.1007/s00253-024-13347-4>
164. Arcudia Hernández, C.E.; Martínez Padrón, A.D.; Martínez Alvarado, E. Marco regulatorio de los bioinsumos en la agricultura orgánica en México. *Tlatemoani* **2025**, *16*. <https://doi.org/10.51896/tlatemoani.v16i50.1105>
165. Mashabela, M.D.; Terefe, T.; Kerchev, P.; Sitole, L.; Mhlango, M.I. Next-generation biostimulants: Molecular insights, digital integration, and regulatory frameworks for sustainable agriculture. *Front. Plant Sci.* **2025**, *16*, 1710899. <https://doi.org/10.3389/fpls.2025.1710899>
166. Battelle Insider. EU biostimulants regulation: Key opportunities and challenges under the FPR. 2025. Available online: <https://inside.battelle.org/blog-details/eu-biostimulants-regulation--key-opportunities-and-challenges-under-the-fpr> (accessed on 20 January 2026).
167. BioAg World Digest. BioAg regulations harmonization. 2025. Available online: <https://www.bioagworlddigest.com/2025/10/bioag-regulations-harmonization/> (accessed on 20 January 2026).
168. Khoulati, A.; Ouahhoud, S.; Taibi, M.; Ezrari, S.; Mamri, S.; Merah, O.; Hakkou, A.; Addi, M.; Maleb, A.; Saalaoui, E. Harnessing biostimulants for sustainable agriculture: Innovations, challenges, and future prospects. *Discover Agriculture* **2025**, *3*, 56. <https://doi.org/10.1007/s44279-025-00177-9>
169. Vergel-Castro, C.; Boom-Cárcamo, E. Challenges and opportunities in the use of microbial inoculants in hydroponic crops: A literature review. *Microbe* **2025**, *9*, 100556. <https://doi.org/10.1016/j.microb.2025.100556>

170. Šatvar Vrbančić, M.; Čoga, L.; Špicnagel, A.M.; Vugrin, N.; Meers, E.; Čop, T. Farmers' preferences and practices regarding bio-based fertilizers: A Croatian perspective. *Sustainability* 2025, 17, 3367. <https://doi.org/10.3390/su17083367>
171. Barvadiya, D.B.; Vahoniya, D.R.; Patel, H.R. Factors influencing and problems faced by farmers in the adoption of biostimulants in Dantiwada Taluka of Banaskantha District, Gujarat. *Arch. Curr. Res. Int.* 2025, 25, 124–134. <https://doi.org/10.9734/acri/2025/v25i71318>
172. Liu, Y.; Shi, K.; Liu, Z.; Qiu, L.; Wang, Y.; Liu, H.; Fu, X.; Liu, X. The effect of technical training provided by agricultural cooperatives on farmers' adoption of organic fertilizers in China: Based on the mediation role of ability and perception. *Int. J. Environ. Res. Public Health* 2022, 19, 14277. <https://doi.org/10.3390/ijerph192114277>
173. Jha, G.K.; Velayudhan, P.K.; Bhatia, A.; Laishram, C.; Kumar, D.; Begho, T.; Eory, V. Transitioning towards sustainable agriculture: Analysing the factors and impact of adopting multiple sustainable inputs by paddy farmers in India. *Front. Sustain. Food Syst.* 2024, 8, 1447936. <https://doi.org/10.3389/fsufs.2024.1447936>
174. Mulugeta, T.; Ilomo, M.; Mueke, A.; Onyango, C.; Matsaunyane, L.; Kritzing, Q.; Alexandersson, E. Smallholder farmers' knowledge, attitudes, and practices (KAP) regarding agricultural inputs with a focus on agricultural biologicals. *Heliyon* 2024, 10, e26719. <https://doi.org/10.1016/j.heliyon.2024.e26719>
175. Cerveira, R.; Pompeu, G.B.; da Cunha, C.F. Perception of grain farmers in the Brazilian Cerrado region regarding the adoption or non-adoption of bioinputs. *Contextus* 2025, 23, e94664. <https://doi.org/10.36517/contextus.2025.94664>
176. Mullens, J.; DePue, J. Commercialization of alternative soil amendments for agricultural use as a nature-based solution. Master's thesis, Duke University, Nicholas School of the Environment, USA, 2025.
177. CADTM. Voracidad "bio" de las multinacionales agroquímicas. 2024. Available online: <https://www.cadtm.org/Voracidad-bio-de-las-multinacionales-agroquimicas> (accessed on 20 January 2026).
178. Intel Market Research. Biofertilizer market growth analysis, dynamics, key players and innovations, outlook and forecast 2025–2032 (Report Code IMR-14313); Intel Market Research, 2025. Available online: <https://www.intelmarketresearch.com/biofertilizer-market-14313> (accessed on 20 January 2026).
179. El País. Los gigantes que mueven los hilos del sector agrícola y fijan el precio de la cesta de la compra. 2024. Available online: <https://elpais.com/economia/negocios/2024-09-07/los-gigantes-que-mueven-los-hilos-del-sector-agricola-y-fijan-el-precio-de-la-cesta-de-la-compra.html> (accessed on 20 January 2026).
180. EIN Presswire. Biological crop protection market: Competition analysis 2025—how players are shaping growth. 2026. Available online: <https://www.einpresswire.com/article/885084514/biological-crop-protection-market-competition-analysis-2025-how-players-are-shaping-growth> (accessed on 20 January 2026).
181. Fortune Business Insights. Mercado de biológicos agrícolas: Tamaño del mercado, participación y análisis de la industria, por tipo, fuente, método de aplicación, cultivo y previsión regional, 2025–2032 (Informe ID: FBI100411); Fortune Business Insights, 2026. Available online: <https://www.fortunebusinessinsights.com/es/industry-reports/agricultural-biologicals-market-100411> (accessed on 20 January 2026).
182. Mounaimi, S.; Hamim, A.; El Boukhari, M.E.M.; Elarroussi, H.; Lyamlouli, K. A comprehensive review of integrating biostimulants and biopesticides for organic berry farming: Exploring challenges and opportunities for Africa. *Front. Sustain. Food Syst.* 2024, 8, 1452823. <https://doi.org/10.3389/fsufs.2024.1452823>
183. Hawes, C.; Christie, A.; Banks, G.; Boldrin, D.; Brandt, J.; Iannetta, P.; Swyst, I.; Turner, I. Long-term regenerative practices enhance in-field biodiversity and soil health for sustainable crop yields. *Front. Sustain. Food Syst.* 2025, 9, 1651686. <https://doi.org/10.3389/fsufs.2025.1651686>
184. Barbosa, M.F.; Sales, R.M.M.; Galarza, F.A.D.; Kruger, C.Q.; Fávoro, L.C.L.; Quirino, B.F. Biological resources driving productivity: Bioinputs for sustainable plant agriculture in Brazil. *Sustain. Microbiol.* 2025, 2, qvaf011. <https://doi.org/10.1093/sumbio/qvaf011>
185. Somorin, T.; Zemadim, B.; Osei-Amponsah, C.; Adamtey, N.; Gebrezgabher, S. Circular bioeconomy as a driver of regenerative multifunctional landscapes; International Water Management Institute (IWMI), CGIAR Multifunctional Landscapes Program, 2025.
186. Das, S.; Dutta, S.; Roy Choudhury, M.; Garai, S.; Mukherjee, S.; Sengupta, S.; Jana, S.; Dey, S.; Dhar, A.; Dutta, S.; Awasthi, A. Regenerating rural soil and ecosystems: A 15-year systematic review of emerging methods and technologies. *Sci. Total Environ.* 2025, 990, 179926. <https://doi.org/10.1016/j.scitotenv.2025.179926>
187. da Silva, M.G.C.; de Medeiros, A.O.; Roque, B.A.C.; dos Santos, M.R.; Bezerra, K.G.O.; de Almeida, F.C.G.; Sarubbo, L.A. Next-generation bioinputs: A systematic review of biosurfactants in sustainable agriculture and research frontiers with bacterial cellulose. *Processes* 2026, 14, 398. <https://doi.org/10.3390/pr14030398>
188. Hnini, M.; Rabeh, K.; Oubohssaine, M. Understanding plant–microorganism interactions: The key roles of soil, rhizosphere, and direct and indirect mechanisms. *AIMS Microbiol.* 2025, 11, 1035–1078. <https://doi.org/10.3934/microbiol.2025046>
189. Rincón-Molina, C.I.; Manzano-Gómez, L.A.; García-Pérez, L.G.; Rincón-Molina, F.A.; Rincón-Rosales, R. Advances and challenges in the production and use of native bacteria as plant probiotics in agronomic applications: A Mexican review. *J. Agric. Food Res.* 2025, 21, 101917. <https://doi.org/10.1016/j.jafr.2025.101917>
190. Farming First. A global model for regenerative agriculture using soil microbes & microbial solutions. 2025. Available online: <https://farmingfirst.org/2025/09/a-global-model-for-regenerative-agriculture-using-soil-microbes-microbial/> (accessed on 20 January 2026).
191. Charlebois, S.; Latif, N.; Ilahi, I.; Sarker, B.; Music, J.; Vezeau, J. Digital traceability in agri-food supply chains: A comparative analysis of OECD member countries. *Foods* 2024, 13, 1075. <https://doi.org/10.3390/foods13071075>
192. Bekkouch, S.; de-Magistris, T. Digitalization in the European agri-food supply chain: A scoping review of traceability, transparency, and sustainability. *Front. Blockchain* 2025, 8, 1701872. <https://doi.org/10.3389/fbloc.2025.1701872>
193. Getahun, S.; Kefale, H.; Gelaye, Y. Application of precision agriculture technologies for sustainable crop production and environmental sustainability: A systematic review. *Sci. World J.* 2024, 2126734. <https://doi.org/10.1155/2024/2126734>
194. Li, Q.; Hadj Hamou, K.; Rekik, Y. Blockchain-enabled traceability in agriculture: A game-theoretic approach to production decisions. *IFAC-PapersOnLine* 2025, 59, 256–261. <https://doi.org/10.1016/j.ifacol.2025.09.045>
195. Huang, Y.; Li, X.; Xu, L.; Ma, Y. Digital traceability in horticulture: A systematic review of edge-cloud-blockchain-terminal (ECBT)

- integration with IoT and AI technologies. *Front. Blockchain* 2025, 8, 1636627. <https://doi.org/10.3389/fbloc.2025.1636627>
196. Pang, S.; Teng, S.W.; Murshed, M.; Bui, C.V.; Karmakar, P.; Li, Y.; Lin, H. A survey on evaluation of blockchain-based agricultural traceability. *Comput. Electron. Agric.* 2024, 227, 109548. <https://doi.org/10.1016/j.compag.2024.109548>
 197. Choruma, D.J.; Dirwai, T.L.; Mutenje, M.J.; Mustafa, M.; Chimonyo, V.G.P.; Jacobs-Mata, I.; Mabhaudhi, T. Digitalisation in agriculture: A scoping review of technologies in practice, challenges, and opportunities for smallholder farmers in sub-Saharan Africa. *J. Agric. Food Res.* 2024, 18, 101286. <https://doi.org/10.1016/j.jafr.2024.101286>
 198. Karkanias, C.; Malamakis, A.; Baniyas, G.F. Blockchain and megatrends in agri-food systems: A multi-source evidence approach. *Foods* 2026, 15, 447. <https://doi.org/10.3390/foods15030447>
 199. Tarhan, Ç.; Göl, B. Digital traceability in food supply chains: Technologies, benefits, and implementation challenges. *J. Appl. Eng. Agric. Sci.* 2025, 2, 7–14.
 200. Moyano Córdoba, I. Mercado mundial de bioinsumos. In *Proceedings of Congreso CASAFE Biológicos 2025*, Argentina, 2025. Available online: <https://www.congresocasafe.com.ar/archivos-descarga/congreso-casafe-biologicos2025/presentaciones/panel-1/ignacio-moyano-cordoba-mercado-mundial-de-bioinsumos-congreso-casafe-biologicos-2025.pdf> (accessed on 22 January 2026).
 201. Techmi Group. El uso de bioinsumos sigue creciendo: Bioestimulantes y biofertilizantes encabezan la tendencia. 2025. Available online: <https://techmigroup.com/el-uso-de-bioinsumos-sigue-creciendo-bioestimulantes-y-biofertilizantes-encabezan-la-tendencia/> (accessed on 22 January 2026).
 202. Global Market Insights. Biostimulants market size: By active ingredients, application, crop, form, source, function, end use, industry analysis, share, growth forecast 2025–2034 (Report ID: GMI1346); Global Market Insights, 2025. Available online: <https://www.gminsights.com/industry-analysis/biostimulants-market> (accessed on 22 January 2026).
 203. Statistics Market Research Consulting. Sustainable agriculture inputs market forecasts to 2032: Global analysis by input type, crop type, farming practice, distribution channel and application; Statistics Market Research Consulting, 2026. Available online: <https://www.marketresearch.com/Statistics-Market-Research-Consulting-v4058/Sustainable-Agriculture-Inputs-Forecasts-Global-43563127/> (accessed on 22 January 2026).
 204. Roots Analysis. Sustainable agriculture market till 2035: Distribution by type of product, type of crops, type of farming system, formulation, application, company size, and geography; Roots Analysis, 2025. Available online: <https://www.rootsanalysis.com/sustainable-agriculture-market> (accessed on 22 January 2026).
 205. IMARC Group. México bio agriculture mercado: Tamaño, participación, tendencias y pronóstico por segmento y región, 2025–2033 (Report ID: SR112026A38559); IMARC Group, 2026. Available online: <https://www.imarcgroup.com/report/es/mexico-bio-agriculture-market> (accessed on 28 January 2026).
 206. MarkNtel Advisors. Global sustainable agrochemicals market research report: Forecast (2025–2030); MarkNtel Advisors, 2025. Available online: <https://www.marknteladvisors.com/research-library/sustainable-agrochemicals-market.html> (accessed on 28 January 2026).
 207. Congruence Market Insights. Agricultural biologicals testing market size, trends, share, growth, and opportunity forecast, 2025–2032 (Report Code: CGNAGR2397); Congruence Market Insights, 2025. Available online: <https://www.congruencemarketinsights.com/report/agricultural-biologicals-testing-market> (accessed on 28 January 2026).
 208. Organisation for Economic Co-operation and Development (OECD). Policies to support green entrepreneurship: Building a hub for green entrepreneurship in Denmark; OECD Publishing: Paris, France, 2022. Available online: https://www.oecd.org/en/publications/policies-to-support-green-entrepreneurship_e92b1946-en.html (accessed on 28 January 2026).
 209. Sharma, S.N.; Subba, R. Entrepreneurship and sustainability: Analyzing the impact of green startups on economic development. *Innov. Green Dev.* 2025, 4, 100280. <https://doi.org/10.1016/j.igd.2025.100280>
 210. Padilla-Esquivel, C.A.; Posadas-Paredes, T.; Alcocer-García, H.; Ramírez-Márquez, C.; Ponce-Ortega, J.M. Multi-objective optimization and K-means clustering analysis of green hydrogen production routes via biomass gasification and water electrolysis. *Processes* 2026, 14, 946. <https://doi.org/10.3390/pr14060946>
 211. Naroju, B.; Chandrashekar, K. Green startups as catalysts for a green economy: Prospects and challenges. In *Proceedings of the 10th International Conference on Economic Growth and Sustainable Development*, 2025.
 212. Nandhini, S.; Sowmya, G. Advancing green entrepreneurship: Bibliometric insights into sustainable innovation and global collaboration. *Discover Sustainability* 2025, 6, 1257. <https://doi.org/10.1007/s43621-025-01230-9>
 213. García, Á. ‘Diputación Impulsa’ crea un nuevo instrumento financiero para apoyar proyectos empresariales en el medio rural cacereño. 2025. Available online: <https://cadenaser.com/extremadura/2025/11/14/diputacion-impulsa-crea-un-nuevo-instrumento-financiero-para-apoyar-proyectos-empresariales-en-el-medio-rural-cacereño-ser-caceres/> (accessed on 30 January 2026).

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