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biofertilizers and circular bioeconomy solutions
for a sustainable agriculture*

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List of acronyms

AMF	Arbuscular Mycorrhizal Fungi
AS	Ammonium sulphate
BNF	Biological Nitrogen fixation
CAGR	Compound Annual Growth Rate
CAN	Calcium ammonium nitrate
CAP	Common Agricultural Policy
CEAP	Circular Economy Action Plan
CISL	Cambridge Institute for Sustainability Leadership
CMC	Component Material Category
DAP	Diammonium phosphate
EBI	European Biochar Industry
EU	European Union
FPR	Fertilising Products Regulation
FYM	Farmyard Manure
GHG	Greenhouse Gas
K	Potassium
N	Nitrogen
N ₂	Dinitrogen
NH ₃	Ammonia
NO ₃ ⁻	Nitrate
NECD	National Emission Ceilings Directive
NO	Nitrogen oxides
N ₂ O	Nitrous oxide
P	Phosphorus
PGPR	Plant growth-promoting rhizobacteria
PSB	Phosphate solubilizing bacteria
TSP	Triple superphosphate

1. Summary

Biofertilizers and biostimulants, derived from microorganisms or organic waste products, are emerging as sustainable alternatives to conventional chemical inputs in agriculture. These bio-based products offer numerous benefits, including enhanced soil fertility, improved crop growth, and increased resilience to environmental stresses, while promoting circular economy principles through the valorization of agricultural and industrial by-products. Despite their potential, the adoption of biofertilizers and biostimulants is hindered by several challenges, such as product inconsistency, high production costs, limited farmer awareness, and regulatory barriers. Addressing these challenges requires innovation in product formulation, optimization of production processes, and the development of cost-effective solutions. Additionally, education and extension services are essential for increasing farmer adoption, while regulatory frameworks need to evolve to accommodate bio-based products derived from non-traditional waste streams. This deliverable highlights the current state of biofertilizers and biostimulants in European agriculture, identifying key barriers to their adoption and proposing strategies to overcome them. Collaborative efforts between researchers, policymakers, and industry stakeholders are crucial for fostering innovation, ensuring product quality, and facilitating knowledge transfer. Ultimately, biofertilizers and biostimulants have the potential to significantly contribute to the European Union's (EU) sustainability goals by enhancing nutrient use efficiency, reducing the environmental impact of agriculture, and supporting the transition towards a more sustainable, circular agricultural system.

2. Introduction

The global demand for food is projected to rise by 56% from 2010 to 2050. This puts significant pressure on food production systems¹. To meet this growing demand, global food production will need to increase by at least 50% over the next half-century. The EU is largely self-sufficient in food production for commodities that can be grown in European climates. However, the EU relies on about one-third of its domestic arable land outside its territory to meet food demands². Climate change and biodiversity loss exert significant challenges to maintaining European food security.

Fertilizers play a significant role in food security. Purchase of fertilizers represents around 6% on average of the share of input costs and up to 12% for arable crops farmers. The EU's Farm to Fork strategy aims to reduce nutrient losses by 50% by 2030 while maintaining soil fertility. However, rising fertilizer prices have prompted farmers to reduce both the quantity of the fertilizers purchased and their use in crops, leading to a temporary decline in EU fertilizers' production. Fertilizer shortages can cause short-term yield reduction, which in turn results in decreased agricultural output and lower food availability³.

As of July 16, 2022, the **EU's Regulation 2019/1009, known as the Fertilising Products Regulation (FPR)**, governs the market placement of fertilising products within the EU. This regulation introduces harmonised standards for various fertilising products, including organic and waste-based fertilisers, soil improvers, and plant biostimulants.

Notably, the FPR does not explicitly define the term "biofertilizer." Instead, it encompasses such products under broader categories like **organic fertilisers** and plant **biostimulants**. According to the regulation, a plant biostimulant is defined as: "An EU fertilising product whose function is to stimulate plant nutrition processes independently of the product's nutrient content, with the sole aim of improving one or more of the following characteristics of the plant or the plant rhizosphere: nutrient use efficiency, tolerance to abiotic stress, quality traits, availability of confined nutrients in the soil or rhizosphere." This definition aligns with the general understanding of biofertilizers as substances containing living microorganisms that enhance plant growth by increasing the availability of primary nutrients to the host plant. Therefore, within the EU regulatory framework, products commonly referred to as biofertilizers are regulated under the categories of organic fertilisers or plant biostimulants, depending on their specific functions and compositions. So, while the term "biofertilizer" is widely used in agricultural and scientific discussions, within the EU regulatory framework, **it is effectively synonymous with organic fertilizer in terms of classification and market placement**. For this deliverable and this project, the term biofertilizer will be adopted instead of organic fertilizer.

This report focuses on compiling information on the state-of-the-art (SoA) in the European fertilizing industry, identifying the strategies launched by the European Commission and the current legislative framework, potential barriers for innovation uptake, and projects related to the development of new fertilizing products. By focusing on EU-specific studies and practices, the report seeks to highlight both advancements and challenges in the adoption of

¹ <https://doi.org/10.1038/s43016-021-00322-9>

² <https://euroseeds.eu/topics/food-security/><https://euroseeds.eu/topics/food-security/>

³ https://agriculture.ec.europa.eu/common-agricultural-policy/agri-food-supply-chain/ensuring-availability-and-affordability-fertilisers_en



biofertilizers and biostimulants for sustainable agriculture. This targeted approach will provide insights into how biofertilizers can contribute to the EU's goals for environmental sustainability and agricultural efficiency.

3. Overview of the fertilizer industry in the EU

3.1. Mineral fertilizers

3.1.1. What are mineral fertilizers?

Mineral fertilizers are produced through chemical or industrial processes or extracted from mineral deposits, which differ from organic materials that contain carbon. These are commonly referred to as chemical, artificial, or inorganic fertilizers. The production of mineral fertilizers involves the extraction of materials from naturally occurring mineral sources and/or the fixation of atmospheric nitrogen into a form that plants can utilize. These fertilizers are distinguished by their concentrated supply of one, two, or three key plant nutrients ⁴. Examples include:

- **Simple mineral fertilizers:** examples are urea, ammonium nitrate, and ammonium sulphate.
- **Complex mineral fertilizers:** include combinations like NP, NK, and NPK blends.
- **Mineral-organic fertilizers:** calcium cyanamide ⁵.

Food and feed production is highly dependent on the availability of soil nutrients, which naturally are insufficient to sustain the current agricultural practices. Fertilizer application enhances plant growth and biomass production, leading to increased crop yields. This approach has the potential to mitigate the global challenge of food security for a growing population. Mineral fertilizers rich in nitrogen, phosphorus, and potassium are commonly used to compensate for nutrient-poor soils. Primary nutrients like nitrogen, phosphorus, and potassium form the foundation of most fertilizers. However, many formulations also include secondary macronutrients such as calcium, sulphur, and magnesium. Furthermore, micronutrients, including copper, iron, manganese, and boron, are frequently incorporated into these complex blends. This tailored approach allows for precise nutrient delivery to meet the specific needs of crops and soils ^{6,7}.

The most common commercial fertilizers in industry are represented in **Table 1**. A more comprehensive list of fertilizer types and origins is available in Annex 7.1.

Table 1. Most common commercial fertilizers. Adapted from ⁸.

Nitrogen fertilizers	Phosphate fertilizers	Potash fertilizers
Urea	Diammonium phosphate (DAP)	Chloride of potash
Ammonium sulphate (AS)	Single superphosphate	Sulphate of potash
Ammonium nitrate (AN)	Triple superphosphate (TSP)	Sulphate of potash-magnesia

⁴ <https://www.fertilizer.org/about-fertilizers/organic-and-mineral-fertilizers/>

⁵ <https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Fertiliser>

⁶ <https://doi.org/10.1016/j.scitotenv.2023.164636>

⁷ https://agriculture.ec.europa.eu/system/files/2019-07/market-brief-fertilisers_june2019_en_0.pdf

⁸ https://publications.jrc.ec.europa.eu/repository/bitstream/JRC70936/npk%20final%20report%20_%20publication%20be%20pdf.pdf

Calcium ammonium nitrate (CAN)	Ground rock phosphate (mineral phosphate)	Nitrate of potash
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3.1.2. Mineral fertilizers market

The decrease in fertilizer use within the EU during 2022 may be attributed to the sharp increase in fertilizer prices throughout 2022, a consequence of the military aggression in Ukraine and the subsequent sanctions imposed on Russia ⁹. After 2022, prices began to decrease, as reported in **Table 2**.

Table 2. Fertilizers price evolution in USD/Mt. Adapted from ¹⁰.

Fertilizers	2022	2023	2024
Diammonium phosphate (DAP)	772.2	550.0	563.7
Phosphate rock	266.2	323.8	321.7
Potassium chloride	863.4	383.2	295.1
Triple superphosphate (TSP)	716.1	480.2	472.6
Urea	700.0	358.0	338.3

In 2024, fertilizer prices exhibited a downward trend compared to the preceding year (2023). This downward trajectory is projected to continue in 2025. However, despite this decline, fertilizer prices are anticipated to remain significantly higher than the average observed before the 2020 period. This sustained elevation is attributed to a confluence of factors, including robust global demand, export restrictions imposed by certain nations (notably China), and sanctions primarily affecting Belarus. The forecast is exposed to upside risks driven by potential escalations in input costs, with natural gas prices being a primary concern ¹¹.

Fertilizers Europe, an association formed by 15 fertilizer manufacturers that represents the interests of most mineral fertilizers manufacturers in the European Union and Norway, reports yearly the fertilizer consumption in Europe and forecast use. The report launched in December 2024 states that the average fertilizer consumption in Europe is 8.7 million tons of nitrogen, 2 million tons of phosphate, and 2.2 million tons of potash, which are applied to 122.9 million hectares of farmland ¹².

In terms of volume, nitrogen constitutes the most extensively utilized nutrient within the European Union's agricultural sector. Its consumption surpasses two-thirds of the combined application of the three primary nutrients – nitrogen, phosphorus, and potassium. Phosphate and potassium are applied in comparatively smaller quantities across EU agricultural lands, each accounting for less than 20% of the total nutrient volume. According to Fertilizers Europe, mineral fertilizers are utilized on approximately 75% of the EU's 179 million hectares of arable land, which equates to roughly 1 million hectares ¹³.

⁹https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agri-environmental_indicator_-_mineral_fertiliser_consumption

¹⁰<https://thedocs.worldbank.org/en/doc/5d903e848db1d1b83e0ec8f744e55570-0350012021/related/CMO-Pink-Sheet-January-2025.pdf>

¹¹<https://thedocs.worldbank.org/en/doc/5d903e848db1d1b83e0ec8f744e55570-0350012021/related/CMO-Pink-Sheet-January-2025.pdf>

¹² <https://www.fertilizerseurope.com/wp-content/uploads/2024/12/Forecast-2024-34-web.pdf>

¹³ https://agriculture.ec.europa.eu/system/files/2019-07/market-brief-fertilisers_june2019_en_0.pdf.

Countries that are among the EU's highest agricultural producers and have the largest utilized agricultural areas tend to use the most nitrogen fertilizer in agriculture: France (2 million tons in 2022) and Germany (1.1 million tons in 2022)¹⁴. **Figure 1** show the consumption of mineral fertilizers (nitrogen and phosphorus) in Europe in 2022.

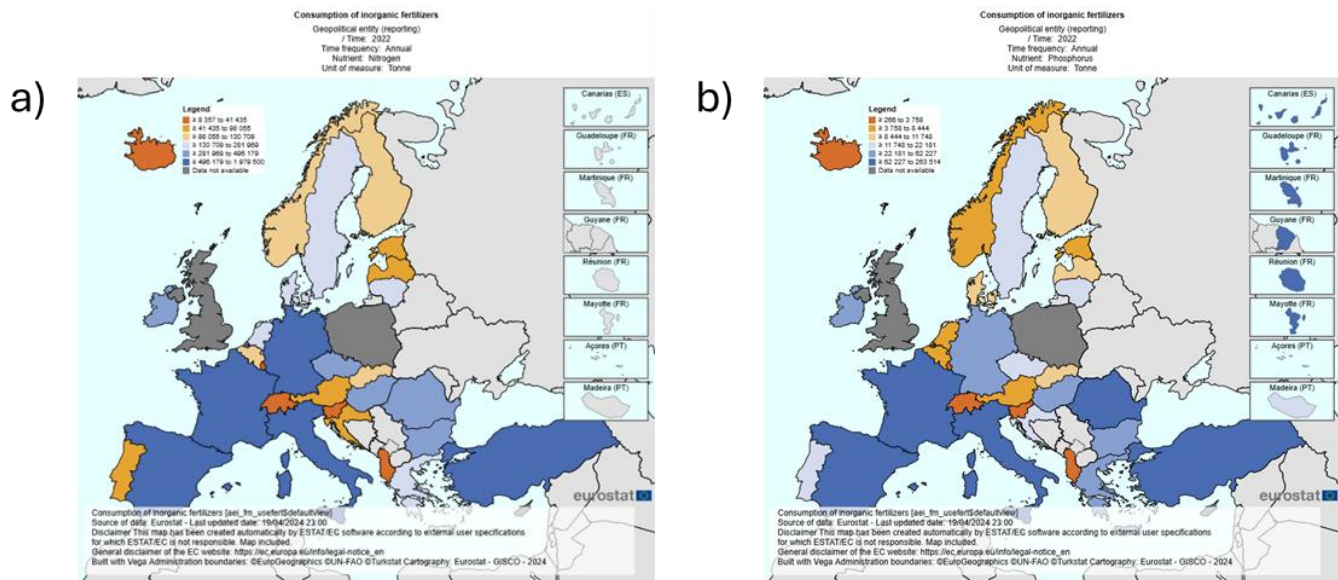


Figure 1. a) Consumption of mineral nitrogen in Europe in 2022; b) Consumption of mineral phosphorus in Europe in 2022. Maps from Eurostat database.

3.1.3. Fertilizer supply risks and sustainable alternatives

A substantial portion of the world's phosphate rock reserves (84%) are concentrated in Morocco, Western Sahara, China, Algeria, and Syria. Projections indicate that most nations, excluding Morocco, possess economically viable phosphate rock reserves with a lifespan of less than 100 years. Furthermore, major producers like the United States and China face even shorter reserves, estimated to last less than 60 years. **While new extraction technologies may extend resource availability, current trends indicate increasing reliance on imports.** The geopolitical landscape in these key producing countries is characterized by instability, creating a significant risk to the uninterrupted supply of phosphate rock for importing nations¹⁵.

Despite vast global reserves of potassium salts, exceeding 7 billion tons, a significant portion (approximately 65%) is concentrated in just three countries: Canada, Belarus, and Russia, highlighting their dominance in potassium salt deposits¹⁶. **This concentration increases supply chain vulnerabilities, particularly in the context of geopolitical conflicts and trade restrictions.**

Europe relies heavily on imports for phosphate and a significant portion of its potassium, despite some domestic production in Germany and a few other countries (United Kingdom, France, and Spain). **This import dependence makes European agriculture particularly**

¹⁴https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agri-environmental_indicator_-_mineral_fertiliser_consumption.

¹⁵ <https://doi.org/10.1016/j.wasman.2021.09.040>

¹⁶ <https://www.statista.com/statistics/604174/distribution-of-potash-reserves-worldwide-by-select-country/>

vulnerable to price fluctuations and supply disruptions. Nitrogen fertilizer production in Europe is heavily dependent on energy costs, with natural gas being the primary fuel source, contributing significantly to production costs, ranging from 50-70% of the total. As a result, the nitrogen fertilizer industry is highly sensitive to variations in natural gas prices¹⁷.

The European fertilizer industry has more than 120 production sites across Europe, where France (15.6%), Germany (14.0%), and Spain (10.7%) show the highest production share. However, the EU is directly dependent on raw material imports. In the summer of 2022, the increase in natural gas prices rendered ammonia production unprofitable, leading to a 70% shutdown of production capacity. The reduced production in the EU also means fewer EU exports to non-EU countries. In the first eight months of 2022, exports of nitrogen intermediates and fertilizers dropped by 9%, while imports increased by 19%.^{18,19}.

The 2014 European Commission report identified phosphate rock (one of the most important sources of phosphorus) as a critical raw material. To ensure long-term phosphorus security, it is crucial to prioritize the recovery of phosphorus from wastewater and other renewable sources, given the anticipated depletion of global phosphate reserves by the end of the century. **However, some studies suggest that improved recycling and extraction methods could extend phosphorus availability, emphasizing the need for more sustainable management**²⁰.

For nitrogen, its synthesis into fertilizer is energy-intensive, requiring approximately 60 MJ of energy per kilogram of nitrogen produced, despite the abundant presence of nitrogen compounds in the environment. Ammonia production processes utilize 1-2% of global electricity generation and 3-5% of the world's natural gas reserves. As a result, ammonia production is one of the most energy-demanding chemical processes worldwide²¹. The nitrogen industry faces scrutiny for its significant environmental impact, including high energy consumption and substantial greenhouse gas emissions during ammonia production. The synthesis of ammonia generates approximately 1.6 metric tons of CO₂ per metric ton of product. **Additionally, nitric acid production releases nitrous oxide (N₂O), a greenhouse gas with a global warming potential approximately 300 times higher than CO₂**²².

Fertilizer production depends on **non-renewable minerals** (Figure 2), often concentrated in a few countries, creating political risks. Excessive or inefficient use has exceeded planetary boundaries, overwhelming the ecosystem's capacity to recover. This reliance on synthetic fertilizers raises serious concerns about the long-term sustainability of current agricultural practices. The excessive application of synthetic fertilizers has detrimental environmental consequences, including water pollution, nutrient depletion, and soil degradation. Studies indicate that a significant portion of fertilizer nutrients, estimated between 30% and 50%, are lost to the environment through leaching into groundwater or volatilization into the atmosphere.²³.

¹⁷https://publications.jrc.ec.europa.eu/repository/bitstream/JRC70936/npk%20final%20report%20_%20publication%20be%20pdf.pdf

¹⁸ <https://doi.org/10.1186/s12302-024-00842-8>

¹⁹ <https://agridata.ec.europa.eu/extensions/DataPortal/fertiliser.html>

²⁰ https://ec.europa.eu/commission/presscorner/api/files/document/print/en/ip_14_599

²¹ <https://www.iea.org/reports/ammonia-technology-roadmap>

²² <https://www.reuters.com/sustainability/land-use-biodiversity/fertile-ground-why-reducing-emissions-fertiliser-production-use-is-ripe-2024-10-23/>

²³ <https://doi.org/10.1016/j.biortech.2019.122223>.

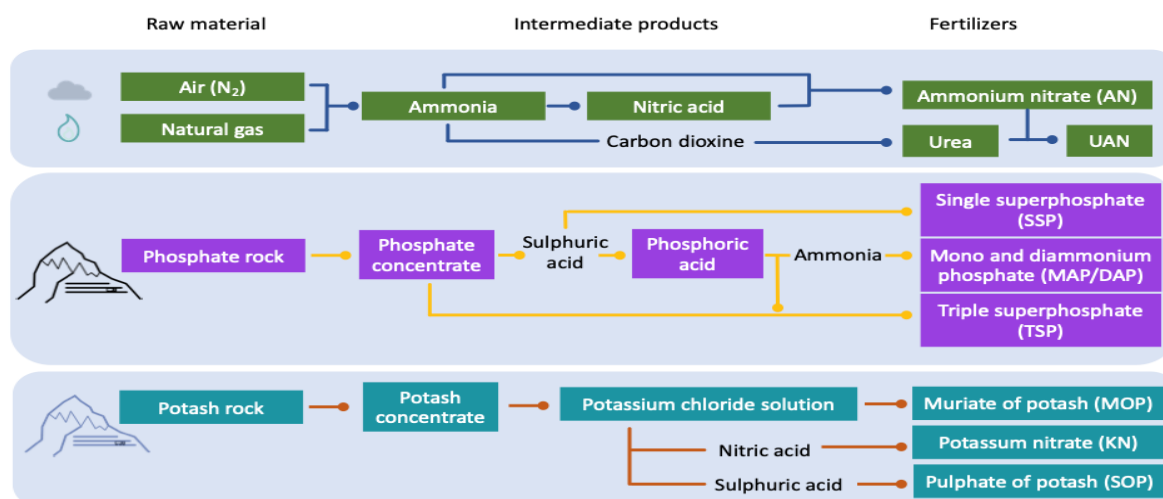


Figure 2. Main source of conventional fertilizers.

The fertilizer industry, particularly nitrogen and phosphorus producers, has been slow to adopt sustainable practices. Large-scale production relies heavily on non-renewable resources, making it difficult to integrate renewable alternatives due to economic barriers. However, recovering phosphorus and nitrogen from waste biomass offers a sustainable alternative, potentially reducing energy consumption and mitigating climate change ^{24,25}.

The updated EU Common Agricultural Policy (CAP) aims to reduce inorganic fertilizer use, aligning with the Farm to Fork strategy of the EU Green Deal by emphasizing the reduction of chemical fertilizer use by 20% by 2030, pushing the industry toward innovation in eco-friendly alternatives. However, usage remains unchanged. The Circular Economy Action Plan (CEAP) seeks to recover nutrients from waste for organic fertilizers, addressing waste management, nutrient loss, and reducing reliance on mineral extraction and intensive fertilizer production, ultimately lowering resource use and environmental impacts ²⁶.

3.2. Development of biofertilizers and biostimulants in sustainable agriculture

3.2.1. What are biofertilizers?

Growing global concern for sustainable waste management is driving the development of bio-based products that can be utilized as valuable nutrient sources in agriculture. Biofertilizers seek to lessen the European Union's reliance on imported mineral fertilizers by repurposing and recycling nutrient-dense by-products. The EU has set a goal of replacing as much as 30% of conventional fertilizers using bio-based alternatives and has created strategies, policies, and legislation to facilitate biofertilizer implementation, including Regulation (EU) 2019/1009 on EU fertilizing products.

As previously stated in Section 1 of this document, according to the EU, **biofertilizers fall under the category of organic fertilizers**, which are defined as fertilizing products composed of organic matter of exclusively biological origin, containing nutrients that improve soil

²⁴ <https://doi.org/10.1016/j.biortech.2019.122223>;

²⁵ <https://doi.org/10.1016/j.wasman.2021.09.040>

²⁶ <https://doi.org/10.1016/j.scitotenv.2023.164636>

fertility. These products originate from biological sources like animal by-products (e.g., livestock manure, dried blood, bone meal), plant residues, human waste (e.g., biowaste from households and commercial activities), and microorganisms. Unlike synthetic fertilizers, biofertilizers are exclusively composed of carbon and nutrients derived from living organisms. They do not include materials of geological origin, such as those derived from fossilized or mineral sources.²⁷ **Table 3** outlines the NPK composition of a variety of biological by-products, which can be utilized as feedstocks to produce biofertilizers. The elemental composition of the main biofertilizers in the EU is presented in Annex 7.4.

Table 3. NPK composition of some biological by-products.

By-product	N (%)	P (%)	K (%)	Notes
Cow manure	0.6	0.2	0.5	Rich in organic matter, slow release.
Pig manure	0.8	0.7	0.5	Higher in phosphorus than cow manure.
Poultry manure	1.5	1.3	0.8	High in nitrogen and phosphorus.
Sheep manure	0.9	0.5	0.8	Good balance of nutrients.
Horse manure	0.7	0.3	0.6	Lower in phosphorus, good for compost.
Compost	2.0	0.5	1.5	Varies based on materials used.
Bone meal	3.0	15.0	0.0	Excellent phosphorus source.
Fish meal	5.0	3.0	2.0	High in nitrogen and phosphorus.
Wood ash	0.0	1.0	5.0	Good potassium source, raises pH.
Green manure	2.0	0.5	2.0	Derived from cover crops.
Seaweed meal	1.0	0.5	2.0	It contains trace minerals.

The global biofertilizer market can be broadly categorized into two primary segments based on their source: organic residue-based biofertilizers and microorganism-based biofertilizers. Organic residue-based biofertilizers encompass materials such as green manure, crop residues, treated sewage sludge, and farmyard manure (an extensive list of agricultural and agro-processing wastes and residues can be found in Annex 7.3). In contrast, microorganism-based biofertilizers are composed of beneficial microorganisms, including bacteria, fungi, and algae²⁸. Biofertilizers, sourced from both plant and animal life, are categorized primarily by their processing level. Raw materials include slurry from anaerobic digestion and farmyard manure (FYM), while well-decomposed examples include compost and digestates.

Biochar does not fit under the EU definition of biofertilizers because it is derived from thermally processed biomass rather than being a direct biological byproduct. Instead, it falls under the category of **soil improvers** in the FPR. Soil improvers are products that enhance soil structure, water retention, or aeration rather than primarily supplying nutrients. Biochar is explicitly listed under Component Material Category (CMC) 3, which covers pyrolysis and gasification materials (see Section 4.1). To be classified under this category, biochar must come from approved feedstocks and be processed under controlled thermal conditions. While biochar itself is not a fertilizer, it can be combined with nutrient sources to form enhanced bio-based fertilizing products. **For example, biochar enriched with nitrogen, phosphorus, or potassium from organic waste could be marketed as an organic fertilizer or soil amendment.** The key distinction between biochar and biofertilizers lies in their function: biofertilizers contain nutrients derived from biological sources and directly improve soil

²⁷ <https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Fertiliser>.

²⁸ <https://doi.org/10.3389/fpls.2022.930340>

fertility, whereas biochar primarily enhances soil properties such as structure, microbial habitat, and water retention. Although biochar does not inherently provide significant amounts of plant nutrients, it can play a complementary role in sustainable agricultural practices when integrated with other fertilizing materials.

3.2.2. *What are biostimulants?*

As defined by the FPR, **a biostimulant is a fertilising product whose function is to stimulate plant nutrition processes independently of the product's nutrient content**, with the sole aim of improving one or more of the following characteristics of the plant or the plant rhizosphere: nutrient use efficiency, tolerance to abiotic stress, quality traits, availability of confined nutrients in the soil or rhizosphere. According to the same regulation, biostimulants are products that act in addition to fertilizers, with the aim of optimizing the efficiency of those fertilizers and reducing the nutrient application rates. Applied in small amounts, they can improve plant vigour and resilience to stresses such as drought and salinity. Biostimulants can complement conventional fertilization programs by strengthening plant's defences and improving nutrient uptake efficiency. Both biostimulants and biofertilizers offer sustainable alternatives to synthetic inputs in modern agriculture. Biostimulants are generally categorized based on their origin and composition into the following types ^{29,30}:

1. **Humic and fulvic acids:** These are organic compounds resulting from the decomposition of plant and animal material. They enhance nutrient uptake, improve soil structure, and stimulate microbial activity. Humic substances can increase root growth and enhance the availability of micronutrients.
2. **Protein hydrolysates and amino acids:** Derived from the hydrolysis of proteins, these biostimulants provide readily available nitrogen and stimulate plant metabolism. They can improve nutrient assimilation, enhance stress tolerance, and promote overall plant vigour.
3. **Seaweed and algal extracts:** Extracts from seaweed are rich in hormones, polysaccharides, and micronutrients. They promote root development, enhance stress resistance, and improve crop quality. Seaweed extracts are known to stimulate germination and increase yield.
4. **Chitosan and other biopolymers:** Chitosan, derived from chitin found in crustacean shells, acts as a biostimulant by enhancing plant defense mechanisms. It can improve resistance to pathogens and abiotic stresses, as well as promote growth.
5. **Inorganic compounds:** Certain non-essential chemical elements and inorganic salts can function as biostimulants. For example, silicon and selenium, though not essential for all plants, can enhance stress tolerance and improve growth.
6. **Beneficial fungi:** Non-pathogenic fungi, including arbuscular mycorrhizal fungi, form symbiotic relationships with plant roots, enhancing water and nutrient uptake, particularly phosphorus. They also improve soil structure and increase plant resilience to environmental stresses.
7. **Beneficial bacteria:** Plant growth-promoting bacteria (PGPB) and rhizobacteria colonize plant roots and stimulate growth by various mechanisms, including nitrogen fixation,

²⁹ <https://doi.org/10.3390/biology13030199>;

³⁰ <https://organicbiotech.com/what-is-the-difference-between-biostimulants-and-bio-fertilizers/>.

phytohormone production, and enhancing nutrient availability. They can also induce systemic resistance against pathogens.

These categories encompass the primary types of biostimulants used in agriculture to promote sustainable crop production. It's important to note that the effectiveness of biostimulants can vary based on factors such as plant species, environmental conditions, and application methods ^{31,32}.

3.2.3. *The role of biofertilizers and biostimulants in sustainable agriculture*

Given the rising expenses associated with chemical fertilizers and their adverse effects on the environment, the importance of biofertilizers and biostimulants in agricultural systems is steadily increasing. This trend reflects a growing awareness of the need for more economically and environmentally sound farming practices ³³.

It is important to recognize that **fertilizer production derived from waste, residues and by-products, supports the implementation of the Sustainable Development Goals (SDGs)**, which encourage sustainable development in social, economic, and environmental contexts. Substituting conventional raw materials with alternative sources can significantly reduce greenhouse gas emissions (GHG) associated with phosphate and potash mining, processing, and the production of nitrogen-based fertilizers. Moreover, organic or waste-derived fertilizers exhibit extended-release properties, minimizing nutrient losses and mitigating the risk of eutrophication. It should be considered that mineral and chemical fertilizers often experience significant nutrient losses due to leaching, volatilization, runoff, and denitrification, reducing their efficiency and contributing to environmental pollution. Studies indicate that 30-50% of nitrogen (N) fertilizers are lost through leaching and denitrification, leading to groundwater contamination and greenhouse gas emissions. Phosphorus (P) losses range between 5-25%, mainly through soil erosion and surface runoff, which contribute to eutrophication. Potassium (K) losses are relatively lower, typically around 10-20%, primarily through leaching in sandy soils ^{34,35,36}.

Improved fertilizer management strategies, including controlled-release fertilizers, soil improvers (e.g., biochar), biostimulants, and precision agriculture techniques, can help mitigate these losses and enhance nutrient-use efficiency.

In addition to supplying essential nutrients, biofertilizers enrich the soil with organic matter, promoting the restoration of degraded land³⁷. **Table 4** outlines the key benefits of incorporating biofertilizers into agricultural practices.

Table 4. Main advantages of using biofertilizers.

³¹https://orbi.uliege.be/bitstream/2268/187492/1/PduJardin2015_Plant-Biostimulants_InPress.pdf?utm_source=chatgpt.com"

³² <https://biostimulants.eu/wp-content/uploads/2024/11/Introduction-to-Biostimulants.pdf>

³³https://www.researchgate.net/profile/Narendra-Kumawat/publication/323185331_Role_of_Biofertilizers_in_Agriculture/links/5a851abc4585159152b81679/Rol e-of-Biofertilizers-in-Agriculture.pdf.

³⁴ [http://dx.doi.org/10.1016/S0065-2113\(05\)87003-8](http://dx.doi.org/10.1016/S0065-2113(05)87003-8)

³⁵ <https://link.springer.com/article/10.1023/A:1013335814593>

³⁶ <https://doi.org/10.1016/j.proeng.2014.09.029>

³⁷ <https://doi.org/10.1016/j.wasman.2021.09.040>.

Soil health improvement	Their application enhances soil aggregation and water retention, gradually improving its quality and fertility, and promoting sustainable soil health.
Long-term results	While immediate results may not be as pronounced, the long-term benefits of biofertilizers are substantial and impressive.
Atmospheric nitrogen fixation	Biofertilizers like Rhizobium and Azospirillum fix atmospheric nitrogen, making it readily available for plant uptake and reducing the need for synthetic nitrogen fertilizers.
Enhanced phosphorus availability	By solubilizing and releasing unavailable phosphorus, biofertilizers increase their content in the soil, benefiting plant growth.
Root Development	The release of growth-promoting hormones by biofertilizers stimulates root proliferation, leading to improved nutrient and water uptake by plants.
Nutrient conversion	Microorganisms within biofertilizers convert complex nutrients into simpler forms, making them easily accessible for plant utilization.
Nutrient supply and plant growth	These fertilizers contain beneficial microorganisms that facilitate the adequate supply of nutrients to host plants, ensuring their healthy development and growth.
Increased crop yields	The use of biofertilizers can significantly boost crop yields, typically ranging from 10 to 25% higher than conventional methods.
Disease suppression	Biofertilizers can also provide a degree of indirect protection against diseases by enhancing plant health metabolism and defense pathways, contributing to healthier plant growth ³⁸ .

Additionally, advancements in bio-based fertilizers, composting technologies, and microbial inoculants will enhance the efficiency and adoption of biofertilizers. With increasing environmental regulations and carbon reduction goals, biochar-enhanced biofertilizers and circular economy-based nutrient recycling will play a key role in the sector's future expansion³⁹.

Biostimulants will also play a key role in sustainable agriculture, as they can significantly influence plant performance at all stages of growth, from germination to harvest. The biostimulants market is expected to also experience rapid growth in the coming years, driven by increasing demand for sustainable agriculture, climate resilience, and improved crop productivity. According to Globe News Wire (2025)⁴⁰, the global biostimulants market is projected to grow at a CAGR of 11-13% from 2023 to 2030, reaching approximately \$6-8 billion by the end of the decade. Key factors fuelling this growth include rising organic farming practices, government regulations limiting chemical fertilizers, and advancements in microbial and seaweed-based biostimulants. Additionally, biostimulants play a crucial role in enhancing nutrient uptake, drought tolerance, and overall plant health, making them a critical tool for sustainable food production. Future trends indicate increasing investments in bio-

³⁸[https://www.researchgate.net/profile/Narendra-Kumawat/publication/323185331_Role_of_Biofertilizers_in_Agriculture/links/5a851abc4585159152b81679/Rol](https://www.researchgate.net/profile/Narendra-Kumawat/publication/323185331_Role_of_Biofertilizers_in_Agriculture/links/5a851abc4585159152b81679/Rol-e-of-Biofertilizers-in-Agriculture.pdf)

[e-of-Biofertilizers-in-Agriculture.pdf](https://www.researchgate.net/profile/Narendra-Kumawat/publication/323185331_Role_of_Biofertilizers_in_Agriculture/links/5a851abc4585159152b81679/Rol-e-of-Biofertilizers-in-Agriculture.pdf)

³⁹ <https://openknowledge.fao.org/handle/20.500.14283/cc0959en>

⁴⁰<https://www.globenewswire.com/news-release/2025/01/15/3009847/0/en/Biostimulants-Market-Size-to-Hit-8-7-Billion-by-2031-At-10-9-CAGR-The-Insight-Partners.html>

based and nano-formulated biostimulants to further optimize efficiency and environmental safety.

Research has shown that biofertilizers and biostimulants can act as elicitors, stimulating the plant's natural defences and promoting root growth, which results in greater crop vigour and productivity. Navarro-López et al. (2024) investigated the potential of microalgae as a biostimulant for watercress, mung bean, and cucumber seeds. The study examined the influence of various biomass processing techniques, including centrifugation, ultrasonication, and enzymatic hydrolysis, on biostimulant activity at different extract concentrations. Cultivating the algae in brewery wastewater, the researchers observed significant enhancements in seed germination and plant hormone activity. A notable increase in germination rate (up to 40%) was observed with untreated biomass at a concentration of 0.1 g/L. Optimal auxin activity (up to 60%) was achieved with a 0.5 g/L extract following cell disruption, enzymatic hydrolysis, and centrifugation. Cytokinin-like activity exhibited a peak (up to 187.5%) with a 2 g/L extract after enzymatic hydrolysis and centrifugation, excluding cell disruption. These findings suggest that microalgae, depending on the extraction method employed, may serve as a promising alternative for stimulating plant growth ⁴¹.

In a related study, the incorporation of a granular formulation containing dried microalgae as a soil amendment (at a rate of 2.3 g/kg) demonstrated a significant positive impact on plant growth. Treated plants exhibited a substantial increase in both fresh and dry weight, reaching up to 10 times the biomass of the control group. These findings suggest that the application of microalgae extracts can significantly enhance plant performance by promoting physiological processes that support optimal growth and soil fertility ⁴².

The global market for biofertilizers is expected to grow significantly in the coming years. Projections indicate that the biofertilizer market will reach USD 1.88 billion by the end of 2025 and according to market reports, this market is projected to grow at a compound annual growth rate (CAGR) of 11.5% between 2024 and 2029 (**Figure 3**). This growth is likely driven by the increasing regulatory scrutiny of chemical fertilizers, particularly in regions like Europe and Latin America, where biofertilizers have gained significant traction ⁴³, rising consumer preference for organic food, government incentives promoting sustainable farming, and concerns over chemical fertilizer runoff and soil degradation.

⁴¹ <https://doi.org/10.3390/molecules25030664>

⁴² <https://doi.org/10.3390/biology13030199>

⁴³ <https://doi.org/10.3390/microorganisms10061220>.

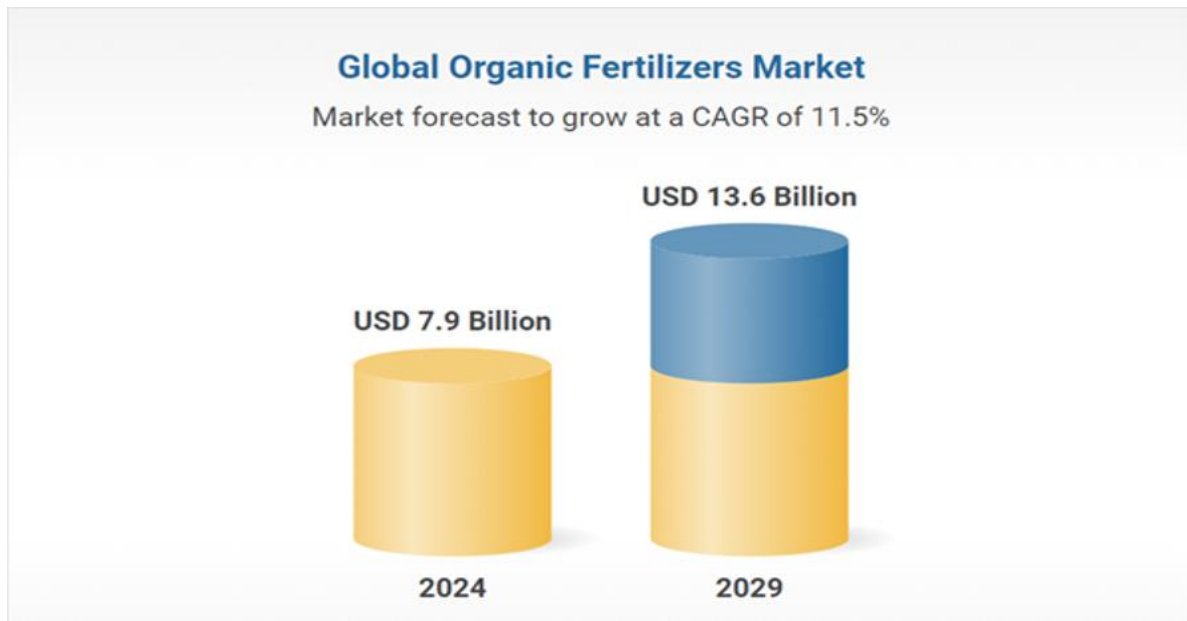


Figure 3. Global organic fertilizers (biofertilizers) market (Taken from ⁴⁴).

⁴⁴ www.researchandmarkets.com/reports/5944322

4. Barriers to innovation and pathways for advancing biostimulants and biofertilizers

4.1. European regulatory framework for biostimulants and biofertilizers

The production and use of biofertilizers and biostimulants are pivotal for transitioning towards sustainable agricultural practices in the European Union. These innovative inputs offer significant potential to reduce reliance on chemical fertilizers, enhance soil health, and mitigate environmental impacts such as nutrient runoff and pollution. However, the widespread adoption of biofertilizers and biostimulants faces several challenges. These include regulatory and legislative hurdles, gaps in technical expertise, market readiness, and limited integration within existing agricultural frameworks. This section explores the current regulatory and legislative landscape for biofertilizers and biostimulants in the EU, identifies barriers to innovation, and highlights opportunities to address these challenges through enhanced cooperation, research, and policy alignment.

The regulatory and legislative framework within the European Union plays a central role in shaping the production and use of biofertilizers and biostimulants. Key strategies and policies highlight the EU's commitment to sustainable agriculture, but the framework is still evolving to address the specific needs of these innovative products.

4.1.1. Key EU initiatives supporting biostimulants and biofertilizers in the Circular Economy and Sustainable Agriculture contexts

The European regulatory framework for biostimulants and biofertilizers plays a crucial role in shaping sustainable agricultural practices across the EU. This framework is guided by a series of action plans and initiatives that promote the adoption of bio-based products, with a strong emphasis on circular economy principles, organic farming, pollution reduction, and soil health restoration. Each initiative, such as the Circular Economy Action Plan, the Common Agricultural Policy (CAP), the Zero Pollution Action Plan, and the Soil Deal for Europe, addresses specific objectives related to environmental sustainability, resource efficiency, and agricultural resilience. These actions are underpinned by targeted regulations, financial incentives, and research initiatives, providing a robust foundation for fostering innovation and supporting the transition towards more sustainable fertilization practices. **Table 5** outlines key actions within these frameworks, highlighting their impact on the promotion of biofertilizers and biostimulants, along with the relevant regulations and support mechanisms.

Table 5. Key EU initiatives and regulatory actions supporting biostimulants and biofertilizers in sustainable agriculture.

Circular Economy Action Plan	Organic Farming and the CAP	Towards Zero Pollution	Soil Deal for Europe
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The EU's Circular Economy Action Plan⁴⁵ prioritizes the recycling of organic waste and nutrient-rich side-streams. Key elements include: <u>Promoting nutrient recycling:</u> Encouraging the transformation of organic residues, such as food waste and agricultural by-products, into biofertilizers. <u>Aligning with waste management goals:</u> Supporting the production of biofertilizers as part of sustainable waste management strategies, ensuring efficient use of resources, and reducing landfill dependence.	The Common Agricultural Policy (CAP) supports the expansion of organic farming through funding and subsidies. This aligns with the increasing demand for biofertilizers, which are crucial for maintaining soil fertility in organic systems. Furthermore, CAP reforms emphasize climate and environmental objectives, which directly favor the adoption of biofertilizers and biostimulants. Financial incentives encourage farmers to transition from conventional to organic or sustainable practices.	The EU's Zero Pollution Action Plan focuses on reducing environmental contamination from agricultural activities. Biofertilizers and biostimulants offer: Reduction in nutrient runoff: By improving nutrient use efficiency, they minimize leaching into water bodies. Air quality improvements: Decreasing reliance on synthetic fertilizers can reduce ammonia emissions and other pollutants.	As part of the EU Mission on Soil Health and Food, this initiative aims to establish 100 living labs and lighthouses to improve soil health by 2030. Biofertilizers are key tools for restoring soil fertility by enhancing microbial activity and organic matter content. Biofertilizers also improve agricultural resilience by supporting sustainable land management practices
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4.1.2. The Farm to Fork Strategy

The Farm to Fork Strategy, a core component of the European Green Deal, outlines ambitious goals for sustainable food production systems. The 2030 Targets for sustainable food production are depicted in **Figure 4**.



Figure 4. Farm to Fork Strategy overall goals (Taken from ⁴⁶).

⁴⁵https://eur-lex.europa.eu/resource.html?uri=cellar:9903b325-6388-11ea-b735-01aa75ed71a1.0017.02/DOC_1&format=PDF

⁴⁶ <https://errin.eu/news/farm-fork-strategy>

As illustrated in **Figure 4**, which emphasizes climate footprint, global transitions, new opportunities, and resilience, the Strategy's targets reflect a clear push toward more environmentally friendly agricultural practice. The reduction of chemical fertilizer use, for instance, aligns with the strategy's goal of reducing the environmental footprint of farming. Specifically, the target is to reduce the overall use and risk of chemical pesticides by 50%, alongside a significant reduction in the use of more hazardous pesticides. Biofertilizers, which offer a sustainable alternative to chemical fertilizers, directly contribute to this reduction by improving soil health and nutrient availability without the adverse environmental effects associated with synthetic inputs.

Similarly, the target to reduce nutrient losses by at least 50%, while ensuring no deterioration in soil fertility, calls for innovative solutions that optimize nutrient use efficiency. Biofertilizers and biostimulants can enhance nutrient cycling and improve soil fertility, contributing to the reduction of fertilizer use by at least 20%, as required by the strategy. Additionally, the aim to boost organic farming by targeting 25% of EU agricultural land under organic practices by 2030 highlights the importance of biological inputs in organic systems. Biofertilizers and biostimulants are essential components in these systems, providing a sustainable source of nutrients and promoting soil health, thus supporting the transition to organic farming ⁴⁷.

The limitations on the use of chemical fertilizers imposed by the European Union have evidently generated debate. Fertilizers Europe states that *"Food chain actors all agree with the main principles set out in the Farm to Fork strategy and are fully aware that constant and substantial improvement must be made to ensure a more sustainable approach for our food systems. Nonetheless, several recently published studies on the Farm to Fork strategy indicate that the current targets, if implemented as proposed, will come at a significant cost for EU farmers and the viability of the entire European agribusiness culture."*⁴⁸

At the same time, the CISL - Cambridge Institute for Sustainability Leadership, interested in answering the same question, namely *"will there be an economic crisis for the European food system because of Farm2Fork?"* notes that focusing on the economic consequences that will be determined in the fallout of the chemical fertilizer industry, the damage would be particularly insignificant, compared to an increase in the price of chemical fertilizers of only 7%.

4.1.3. Rise in organic food sales fuel demand for organic fertilizers market

The growing demand for organic food is closely linked to the increased need for biofertilizers and biostimulants, a trend that aligns with the European Union's Farm to Fork Strategy. This strategy aims to promote sustainable agricultural practices, including organic farming, which excludes synthetic chemicals and pesticides. Organic farming relies heavily on biofertilizers to maintain soil fertility and provide essential nutrients for crops, helping to reduce the environmental footprint of food production. As consumer awareness about health and environmental concerns increases, demand for organic food products has surged. This

⁴⁷ https://ec.europa.eu/info/food-farming-fisheries/sustainability/farm-fork-strategy_en

⁴⁸ <https://www.fertilizerseurope.com/wp-content/uploads/2021/10/FARM-TO-FORK-%E2%80%93-IT-IS-TIME-TO-LISTEN-TO-WHAT-THE-DATA-SAYS-.pdf>

growing preference for organic produce drives farmers to adopt organic farming methods, further boosting the demand for organic fertilizers.

In line with the Farm to Fork Strategy's objective of increasing organic farming across the EU, organic retail sales in Europe reached USD 64.42 billion in 2023 ⁴⁹. This growth reflects the rising consumer interest in food with reduced chemical residues and a lower environmental impact. One of the most significant contributors to this demand is the cereals and grains sector, which remains the second-largest segment within the organic fertilizers market. As staple food crops such as wheat, rice, corn, barley, and oats continue to see high demand globally, governments are also incentivizing organic farming through certification schemes and regulatory support. These schemes ensure that organic farming practices, including the use of organic fertilizers, meet strict standards, thus encouraging farmers to invest in fertilizers that maintain soil health and crop vitality ⁵⁰.

This dynamic interplay between consumer demand, regulatory support, and organic farming practices illustrates the importance of sustainable fertilization strategies in achieving the EU's Farm to Fork targets for a more sustainable and resilient food system.

4.1.4. EU Fertilizing Products Regulation (FPR) 1009/2019

This regulation, enforced since July 2022, represents a significant step in opening the Single Market to organic and waste-based fertilizers. It provides harmonized standards, namely, a clear set of safety, quality, and labelling requirements for fertilizers, enabling innovative products like biofertilizers to compete with traditional chemical fertilizers.

EU fertilizing products must comply with the requirements of at least one product function category (PFC) in terms of safety, quality, and labelling (**Figure 5**).

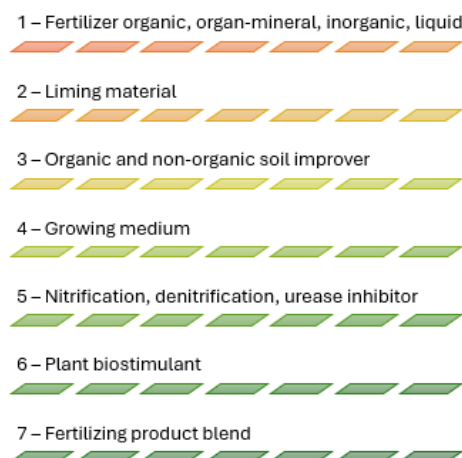


Figure 5. List of PFC in 1009/2019 Regulation.

Furthermore, all component materials must be covered by a component material category (CMC) and comply with its relevant requirements (REACH, end-of-waste criteria, animal by-product regulation). **Figure 6** shows the CMC List for Reg. 1009/2019.

⁴⁹ <https://www.fibl.org/fileadmin/documents/shop/1254-organic-world-2023.pdf>

⁵⁰ https://ec.europa.eu/info/food-farming-fisheries/sustainability/farm-fork-strategy_en

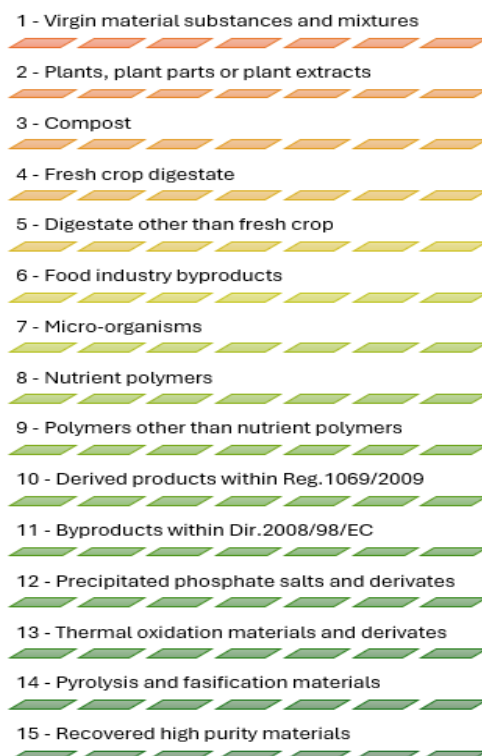


Figure 6. List of CMC in 1009/2019 Regulation.

Finally, by broadening the definition of fertilizers, the regulation facilitates cross-border trade within the EU, encouraging innovation and scaling of biofertilizer production. More products are covered by the EU Fertilizing regulation, and it opens the door to new technologies for producing biofertilizers.

4.1.5. Research and Innovation Support

The EU has invested in numerous research initiatives to advance biofertilizer technologies, by different calls as Horizon Europe, LIFE Programme, European Innovation Council (EIC) Accelerator, Circular Bio-based Europe Joint Undertaking (CBE-JU). **Table 6** shows the most relevant calls for research related to biofertilizers and biostimulants, focusing on sustainability, bio-based alternatives, and agriculture.

Table 6. Relevant European funding programs and open calls for 2025 focused on biofertilizers, biostimulants, and sustainable agriculture research.

Funding program	Relevant call topics	Open date	Deadline
Horizon Europe	Bio-based products, sustainable agriculture, and biostimulants development.	April 2025	September 2025
CBE-JU	Bio-based fertilizers, circular agriculture, and nutrient recovery.	April 2025	September 2025
LIFE	Climate action, resource efficiency, and sustainable agriculture.	April 2025	TBD

Eurostars	R&D projects for SMEs, including biostimulants and fertilizers.	January 2025	March 2025
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Below there's a list of projects focused on optimizing soil health by improving agroecological practices and by biofertilizers:

- **NUTRIMAN:** Nutriman is a Nitrogen and Phosphorus thematic network compiling knowledge of "ready-for-practice" recovered bio-bases fertiliser technologies, products, applications and practices for the interest and benefit of farmers
- **B-First:** Integrating biofertilizers into conventional farming systems. The project integrates the valorization of bio-waste in agriculture by creating new circular and bio-based value chains.
- **LEX4BIO:** Providing recommendations for biofertilizer use across different regions. This project works to collect and process regional nutrient stock, flow, surplus, and deficiency data, and reviews the assessing of the required technological solutions.
- **STRATUS:** STRATUS aims at connecting advisors across Europe to support farmers bringing the knowledge on integrated fertilization management into practice, to achieve the ambition of the Farm to Fork and Biodiversity Strategies, thus reducing nutrient losses to the environment while maintaining soil fertility.

Other projects focused on developing new products, tailored for diverse agroecological settings, are detailed below:

- **RUSTICA:** Designing value chains for nutrient recycling. The project provides technical solutions to convert organic residues from the fruit and vegetable sector into novel bio-based fertilizers, addressing the needs of organic agriculture.
- **FERTIMANURE:** Promoting farmer-driven manure management solutions. The project focuses on how to improve the agronomic use of recycled nutrients from livestock manure to reconnect nutrient flows between crop production and the rearing of livestock.
- **SEA2LAND:** Exploring nutrient recovery from marine and aquaculture by-products. This project promotes the production of large-scale fertilizers from raw materials coming from fisheries waste.

Many projects also focus on the capture and carbon footprint of fertilizers, including bio-sourced ones, to study the impact of fertilization on greenhouse gases, and the potential of biofertilizers to limit them, or to study the carbon storage in soils, to mitigate climate change and enhance soil quality.

4.2. Barriers to adoption and challenges facing biostimulants and biofertilizers

The adoption of biostimulants and biofertilizers as sustainable agricultural inputs is hindered by multiple factors. These challenges span economic, technical, regulatory, and environmental domains, creating a complex landscape that requires integrated solutions. **Table 7** shows an in-depth analysis contextualized with findings from recent studies and the regulatory landscape.

Table 7. Barriers and challenges to adopt biostimulants and biofertilizers in the European context.

Economic Barriers	
Profitability Concerns	For biostimulants and biofertilizers to be adopted widely, they must demonstrate clear economic benefits. Yield improvements must translate into higher revenues that exceed the cost of the products. Example: Schütz et al. (2018) reported a 16% average yield increase with microbial biostimulants, but this improvement may not always justify costs, particularly for low-margin crops.
High Initial Costs	Many biostimulants and biofertilizers have a premium price compared to conventional fertilizers, discouraging small-scale farmers with limited financial resources.
Market Perception	Farmers often perceive biostimulants and biofertilizers as riskier investments compared to well-established agrochemicals.
Technical Challenges	
Efficacy Variability	The performance of biostimulants and biofertilizers is highly context-dependent, influenced by factors such as soil properties, crop type, and environmental conditions.
Microbial Products	AMF (arbuscular mycorrhizal fungi) thrives in soils with low organic carbon and low phosphorus (10-25 kg P/ha). Nitrogen-fixing microorganisms prefer higher soil organic carbon and phosphorus levels (>45 kg P/ha). Phosphorus solubilizers are most effective in intermediate phosphorus levels (25-35 kg P/ha).
Non-Microbial Biostimulants	Yield increases vary significantly based on the type of biostimulant, with plant extracts (e.g., moringa) outperforming others like phosphites (Li et al., 2022).
Inconsistent Outcomes	Yield improvements are often not uniform across different crops, with legumes and vegetables showing higher responses compared to cereals or root crops.
Climatic Sensitivity	The efficacy of these products is significantly affected by climate and soil conditions: Greater effectiveness in arid, saline, and low-organic-matter soils. Weaker effects in regions with high organic matter content (>5%) or in temperate climates like northern Europe.
Regulatory and Policy Barriers	
Lengthy and Complex Approval Processes	While the EU Fertilizing Products Regulation (2019/1009) provides a framework for harmonization, the approval process remains slow and cumbersome, particularly for innovative products.
Inadequate Testing Standards	A lack of standardized protocols for efficacy evaluation and field trials delays market entry and creates uncertainty for manufacturers.
Global Regulatory Disparities	Variability in regulations across regions (e.g., EU vs. North America) complicates international trade and adoption.
Intellectual Property Concerns	Limited protection for microbial strains and formulations can discourage investment in research and development.
Ban on the use of certain biomass	In the new fertilizing regulation, sewage sludge and industrial sludge are not accepted as component material categories. Thus, all business cases developed by commercializing biofertilizers produced from sludge would not be accepted in the EU market.
Limited microbial families authorized under 2019/1009 Regulation	The EU Fertilizing Products Regulation (2019/1009) restricts the approval of microorganisms for biofertilizer products to four families: <i>Azotobacter</i> spp., <i>Mycorrhizal</i> fungi, <i>Rhizobium</i> spp., and <i>Azospirillum</i> spp., limiting the diversity of microbial-based products available in the market.

Environmental and Agronomic Barriers	
Soil Health Dependency	The performance of biostimulants and biofertilizers is closely tied to soil properties, which vary widely between regions. Tailor-made solutions are needed. High soil fertility and organic matter reduce the benefits of microbial inoculants. Low soil biodiversity may hinder the establishment of introduced microorganisms.
Unintended Ecosystem Effects	Overapplication or misuse of microbial biostimulants could disrupt native microbial communities, potentially leading to ecological imbalances.
Awareness and Knowledge Barriers	
Limited Farmer Awareness	Many farmers are unaware of the benefits and correct application methods for these products.
Insufficient Training Programs	A lack of educational initiatives and technical support limits the ability of farmers to integrate biostimulants and biofertilizers into their practices effectively.
Skepticism About Efficacy	Inconsistent results in field trials fuel skepticism among potential users, slowing adoption rates. Also, the non-visual aspect of the results of a biostimulants application in a plot can be very limiting for a farmer used to products (fertilizer, phytosanitary) with a very pronounced visual effect.

The scaling up of biofertilizer production in the EU also faces several challenges that span regulatory, technological, economic, and social domains. Regulatory frameworks remain fragmented, creating uncertainty for potential investors and manufacturers. Complex waste management policies and inconsistent market access further impede development. Technological barriers persist, with ongoing needs to improve production processes, enhance product quality, and ensure competitive performance compared to conventional fertilizers. Stakeholder engagement and collaboration across the value chain are crucial but often difficult to achieve, requiring sophisticated coordination mechanisms. Moreover, public acceptance and awareness about biofertilizers remain limited, necessitating comprehensive educational and demonstration initiatives. Environmental performance considerations add another layer of complexity, demanding continuous innovation to ensure sustainable and efficient bio-based industrial systems.

These interconnected barriers require a holistic, multi-stakeholder approach involving policymakers, researchers, industry players, and agricultural communities to successfully transform biofertilizer production into a scalable, circular bioeconomy solution. Specific challenges include:

- **Quality Control:** Ensuring consistency in the quality and efficacy of biofertilizers and biostimulants is critical. Microbial-based products, however, are highly sensitive to environmental conditions during storage and transport (Kahle, 2023).
- **Regulatory Compliance:** The registration of biological products within the EU entails diverse and often costly regulatory requirements, which can delay market entry or restrain some innovative company to invest in this area.
- **Cost and Infrastructure:** High production costs and limited infrastructure can hinder scalability, making it challenging for these products to compete with chemical fertilizers.

- Market Acceptance: The dominance of chemical fertilizers in agricultural markets can slow the adoption of biofertilizers. Raising awareness among farmers and encouraging the inclusion of biofertilizers and biostimulants in fertilization strategies are vital steps.
- Environmental Concerns: While biofertilizers derived from biowaste and biomass contribute to nutrient recycling and circular economy goals, risks of contamination – such as heavy metals – must be managed to ensure safe application.
- Mapping residues, by-products, and organic waste suitable for biofertilizer production. There is a general lack of information regarding the types, quantities, and locations of residual biomass available for this purpose. In some EU countries, efforts have been made to develop a GIS-based database, but this has proven challenging due to the absence of EU regulations and the reluctance of factories and farmers to share data on their residues.

4.2.1. Lack of residue mapping systems: a challenge for biostimulant and biofertilizer adoption

Agricultural and agro-processing regions in the EU lack a comprehensive system for mapping residues, by-products, and organic waste. This long-standing gap has hindered the efficient utilization of these materials for purposes such as biofertilizer production and is increasingly contributing to environmental challenges ⁵¹.

For example, in the Emilia-Romagna region, agriculture and agro-processing are the primary economic activities. The region features a mix of small farms, mostly organized into cooperatives, as well as large farms and major agro-processing industries such as Barilla, Orogel, Cremonini Group, the Parmigiano Reggiano Consortium, the Parma Ham Consortium, and Apo Fruits. However, data collection and interviews reveal a lack of an efficient system for farmers to dispose of or repurpose agricultural residues, such as pruning waste. For farmers managing 20, 30, or 50 hectares, transporting residues to a processing facility – even one located nearby – is often not practical or economically viable. As a result, the Emilia-Romagna region grants farmers special permits each year to burn residues near their fields, leading to smoke and air pollution that affects surrounding areas ^{52,53}.

Efforts to address this issue have been made but remain incomplete. For instance, Clust-ER Agrifood initiated the GEOLEFTOVER project, which aimed to develop a residue management system. However, due to various challenges and budget constraints, the project was never completed ⁵⁴. Similarly, the BiorefER project, led by the University of Bologna, developed a database for residues and organic waste, listing potential materials from different agricultural and agro-processing activities (BiorefER Database). However, it did not include key chemical and physical properties of each material or specify their locations, limiting its practical utility ⁵⁵.

In contrast, Spain has made progress in this area. Within the framework of a Bio-Based Industries (BBI) project, a Spanish consortium coordinated by the Basque research center CEIT

⁵¹ <https://doi.org/10.1016/J.SCITOTENV.2019.05.219>.

⁵² https://base.socioeco.org/docs/emilia_romagna_by_david_thompson_110604.pdf

⁵³ <https://www.investinemiliaromagna.eu/sectors/food-valley>

⁵⁴ <https://agrifood.clust-er.it/en/>

⁵⁵ <https://site.unibo.it/environmental-management-research-group/en/pagina-esempio/central-europe/the-biorefining-opportunities-in-emilia-romagna.pdf/@download/file/The%20Biorefining%20Opportunities%20in%20Emilia-Romagna.pdf>

developed an innovative decision-support tool. This tool uses mathematical models to predict agri-food residual streams and determine the best routes for their valorization. The project, completed in 2023, represents a significant step forward in addressing residue management challenges ⁵⁶.

4.3. Key elements for successful implementation of biofertilizers and biostimulants in the EU

The effective adoption of biofertilizers and biostimulants in the European Union is essential for advancing sustainable agriculture, improving soil health, and reducing dependency on synthetic inputs. However, integrating these bio-based alternatives into agricultural practices faces significant challenges, including technical, economic, regulatory, and social barriers. Addressing these obstacles requires targeted solutions and strategic approaches that prioritize quality assurance, compatibility with specific agricultural conditions, and enhanced farmer knowledge.

Key problems and solutions related to the adoption of biofertilizers and biostimulants emphasize the need to improve product efficiency, ensure consistent quality, and promote greater awareness among end-users. Additionally, implementation barriers associated with various waste categories, such as biological waste, sewage sludge, wastewater, and biomass ash, must be tackled through tailored recommendations. Circular economy principles play a vital role in unlocking the value of bio-based fertilizers, promoting waste recovery, and fostering innovative agricultural practices across Europe. Strategic approaches to overcome adoption barriers for biofertilizers are summarized in **Table 8**, including recommendations across waste categories (biological waste, food waste, wastewater, etc.).

Table 8. Challenges and recommendations for the adoption of biofertilizers (*Adapted from* ⁵⁷).

Category	Implementation challenges	Recommendations
Digestate	Digestate often fails to meet EU standards without treatment	Apply post-treatments and/or product formulations to meet biofertilizer standards
Wastewater	Inadequate policy incentives for nutrient recovery	Adopt circular economy indicators to encourage nutrient-rich waste stream recycling
Biomass ash	Limited coverage under New Fertilizer Product Regulation (FPR)	Enhance Waste Framework Directive (WFD) and FPR to support the recycling of ash-based materials
Food waste	Cultural, technological, and economic barriers	Tailor recovery solutions to local conditions for effective processing and nutrient extraction
Fertilizers from water/wastewater	Low end-user experience and social acceptance	Conduct dissemination activities, and build social trust through awareness and education
Organic waste	Issues of odor, nutrient consistency, and ease of application	Enhance processing to reduce odor and improve nutrient consistency; provide technical guidance

⁵⁶ <https://www.model2bio.eu/the-project>

⁵⁷ <https://doi.org/10.1016/j.scca.2023.100033>

Table 9. Problems and solutions for the adoption and use of biostimulants. outlines the key challenges associated with the adoption and use of biostimulants, along with corresponding solutions to address these issues.

Table 9. Problems and solutions for the adoption and use of biostimulants.

Problem	Solution
Inefficient products	Selection of compatible strains to specific climatic conditions, crops, and soil Good characterisation of product's mode of action and potential environmental interactions
Low-quality products (lack of viable cells)	Quality assurance and research by the producers
Mutation of cells during fermentation	
High investments costs	Use of alternative media such as industrial by-products
Poor understanding of the role of biostimulants and knowledge of application and proper storage	Increase farmers' awareness by communication and direct consultation, extension and meeting, etc

5. Roadmap for sustainability and innovation

5.1. Innovation in biofertilizers and biostimulants

The EU market for biostimulants and biofertilizers is rapidly expanding, driven by demand for sustainable agriculture practices and supported by regulatory initiatives like the EU Green Deal and Farm to Fork strategy. Several new biostimulants and biofertilizers products and technologies have been introduced in the EU market recently. Examples of these products are Agtronutrition's innovative biofertilizers Amylys and Optys, and its biostimulant range including Acrecio and Alcygol⁵⁸. In Italy, Italtollina has introduced the innovative biofertilizer Guanito and the biostimulant Atriva⁵⁹. From France, Elephant Vert offers the innovative Fertinova range as a biofertilizer, along with biostimulants such as Econitrate and Novastim⁶⁰. In Portugal, Rovensa Next's biofertilizer Wiibio and biostimulant Azzofiz stand out for their unique contributions to the sector⁶¹. A more detailed list of companies commercializing biofertilizers in some European countries is given in Annex 7.2.

The growing interest in utilizing biomass residues to produce biofertilizers and biostimulants has led to the development of innovative technologies for converting various types of raw materials. Microalgae-based biofertilizers are becoming increasingly significant as an eco-friendly solution that combines waste treatment with the production of biofertilizers. One notable initiative in this area is the Horizon 2020 SABANA project, which aims to develop a sustainable microalgae-based biorefinery for producing biostimulants and biofertilizers. The project emphasizes a Zero-Waste strategy by utilizing nutrients from municipal wastewater. Additionally, the CARTIF foundation in Spain, through the WALNUT project, extracts nitrogen and phosphorus from wastewater to create microalgae-based biofertilizers⁶².

Struvite-based biofertilizers are also gaining popularity in addressing the challenges of accessing phosphate. Struvite refers to the process of recovering phosphorus from sources such as animal manure, digestate, and wastewater. The resulting products are effective, water-soluble fertilizers that provide higher levels of phosphorus and can be combined with other nutrients to create an NPK (nitrogen, phosphorus, potassium) formulation. Various technologies have been developed for this purpose across different projects in Europe, including the NuReSys, PHORWater, and REVAWaste processes⁶³.

Biochar production from a variety of feedstocks has shown significant potential as a soil conditioner. Specifically, sludge biochar is generated through the pyrolysis of sewage sludge, enhancing soil fertility. In addition to its nutrient content, a technology developed in Denmark has demonstrated that sludge biochar can effectively remove pharmaceuticals from wastewater. The European Biochar Industry (EBI) is actively working to have sewage sludge biochar included in the EU Fertilizing Products Regulation (FPR)⁶⁴. Several technologies are

⁵⁸ <https://www.agronutrition.com/en/>

⁵⁹ <https://www.italpollina.com/>

⁶⁰ <https://www.elephant-vert.com/en/>

⁶¹ <https://www.rovensa.com/>

⁶² <https://walnutproject.eu/pilot/industrial/>

⁶³ https://nutriman.net/farmer-platorm/product/id_250

⁶⁴ <https://swedenwaterresearch.se/en/company-news/ebi-is-working-to-include-sludge-biochar-in-the-fpr/>

available for producing sludge biochar with heavy metals such as cadmium and arsenic are largely removed ⁶⁵.

Another concept for improving soil fertility through the activation of soil-inhabiting microorganisms is “Rhizosphere engineering.” This can be achieved by tailoring the application of certain inocula, crop genotypes, and selected farming practices to stimulate beneficial rhizosphere microorganisms ⁶⁶. Moreover, gel-based biostimulants are an emerging trend in industry. These formulations offer several advantages, including improved adherence to plant surfaces, controlled release of active ingredients, enhanced stability and shelf-life, and easier application compared to liquid formulations. These gels can incorporate a variety of active ingredients like amino acids, seaweed extracts, or beneficial microorganisms.

Combined application of biostimulants with chemicals, e.g., herbicides, reduce damage to crops and result in yield increase. One such example is Syngenta’s biostimulant MEGAFOL (an extract from brown algae), which reduced stress and herbicide damage in sugar beet. Such combined practice of biostimulants and herbicides reduced chemical input and boosted the growth of several crops in field trials in Greece ⁶⁷.

In the EU, several projects have been conducted to assess the potential of using biomass residues—such as microalgae, struvite, sludge from different sources, and animal manure—as biofertilizers, in line with the principles of the circular economy (**Table 10**).

⁶⁵ <https://www.phosphorusplatform.eu/images/scope/ScopeNewsletter144.pdf>.

⁶⁶ <http://dx.doi.org/10.1016/j.rhisph.2017.04.012>

⁶⁷ <http://dx.doi.org/10.3389/fpls.2024.1436310>

Table 10. Current trends and technologies for the production and application of biofertilizers and biostimulants.

Technology	Description/Category	Country	Company/Project	Links
Slurry manure treatment				
N ₂ plasma technology	Adding air and electricity into the liquid manure/ digestate, the system creates a nitrogen-enriched organic (N ₂ fixation through plasma reactors)	Norway	N2 applied SmartNitroFarm EU- funded project	[1]
Slurry manure acidification	Manure treatment with sulfuric acid	Baltic countries Sweden	Baltic project (Björs, n.d.)	[2]
Membrane technology	Membrane filtration, membrane contactor and reverse osmosis to recover nutrients (macro- and micro-) and water from the liquid fraction of pig slurry	Spain	FERTIMANURE (on-farm experimental pilot in Spain)	[3]
Poultry litter (manure)				
Poul-AR®	Production of ammonia sulphate/nitrate from poultry manure	Spain	Ahidra NUTRIMAN platform	[4]
AMFER®	Stripping technology enables the production of ammonium nitrate/ ammonium sulphate	Netherlands	Colsen	[5]
PK fertilizer	Derived from hydrated ash from poultry manure	Netherlands	BMCMoerdijkBV	[6]
Biochar				
FERTIPLUS	Assessed the added value of combining biochar with compost during storage.	Belgium	Research project by ILVO	[7]
Terra-Preta biochar	A product produced by the "3R" Recycle-Recover-Reuse high-temperature pyrolysis technology.	Hungary	Technology produced as part of the NUTRIMAN project.	[8]
Animal Bone Char (ABC) Bio-Phosphate	Bio-Phosphate products recovered from food-grade animal bone by the "3R zero emission pyrolysis" process	Hungary	3R-BioPhosphateLtd.	[9]
Microalgae				
Microalgal slow-release fertilization	Production of Microalgal Slow-Release Fertilizer by Valorising Liquid Agricultural Digestate	Consortium of European countries	Project Interreg Baltic Sea Region	[10]
ALGAENAUTS	The project uses seawater and wastewater as nutrient sources for cultivating microalgae strains with proven biopesticide and biostimulant activity.	Spain	Biorizon Biotech - This innovation project, funded under the European Maritime, Fisheries and Aquaculture Fund (EMFAF)	[11]

Water2Return (W2R)	Resource-oriented solutions for wastewater treatment based on a circular economy approach	Consortium of 8 European countries	Project Innovation Action co-funded by the European Commission under its Horizon 2020 programme	[12]
Struvite				
Biostru®	Struvite from digested sludge	Belgium	NuReSys	[13]
PHORWater	Develop an innovative and cost-effective method for phosphate recovery from wastewater treatment plants.	Spain	European LIFE+ project for the recovery and reuse of phosphorus from wastewater	[14]
REVAWASTE	Struvite from digestate and pig manure treated with Magnesium chloride and NaOH	Spain	Fundación Cartif	[15]
NPHarvest	This technology uses wastewater from biogas plants, wastewater treatment plants, or farms to produce P and N	Finland	The NPHarvest company has developed a nutrient catcher that is installed in wastewater management systems to recover nitrogen and phosphorus from wastewater	[16]
Ash2Phos	A circular solution for recovering phosphorus and other resources from sewage sludge ash	Sweden/ Germany	This is a technology provided by EasyMining	[17]
B-Ferst	Valorization of bio-waste in agriculture	Spain, Portugal, Italy and Poland	Project. Bio-based industries consortium	[18]
Digestate				
BENAS process	Ammonium sulphate from co-digestion of corn silage, chicken manure, and other biowaste	Germany	GNS Gesellschaft für Nachhaltige Stoffnutzung mbH	[19]
NOMAD	NOMAD (Novel Organic recovery using Mobile Advanced technology) is primarily designed to reduce volume, recover nutrients in compact formats, and remove harmful pollutants such as antibiotics.	Several countries are involved, including Italy, China, and UK.	Horizon 2020 project	[20]
Compost				
CORE	CORE “COMPOSTING IN RURAL ENVIRONMENTS” is an initiative that promotes composting and anaerobic digestion in rural areas across Europe.	Several countries are involved.	Project funded by Interreg Europe	[21]
Extracts from biomass				

abonoCARE®	Provide technologies for conditioning, conversion, fractionation and mixing for producing plant nutrients from organic waste.	Consortium of 11 industrial partners and 6 research partners	n/a	[22]
Acadian®	Seaweed extract from the algae <i>Ascophyllum nodosum</i>	Marketed by Azelis, Denmark	Commercial product	[23]
Bio4Safe	Biostimulants from seaweeds	Consortium of European countries	Project. Funded by Europe via the Interreg 2 Seas Programme	[24]
Microbial-based biostimulants				
VESTA®	This product contains a diverse microbial population, microbial metabolites, soluble humus, and humic material.	Sovitae is working in Europe, Middle East and Africa (EMEA)	Commercial product	[25]
Decision support systems (DSS)				
CropSAT	Web-based DSS that provides vegetation index (VI) maps from Sentinel-2 satellite data. Design variable-rate application (VRA) files for inputs like nitrogen, fungicides, or growth regulators based on VI maps.	Free for global use, in practical use since 2015, mainly in Scandinavia	Web-based decision support system integrating remote sensing technologies with decision-making processes for precision agriculture, including the application of biostimulants and biofertilizers.	[26]
Agrobit's Drone-based DSS	Using drones for multi-temporal analysis of trial plots, which could be adapted for biostimulant and biofertilizer applications. Measurement of vegetation area, biomass volume, and vegetation indices (NDVI, NDRE, GNDVI)	Italy	Company It provides different applications and DSS, including sensors and drones	[27]
Bio4safe Database	This database is designed to help growers make better decisions about which biostimulants to use for their specific crops and conditions	Consortium of European countries	Project Bio4safe	[28]

5.2. Mapping of patent databases related to biofertilizers and biostimulants

The urgent need to shift from traditional cultivation methods to more sustainable production practices has attracted the attention of researchers worldwide. Significant efforts have been made to develop and test the use of biomass waste for producing biofertilizers and biostimulants from a circular economy perspective. Many of these advancements have resulted in commercially viable methods or products that are protected by patents. In recent years, various methods for producing biofertilizers and biostimulants have been registered, aiming to establish sustainable practices that enhance plant growth and increase crop yields. Biofertilizers work by improving the availability of nutrients for plants, while biostimulants not only enhance the absorption capacity of these nutrients but also promote greater root development. Additionally, biostimulants can improve a plant's resistance to pests and environmental stresses, offering a sustainable alternative to traditional chemical pesticides ⁶⁸. Many methods and products have been developed in both China and the USA, but a significant number of patents related to biofertilizer production have emerged from Europe. **Table 11** presents examples of patents in the biofertilizer and biostimulant sectors that have been established by European countries over the past five years.

Many patents related to the production methods of biostimulants focus on the development of microbial cultures, such as fungi and bacteria, which create a symbiotic relationship with plant roots, resulting in enhanced growth and increased nutrient absorption. The growth of specific cyanobacteria and microalgae cultures in hydroponic cultures is also referred to as an effective method for enhanced root development and promoting the biostimulant effect ⁶⁹. Furthermore, the use of macroalgae as a biofertilizer and biostimulant has been gaining increasing interest. This is due to its chemical composition, which provides essential nutrients and promotes plant growth. Macroalgae contains substances such as auxins, cytokinin, and gibberellins, which contribute to these growth-promoting effects ⁷⁰.

The production of biofertilizers and biostimulants from biomass residues is an efficient and sustainable method for enhancing the value of this waste stream in accordance with circular economy principles. Some patents have been recently registered based on studies using different sources of biomass waste, such as agricultural waste, effluents from animal husbandry, and compost from the anaerobic digestion of organic waste. Due to the complexity of managing animal wastes, finding ways to recover them to produce biofertilizers presents an opportunity to promote more sustainable agricultural practices. Recently, several studies have focused on the anaerobic digestion of livestock waste and the application of the resulting digestate as a biofertilizer ^{71,72,73}. Consequently, the promising results reported by scientific research are reflected in increased patents for methods or products developed using animal husbandry waste. Additionally, organic waste can be converted through thermochemical processes such as carbonization, pyrolysis, and gasification to produce biochar, which has enhanced properties that serve as biofertilizers and biostimulants ⁷⁴.

⁶⁸ <https://doi.org/10.1016/j.envres.2023.116357>

⁶⁹ <https://doi.org/10.3390/biotech13030027>

⁷⁰ <https://doi.org/10.1016/j.scienta.2024.113312>

⁷¹ <https://doi.org/10.9734/jsrr/2020/v26i330231>

⁷² <https://doi.org/10.3390/fermentation9050436>

⁷³ <https://doi.org/10.1016/j.cep.2023.109660>

⁷⁴ <https://doi.org/10.1016/j.biteb.2024.101893>

Table 11. Some European patents on the biofertilizer and biostimulant fields from 2020 to 2024.

Reference	Country	Title	Description	Publication
RO135023A2	Romania	Biostimulant with balanced triggering of defense response in plants	The invention relates to a biostimulant with balanced priming action of the plant defense response, intended for application by foliar treatment to increase the resistance of plants to biotic and abiotic stresses and to promote the accumulation of biologically active compounds in crop plants.	30/06/2021
HU231205B1	Hungary	Biostimulator foliar fertilizer with mainly heterotrophic microalgae and effective soil conditioner	The invention is in the field of microalgae biostimulators. Mainly conditioner and process for the production of heterotrophic microalgae biostimulator soil conditioner and bioeffector.	28/10/2021
UA149860U	Ukraine	Process for preparation of biogas and biofertilizers from organic wastes	Methods of obtaining biofuel and biofertilizers from organic waste of animal and plant origin, including grinding, heating, homogenization, and anaerobic processing in a reactor of organic waste, such as chicken manure, with biogas extraction and unloading of fermented mass with subsequent separation into liquid and solid phases, in addition to organic cellulose-containing additive, to be applied in agricultural production.	08/12/2021
RU2771225C1	Russia	Method for increasing soil fertility in the cultivation of agricultural crops	The invention relates to agriculture, namely to the processing of waste from poultry enterprises in the form of bird droppings, and can be used to obtain ready-made, safe granular fertilizers containing all the necessary components to effectively improve the soil, growth conditions and create favorable conditions for the life of soil microorganisms	28/04/2022
EP3194348B1	European Patent Office	Method for processing poultry manure for getting organic fertilizer and biogas	This invention relates generally to the method of biological processing of organic mass, in particular, poultry manure, and may be used both in agriculture and other fields for obtaining biogas and organically clean fertilizers.	08/03/2023
ES2954666T3	Spain	Compositions of <i>Bacillus thuringiensis</i> rti545 and methods of use to benefit plant growth and control plant pests	Compositions of <i>Bacillus thuringiensis</i> isolated to apply to seeds and roots of plant growth and control pests.	23/11/2023
ES2956068T3	Spain	Regeneration of biocarbon and/or fertilizer substrate	The invention relates to the composition of the regeneration of biocarbon and/or fertilizer substrate to take advantage of the excellent effects of sheep manure together with the properties of biocarbon.	12/12/2023

Reference	Country	Title	Description	Publication
DE202023106075U1	Germany	A composition and device for producing biofertilizer/ biostimulant from algae and seaweed	The invention relates to the field of composition and device of biofertilizers and biostimulants. In particular, the invention relates to a composition and a device for producing biofertilizer/biostimulant from algae and seaweed in the cultivated plant <i>Abelmoschus esculentus</i> .	06/12/2023
ES2956068T3	Spain	Regeneration of biocarbon and/or fertilizer substrate	The invention relates to the composition of the regeneration of biocarbon and/or fertilizer substrate to take advantage of the excellent effects of sheep manure together with the properties of biocarbon.	12/12/2023
RO138110A2	Romania	Biostimulating fertilizer formula and method for applying the same	The invention refers to a product with biostimulant properties for plants, which optimizes plant nutrition, favors the absorption and metabolism of molecules, stimulates root and extra-root vegetative development, and ensures the prevention and treatment of nutritional deficiencies.	30/04/2024
ES2967950T3	Spain	Compositions and methods to stimulate plant growth	The invention relates to compositions and methods for stimulating plant growth and/or for stimulating the natural defenses of plants. In particular, the invention relates to a new malt sprout juice or juice extracted from malt sprouts as a biostimulant or for preparing a biostimulant agent to stimulate and/or promote plant growth.	06/05/2024
ES2968085T3	Spain	Method for conversion of poultry manure	The invention relates to the field of agriculture, more particularly to the field of waste from poultry farms to produce organic fertilizers and biogas and can be useful both in bioenergy plants for poultry farms and in bioenergy plants for the conversion of waste. It aims to address the sustainable use of waste from poultry farms and livestock waste.	07/05/2024
DE202024103237U1	Germany	System for producing organic fertilizers and biochar from biogas waste	The invention relates to waste management and renewable energy production, particularly to a system for processing biogas waste into organic fertilizers and biochar.	06/08/2024
WO2024177526A1	Portugal	Cyanobacteria and microalgae plant biostimulants	The invention refers to a consortium of cyanobacteria and microalgae as plant biostimulants. The consortium showed biostimulant potential in hydroponic cultures, and the microorganisms did not lead to stressful parameters. The said composition can be advantageously used potential as natural plant biostimulants, constituting a step forward towards use to boost crop production and/or the recovery of damaged soil, while avoiding pesticides and allowing biodiversity.	29/08/2024

6. Conclusions

The integration of biofertilizers and biostimulants into agricultural practices presents a promising avenue for advancing sustainability within European agriculture, aligning with the European Union's ambitious environmental goals, such as those outlined in the European Green Deal and the Farm to Fork strategy. These bio-based products offer significant potential in reducing dependency on conventional chemical fertilizers and pesticides, thus mitigating environmental degradation while promoting sustainable productivity. However, several technical, economic, regulatory, and societal barriers remain that must be addressed to ensure their widespread adoption and effective integration into existing agricultural systems.

Biofertilizers, such as those derived from organic waste-based products like struvite and biochar, and biostimulants, including humic substances, seaweed extracts, and microorganisms (e.g. *Rhizobium*, *Azospirillum*, mycorrhizal fungi), contribute to improving soil fertility, enhancing plant growth, and increasing crop resistance to abiotic stresses. Additionally, they play a pivotal role in promoting circular economy principles by facilitating waste valorization, transforming agricultural and industrial by-products into valuable inputs. These products not only support agricultural productivity but also reduce the environmental footprint of farming, particularly by enhancing nutrient use efficiency, reducing nutrient leaching, and improving soil organic matter content.

Despite these advantages, the biofertilizer and biostimulant sectors face significant challenges that hinder their broad-scale adoption. Key issue are the insufficient standardization of product formulations, which can lead to inconsistent efficacy and quality. Additionally, there is a lack of information sharing regarding byproducts and waste generated from agricultural and agro-processing activities. The biofertilizer sector requires an institutionalized, regulated, and geo-referenced system to incentivize farmers and both food and non-food processing industries to share data on their residues. Ideally, this system should be built on a GIS-based database, where each type of residue is listed along with its quantity and quality (including chemical and physical analyses such as nutrient content, pH, moisture, C/N ratio, etc.), as well as the location of generation and its seasonality. The database should be supported by a regulatory framework, potentially inspired by the existing Extended Producer Responsibility (EPR) systems implemented in the EU for various recyclable materials. It could be managed by either public or private entities and should also provide financial support to cover collection and transportation costs.

Current manufacturing processes often lack optimization, resulting in suboptimal biofertilizer formulations that may not be effective across diverse agroecosystems or soil types. Furthermore, high production costs, particularly for bio-based inputs derived from waste streams, pose economic barriers that limit market access. To address these concerns, it is imperative to invest in research and innovation to optimize production methods, enhance the bioavailability of active ingredients, and improve formulation stability under varying environmental conditions.

Farmer adoption of these bio-based products is also hindered by a lack of awareness and knowledge regarding their benefits and appropriate application techniques. Many farmers are unfamiliar with the potential advantages of biofertilizers and biostimulants, and the complexity of integrating these products into conventional farming systems can be perceived as a barrier to their uptake. Education and extension services that provide clear, evidence-

based guidance on their application, efficacy, and benefits are essential for increasing adoption rates. Demonstration trials and on-farm experimentation can further support the dissemination of knowledge and facilitate the acceptance of these products in real-world farming contexts.

Regulatory challenges represent another significant obstacle to the widespread use of biofertilizers and biostimulants, particularly those derived from non-traditional waste streams. The European Fertilizing Products Regulation (FPR) and the Waste Framework Directive (WFD) must be adapted to allow for the broader inclusion of products derived from organic waste, ensuring that biofertilizers and biostimulants produced from wastewater, food waste, or sewage sludge are adequately regulated. Harmonized standards across EU member states are necessary to ensure product safety and quality, as well as to foster cross-border trade and market development. Additionally, regulatory frameworks should encourage research into the environmental impacts of these products, particularly regarding their long-term effects on soil health, biodiversity, and nutrient cycling.

Moving forward, there is a need for a comprehensive and collaborative approach to overcome the challenges facing the biofertilizer and biostimulant sectors. Multi-disciplinary research focused on improving product formulation, investigating the long-term efficacy of bio-based inputs, and understanding their interactions with soil microbiota is critical. Policy frameworks should incentivize investment in innovation, the optimization of production processes, and the development of cost-effective products. Public-private partnerships can facilitate technology transfer, while research-driven policy development will help overcome regulatory barriers. Furthermore, promoting knowledge exchange and training opportunities will support the uptake of bio-based inputs at the farm level, contributing to a broader transition towards sustainable agricultural practices.

Finally, biofertilizers and biostimulants offer significant promise as key components of sustainable agricultural systems within the EU. By addressing the technical, economic, and regulatory challenges outlined above, these products can play a crucial role in enhancing soil fertility, improving nutrient use efficiency, and reducing the environmental impact of agricultural practices. Through continued innovation, collaborative efforts, and supportive policy frameworks, biofertilizers and biostimulants can contribute to achieving the EU's sustainability goals and advancing the transition towards a more circular, resource-efficient agricultural system.

7. Annex

Annex 7.1. Fertilizer Glossary

Table A. 1. Fertilizer glossary.

Name	Nutrients Percentage	Type/Origin	Notes
Nitrogen-based			
Urea	46% N	Produced from liquid ammonia generated through the Haber-Bosch process, using natural gas and gaseous nitrogen. The process combines gaseous nitrogen (N_2) and hydrogen (H_2) under high pressure and temperature in the presence of a catalyst and compressed carbon dioxide.	One of the most common nitrogen fertilizers. It is used on many crops, especially cereals, to promote vegetative growth.
Ammonium nitrate	33-34% N	Reaction between ammonia (NH_3) and nitric acid (HNO_3).	Rapid nutrient release. Very effective for crops with high nitrogen requirements.
Ammonium sulphate	24% S, 21% N	Reaction between ammonia and sulfuric acid.	Ideal for sulphur-deficient soils and crops such as rice, rapeseed, and brassicas.
Phosphorus-based			
Ammonium phosphate MAP	52% P, 12% N	Reaction between ammonia and phosphoric acid (H_3PO_4), produced through the wet process, in which phosphate rock is treated with sulfuric acid to release H_3PO_4 .	Root development, especially in the early growth stages.
Diammonium phosphate DAP	46% P, 18% N	Similar to MAP but with higher ammonia content.	Highly soluble, used on many cereal and horticultural crops.
Triple superphosphate TSP	45% P	Reaction between phosphate rock and phosphoric acid.	Wheat, corn, and vegetables.
Potassium-based			
Potassium chloride KCl	60% K	Produced from Sylvite (KCl), a mineral primarily composed of potassium chloride, often associated with other salts like sodium chloride (NaCl), and from Carnallite	Potatoes, tomatoes, and beets.

		(KCl·MgCl ₂ ·6H ₂ O), another important mineral containing potassium chloride combined with magnesium chloride and water.	
Potassium sulfate K ₂ SO ₄	50% K, 18% S	Potassium chloride is the main source of potassium used in the production process, reacted at high temperatures (500/600 °C) with sulfuric acid, magnesium sulphate, or natural sulphates such as langbeinite or schoenite.	Crops sensitive to chlorine, such as tobacco and citrus fruits.
Potassium nitrate KNO ₃	46% K, 13% N	Produced through chemical processes involving the reaction between potassium salts and nitrate-containing compounds.	Horticultural and fruit crops.
NPK Complex			
20-20-20	-	Produced through balanced mixing of major simple or compound fertilizers containing two elements.	-
Organic			
Organo-mineral	-	The same formulas as mineral fertilizers with added organic components derived from commercially available amendments.	-
Soil Amendments			
Manure	1/0.3-0.5/0.3-1/0.5	Excreta from various domestic animals (cattle, sheep, goats, horses, pigs), either raw or dried.	Restores soil properties more quickly but requires nearby livestock farms (transport costs).
Compost	1-1-1	Aerobic degradation process at temperatures between 50 and 70 °C, varying depending on input materials.	Generally, more stable and suitable for broader use compared to other amendments (manure), safer in terms of pathogens and weed seeds.
Poultry manure	3-4-3	Derived from poultry excreta.	Higher nutrient content, especially phosphorus, compared to other amendments.
Vermicompost	1-0.5-0.8	Earthworm castings.	More concentrated amendment, rich in hormones and enzymes.

Animal meals	Blood meal 12-0-0; bone meal 3-15-0; fish meal 9-6-2	By-products of meat and hide processing, dried and ground.	It contains essential micronutrients such as calcium, iron, zinc, and magnesium.
Plant meals	Vinasse 2-1-5; wood ash 0-1-3/6	By-products from agricultural or forestry product processing or use.	Rich in carbohydrates and proteins that feed beneficial soil microorganisms.
Seaweed	1-0.2/0.5-2/4	Produced through drying and pulverization, extraction, or maceration processes.	Particularly rich in potassium and other micronutrients and bioactive compounds.
Black soldier fly larvae	3/5-3-2/3	Larval excreta.	Nutrient variation depends on the diet fed to the larvae and the waste material used.

Annex 7.2. List of biofertilizer companies

Table A. 2. List of biofertilizer companies.

Company	Country	Products	Description	Link
Bionema Group Ltda.	UK	Biofertilizer - BioNFix range, Rhizosafe. Biostimulant - Rootvita, Groprim, Floretocare, Omirise, Grostimula, O-Stimula.	Seed dressing or soil inoculant based on select strains of <i>Paenibacillus azotofixans</i> BNL1913, <i>Azospirillum lipoferum</i> BNL714, and <i>Bradyrhizobium japonicum</i> BNL1061, which enhance N fixation. <i>Rhizophagus irregularis</i> colonizes and forms symbiotic relationships with plant roots. They invigorate the plant's natural processes, optimizing nutrient absorption and utilization and enabling plants to make better use of available nutrients, leading to stronger, healthier growth and improved yields.	https://bionema.com/
Corteva Agrisciences	Spain	Biofertilizer - Vitasoil. Biostimulants - TrichoSym Bio, Mycoup, Residir.	Soil regenerator based on selected rhizospheric microorganisms that increases the microbial population of soils and substrates in intensive agricultural systems. Composed of the beneficial fungus <i>Trichoderma harzianum</i> T-78, it stimulates development by improving plant nutrition through the solubilization of macro and micronutrients, increasing the resistance of plants to abiotic stress, and improving the absorption of water and nutrients for the root system.	https://symborg.com/es/
Microalgaex	Türkiye	Biofertilizer - Microalgaex® CTRX	Microalgae strains from various families demonstrate hormone-like activities, such as auxins, gibberellins, and abscisic acid. By harnessing natural plant hormones from microalgae species, biofertilizers can enhance plant growth, yield, and defense response against abiotic stress.	https://microalgaex.com/
Seafields	UK	Biostimulant from Sargassum biomass	Catch and grow Sargassum to atmospheric CO ₂ capture. The Sargassum is converted into a range of products, including bioplastic, biostimulants, and biofuels.	https://www.seafields.eco/

Chlydro	Spain	Biostimulant from microalgae biomass	Cultivation of microalgae to capture CO ₂ in wastewater using biomass for use as biofertilizers for companies in the agricultural sector.	https://www.chlydro.com/
Rovensa Next	Spain	Biofertilizer – Wiibio, Brotaverd. Biostimulant – Azzofiz, Biimore, Vegenergy.	A soil-regenerating biofertilizer with biostimulant properties. This product is based on a bacterial strain of <i>Bacillus subtilis</i> to enhance soil microbiota and improve plant development.	https://rovensanext.com/en/
Elephant Vert	France	Biofertilizer - Fertinova range. Biostimulant – Econitrate, Novastim, Ovalis Rhizofertil.	A range of 100% natural organic fertilizers rich in organic matter, N-P-K nutrients, and trace elements of natural origin. It promotes the growth and development of potassium-demanding crops. Econitrate is based on algal cream (<i>Ascomyces nodosum</i>) and molybdenum stimulates the genes of nitrate absorption and thus multiplies the transport of nitrogen to the plant. Novastim is derived from the fermentation of the bacterium <i>Bacillus subtilis</i> recognized for its biostimulant properties.	https://www.elephant-vert.com/
AgroNutrition	France	Biofertilizer – Amylys, Conidis, Optys. Biostimulant – Acrecio, Alcygol range, Chelonia BMO.	Liquid biofertilizers which facilitates the fixation of atmospheric nitrogen for the plant, strengthen roots and accelerate emergence, improve crop residue degradation, enhance the soil carbon cycle, increase yield, and improve the microbiological activity in the soil and germination faculty. Stimulates the root growth and development of plants and optimizes the natural ability of plants to assimilate and value nutrients. They also improve plant vigour while limiting stressors.	https://www.agronutrition.com/
Italpollina	Italy	Biofertilizer – Guanito, Italpollina 4-4-4, Laphrassea. Biostimulant – Atriva range, Glyss SP, Vengamin 2-1-3.	The company focuses on developing eco-friendly solutions to enhance soil fertility, improve plant health, and promote sustainable farming practices. Their innovative products include biofertilizers, natural biostimulants, and beneficial microorganisms.	https://www.hello-nature.com/int/

SCAM	Italy	Biofertilizer – Algae Fitostim, Linfor, Ferroumate. Biostimulant – Abstrim SW 30, Fitostim.	The company emphasizes sustainable agriculture, focusing on products that enhance crop performance while preserving environmental integrity. SCAM operates a modern production facility and has expanded its market presence both nationally and internationally. A company specializing in organic and special fertilizers, to strengthen its position in the organic fertilizer segment.	https://www.scam.it/
YARA	International	Biofertilizers - Nitrogen-based, compound, micronutrient-enriched fertilizers, sulfur-enriched. Biostimulants - Biological plant growth promoters.	Yara Italia, a branch of Yara International, is a leading provider of crop nutrition solutions and fertilizers in Italy. The company specializes in sustainable agricultural practices, aiming to enhance crop quality and yield while minimizing environmental impact. Yara Italia offers a wide range of fertilizers and biostimulants tailored to local agricultural needs, including products for precision farming and fertigation systems.	https://www.yara.it/
FERTILEVA	Italy	Biofertilizers, Organomineral Fertilizers	The company specializes in the production and sale of organic, biological, and ecological fertilizers. Their product range includes soil improvers, organic and organomineral fertilizers, and correctives suitable for conventional, organic, and biodynamic agriculture. These products are available in both powder and pellet forms, catering to diverse agricultural needs.	https://www.fertileva.it/
Agribios	Italy	Fertilizers (Organic, Organo-Mineral, Fertilizers with Beneficial Microorganisms) Soil Conditioners and Correctives	Founded in 1973, Agribios Italiana specializes in the production of organic and organo-mineral fertilizers tailored for both organic and conventional agriculture. The company emphasizes sustainability and environmental respect, offering innovative solutions to enhance agricultural productivity while maintaining ecological balance.	https://agribiositaliana.it/en/
Agricola Internazionale	Italy	Fertilizers, Biostimulants, Plant Protection Products	With over 30 years of experience, the company offers a comprehensive range of products, including special fertilizers, biostimulants, fertilizers, and plant protection products. Agricola Internazionale is recognized as a leader in modern agriculture, providing effective and tailored solutions to meet the specific needs of contemporary farming practices.	https://www.agricolainternazionale.it/

Novafert	International group (Italy branch)	Alternative Fertilizers, Controlled Release Fertilizers (CRFs)	The company is involved in projects like NOVAFERT, which demonstrates the technical, economic, and environmental feasibility of using a wide portfolio of alternative fertilizing products. This initiative aims to facilitate the replacement of synthetic and mineral fertilizers, contributing to a more sustainable agricultural sector.	https://www.novafert.eu/
Compo Expert	German	Slow and Controlled Release Fertilizers, Water-Soluble and Liquid Fertilizers, Biostimulants, and Soil Conditioners	The company specializes in the production and distribution of high-quality specialty fertilizers and biostimulants. The company's product portfolio includes specialty mineral and stabilized fertilizers, slow and controlled release fertilizers, water-soluble and liquid fertilizers, biostimulants, trace elements, and soil conditioners.	https://www.compo-expert.com/it-IT
LEA	Italy	Biofertilizer – Algalea 95P, Sprint Veg, Veg-aid 5.15., Start K.	Specialized in the development and distribution of agricultural products, including fertilizers and biostimulants. Their offerings are formulated to support sustainable farming practices and improve crop productivity. The company emphasizes the use of innovative solutions to address the challenges faced by modern agriculture.	https://www.leaagricoltura.it/
BRENNTAG	Global company, with branches in Italy	Biofertilizer, liquid fertilizer, bio stimulants	It acts as a key supplier of a wide range of products across multiple sectors, including agriculture, pharmaceuticals, food, and more. The company provides chemicals and ingredients for formulation and manufacturing, with a focus on ensuring high-quality products and efficient supply chains for their clients.	https://www.brenntag.com/en-it/industries/agriculture/
UNIMER	Italy	Biofertilizer, Organic mineral fertilizer	UNIMER's product line includes organic soil improvers, biofertilizers, and organo-mineral fertilizers, all designed to enhance soil health and promote sustainable crop nutrition. The company emphasizes environmental sustainability and the restoration of organic matter in soil to mitigate climate change effects.	https://www.unimerfertilizzanti.it/
Groupe Rouiller	France	Biofertilizer	The company specializes in the production and distribution of special fertilizers and biostimulants, aiming to meet the specific nutritional needs of plants. Their products are designed to support	https://it.timacagro.com/

			sustainable agriculture practices, ensuring high productivity and quality.	
Organazoto	Italy	Biofertilizers, Organo-Mineral Fertilizers, Soil Amendments	Specialized in the production of fertilizers, soil conditioners, and amendments for professional agriculture. The company emphasizes environmental sustainability and the restoration of organic matter in soil to mitigate climate change effects.	https://www.organazoto.it/
FCP Cerea	Italy	Granular Fertilizers, Water-Soluble Fertilizers	Specialized in the production of granular mineral and organo-mineral compound fertilizers, water-soluble fertilizers, and liquid products for special nutrition. The company is located in the heart of the Po Valley, one of Italy's most important agricultural regions, providing strategic logistical advantages.	https://fcpcerea.it/
ILSA	Italy	solid and liquid organic and organo-mineral fertilizers, BIOILSA, ILSAFERT, ILSA AGRO, Biostimulants	ILSA is committed to sustainable agriculture, offering innovative products that meet the specific nutritional needs of plants while minimizing environmental impact. The company focuses on developing "intelligent" biofertilizers and biostimulants to support modern farming practices.	https://www.ilsagroup.com/en/
Green Ravenna	Italy	Agricultural Fertilizers, Plant Protection Products, Home & Garden Products	Over the years, it has expanded its product range to encompass the entire agricultural sector, providing solutions for both professional and non-professional users.	https://en.greenravenna.it/
Germina	Italy	Biofertilizers, Foliar fertilizers, Biostimulants	They focus on developing products that enhance soil health, reduce environmental impact, and improve crop productivity. Their offerings include products that cater to a wide range of agricultural needs, including organic farming and precision agriculture.	https://www.germina-nutrition.com/
A.G.M. Srl	Italy	All biofertilizers: Granular, Foliar, Fertirrigation, Special	Operating in the field of animal blood processing and production of biofertilizers. The key aspect of the products we offer is their cost-benefit ratio, ensuring compliance with production standards (quantity and quality), nutrient application (particularly nitrogenous substances), lignification, and budding.	

			Finally, all our products comply with European nitrate regulations.	
Terrial	France	Biofertilizers, Biostimulants	Specialist in the fertilization and valorization of organic co-products for more than 25 years, Terrial develops efficient agronomic solutions for agriculture. These optimize the resources of the land, maintain the natural fertility of the soil and contribute to quality harvests. Their model is based on the use of renewable carbon and its storage, from the recovery of co-products and bio-waste to their transformation into fertilization solutions.	https://www.terrial.fr/
Agrauxine by Lesaffre	France	Microorganisms and microorganisms derived products	Agrauxine is the Lesaffre division dedicated to biosolutions for crop production. Thanks to the recognized expertise of the Lesaffre group in fermentation, Agrauxine develops, manufactures and markets solutions based on microorganisms (yeasts, bacteria, fungi) for biocontrol, biostimulant and bionutrition markets.	https://agrauxine.com/fr/
Cybele Agrocare	France	Microorganisms (PGPR)	CYBELE AGROCARE is a French industrial leader specialized in crop nutrition (NPK) thanks to the natural action of living microorganisms. Cybèle is an agri-biotech start-up that markets natural rhizobacteria with scientifically proven agronomic interests, and offers farmers biofertilizers that limit the use of mineral fertilizers while securing their yields.	https://www.cybele-agrocare.com/
Veragrow	France	Biostimulants derived from vermicompost	Veragrow's mission is to provide farmers with high-performance and easy-to-use products. We are contributing to the agro-ecological transition through innovative and sustainable solutions. Veragrow offers a range of biostimulants, derived from earthworm science, to meet the needs of plants and soils.	https://veragrow.fr/
Gaiago	France	Biostimulants	GAIAGO develop, manufacture and market soil revitalization products that naturally activate their functionality while limiting the impact of chemistry on crops.	https://www.gaiago.eu/
Mycea	France	Biostimulants – mycorrhizal fungi	The mycorrhizal fungi present in all soils are essential for the life of 80% of terrestrial plants. Living in symbiosis with the roots of their host, mycorrhizal fungi have a positive impact on the development	https://mycea.fr/

			of the plant thanks to the mycelial network they form around its roots. Mycea values these fungi as a biostimulant for plant growth.	
Penn-Ar-Bed	France	Biofertilizers and Biostimulants derived from aquatic resources	PENN AR BED manufactures its own extracts and various fertilizer solutions based on marine raw materials for professionals, for agricultural uses as well as green spaces. They also market certain raw materials for use in agriculture, cosmetics and food industry	https://biotechnologies-marines.com/
Laboratoire Biodevas	France	Biostimulants from vegetal extracts	Biodevas Laboratories is a Research and Development laboratory, specialized in the design of Biosolutions from 100% natural assets from its exclusive extraction process. Since 2005, Biodevas Laboratoires has been recognized as a technological leader in the enzymatic regulation of oxidative stress in living beings by endogenous means aimed at stimulating anabiosis.	https://biodevas.fr/
AgWI	France	Biofertilizers	It converts biomass, co-products and waste into high agronomic value fertilizer and biostimulants.	https://agwi.fr/
Invers	France	Biofertilizers from insect frass	Using the frass as biofertilizer has many advantages Benefits that Invers is already exploiting with its partner farmers, as a lever for a more global transition to agroecological practices. e of the game.	https://invers-groupe.fr/
Mycophyto	France	Biostimulants – mycorrhizal fungi	At MYCOPHYTO, our plants are greenhouses. We identify arbuscular mycorrhizal fungi, multiply them and then produce them. Our innovation is a cutting-edge technology where we combine approaches of Artificial Intelligence and agronomy to put the historical natural allies of plants back at the center of the game.	https://www.mycophyto.fr/
Axioma	France	Biostimulants from vegetal extracts	At Axioma Biologicals, our ambition is to enable people to eat better, in quality and quantity. To do this, we develop and manufacture sustainable, low-carbon, certified bio-stimulants and biocontrol products (CBD). These innovations are the result of continuous exchanges with farmers, as well as with our various partners. We research, design and produce our Biosolutions on behalf of our distribution partners.	https://www.axioma-biologicals.com/

Annex 7.3. Main types of agricultural and agro-processing waste and residues

Table A. 3. Main types of agricultural and agro-processing waste and residues.

Type	Product	By-product
Agricultural field residues		
Herbaceous	Soft wheat	Straw
	Durum Wheat	Straw
	Barley	Straw
	Rice	Straw
	Sorghum	Straw
	Corn	Stalks, cobs, stems
	Rapeseed	Stem, leaves, waste
	Soy	Stem, leaves, waste
	Sunflower	Stem, leaves, waste
	Sugar Beet	Leaves, crowns
	Legumes	Pods, stems, leaves
	Potato	Leaves, stem, waste product
	Tomato	Leaves, stem, waste product
Tree crops	Peach-Nectarine	Pruning residues
	Apricot	Pruning residues
	Plum	Pruning residues
	Apple	Pruning residues
	Pear	Pruning residues
	Cherry	Pruning residues
	Kiwifruit	Pruning residues
	Persimmon	Pruning residues
	Vine	Vine shoots
	Olive	Pruning waste
		Wood
	Walnut	Pruning residues
Horticultural residues		
Horticultural	Total minor horticultural crops	Leaves, stem, waste product
Livestock & SOA residues		
Livestock residues	Cattle	Slurry
		Manure
	Pigs	Slurry
	Poultry	Broiler litter (husk, straw, sawdust)
		Layer litter
SOA	Cattle	Rumen content
		Blood
		Meat scraps, offal, fat
		Head
		Liver, lungs, heart, spleen, rumen
		Minor organs and skin
	Pigs	Offal
		Intestines
		Blood

		Bristles and hooves
		Bones and trimmings
	Poultry	Feathers and quills
		Blood
		Intestines
		Head and legs
		Skin and neck
Dedicated agricultural crops		
Herbaceous	Sweet Sorghum	Whole ensiled sorghum
	Sweet Corn	Whole ensiled corn
	Sweet Triticale	Whole ensiled triticale
Tree crops	Woody Poplar	Chipped poplar
Agro-industrial residues		
Herbaceous	Soft Wheat	Bran
		Middlings
		Shorts
		Flour middlings
	Durum Wheat	Bran
		Middlings
		Shorts
		Flour middlings
	Rice	Husk
		Bran
		Germ
		Breakages
	Sugar Beet	Pulp
	Tomato	Pulp, waste
		Peelings
	Potato	Waste and peels
	Legumes	Waste and peels
Sunflower	Seed pressing waste	
Rapeseed	Seed pressing waste	
Soy	Seed pressing waste	
Tree crops	Peaches and Nectarines	Peels, pulp, waste
		Pits
	Apricots	Peels, pulp, waste
		Pits
	Apples	Total processing waste
	Pears	Total processing waste
	Wine Grapes	Pomace
		Grape seeds
		Stems
		Lees
	Olives	Vegetation water
		Defatted pomace
Pomace flour		
Olive pits		

	Walnuts	Shell
Beer	Beer	Spent grains
Milk	Milk and dairy products	Whey
		Ricotta whey
Wood, recycled paper & forestry streams		
Wood	First and second processing	Sawdust and shavings
Forestry	Public greenery	Mowing and pruning
	Forest management	Wood and pruning
Process water & sludge		
Sludge treatment	Wastewater sludge	Wastewater sludge
Post-consumption residues		
OFMSW	Mixed waste collection	Mixed organic waste
	Separate organic waste	Separate organic waste
	Green waste collection	Green waste collection
New promising biomasses		
Marine biomass	Fish residues	Fish residues
	Beach debris	Wood
		Small organic matter
Seed processing	All seed types	Seed processing residues

Annex 7.4. Elemental composition of main organic fertilizers (biofertilizers) in the EU

Table A. 4. Elemental composition of main organic fertilizers in the EU ^{75,76}.

Fertilizer	N (%)	P ₂ O ₅ (%)	K ₂ O (%)	Notes
Blood meal	12.0	0.0	0.0	High nitrogen content, promotes rapid vegetative growth.
Bone meal	3.0	15.0	0.0	Excellent source of phosphorus, supports root development and flowering.
Fish emulsion	5.0	2.0	2.0	Balanced nutrient source, fast-acting, beneficial for seedlings and transplants.
Seaweed extract	1.0	0.5	2.5	Provides trace minerals and growth hormones, enhances stress resistance.
Feather meal	12.0	0.0	0.0	Slow-release nitrogen source, suitable for long-term feeding.
Alfalfa meal	2.5	0.5	2.5	Contains growth stimulants, improves soil structure and microbial activity.
Cottonseed meal	6.0	2.5	1.5	Acidic nature, ideal for acid-loving plants, provides slow-release nutrients.
Soybean meal	7.0	0.5	2.3	High in nitrogen, promotes healthy foliage growth.
Humic acid	0.6	0.2	0.4	Enhances nutrient uptake, improves soil structure and fertility.
Worm castings	1.5	2.5	1.3	Rich in beneficial microorganisms, improves soil aeration and water retention.
Vinasse	0	0	5	From sugar production residues
Chicken manure	5	4	3	Rich in nitrogen and phosphorus

⁷⁵<https://agronotizie.imagelinenetwork.com/fertilizzazione/2020/12/15/concime-npk-significato-e-usi-in-agricoltura/68806>

⁷⁶ <https://doi.org/10.1016/j.biortech.2019.122223>