








## FROM ORGANIC WASTE TO SUSTAINABLE AGRICULTURE: VALORIZATION PATHWAYS FOR ORGANIC FERTILIZER AND BIOFERTILIZER PRODUCTION IN ORGANIC FARMING-A REVIEW

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### ABSTRACT

Article information  
Article history:  
Received: 14 /4 /2026  
Accepted: 27/6/2026  
Available: 30/6/2026

#### Keywords:

Organic waste, biofertilizers,  
waste management,  
composting, sustainable  
agriculture.

#### DOI:

<https://doi.org/10.3389/9/magrj.v54i2.51186>

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This literature review explores the importance of organic fertilizers as a strategy for sustainable management of organic waste and promotion of organic agriculture. In particular, it aims to establish the link between the production and conversion of organic by-products into bioresources and their integration into organic agriculture. It reviews the various technical processes of converting organic waste into fertilizer. Among the processes examined, composting remains the most widely used because of its technical simplicity and economic profitability. Other processes examined that may be used to recover the mineral elements contained in organic by-products include anaerobic digestion, vermicomposting, solid and liquid fermentation, biochar production. Thus, the various studies examined on the application of these fertilizers reveal that they contribute to a significant improvement in soil fertility while increasing microbial biomass and enzymatic activity, particularly those of urease, phosphatase and dehydrogenase. In addition, these fertilizers are responsible for the increase of the yield rate that can exceed 50% in comparison with untreated soil and the nutritive value of crops. Despite multiple advantages, the valorization of organic waste for agricultural purposes still requires rigorous management, standardization and reasoned integration.

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## INTRODUCTION

In recent years, the increase in food consumption linked to the growth of the world population has led to a significant production of organic waste, especially in developing countries (Koné *et al.*, 2021; Nosheen *et al.*, 2021). These by-products include not only food waste, but also agricultural waste generated during or after harvest as well as green waste from gardens (Sasmita *et al.*, 2022).

Consequently, the accumulation of this waste and its inappropriate disposal is a major environmental challenge due to its harmful consequences. Thus, the transformation of organic waste into organic fertilizers offers a viable solution to this problem, while meeting the growing food demand and environmental concerns associated with mineral fertilizers (Abou *et al.*, 2025). This approach to waste management provides numerous benefits, as it frequently mitigates the effects related to waste accumulation. Their agricultural application provides an ecological alternative to sustain or enhance agricultural output while safeguarding soil health and mitigating environmental impacts.

Furthermore, chemical fertilizers have been widely considered to increase crop yields and productivity in many regions for many years. These agrochemicals have been a major challenge for agriculture in recent years because of their adverse effects on the environment. In some cases, the use of these substances can lead to a significant decrease in soil fertility, water pollution, increased resistance to pests, loss of biodiversity and economic losses (Nosheen *et al.*, 2021; Areeshi *et al.*, 2022). In addition to their environmental impact, these chemicals have harmful effects on human health and are also costly, making their future use no longer a viable option.

Consequently, the application of organic fertilizers and biofertilizers in agriculture can effectively rehabilitate degraded soil. These organic substances, more particularly biofertilizers, include microorganisms capable of increasing soil fertility, fixing atmospheric nitrogen, and solubilizing phosphorus (Chaudhary *et al.*, 2022). Moreover, microbial inoculants contribute to accelerating the decomposition of organic matter and function as agents for biological control and bioremediation (Singh & Kumar, 2023). Consequently, initiatives for organic waste management should focus on converting it into biofertilizers to reduce environmental impacts and promote a circular economy.

This literature review aims to evaluate the efficacy of organic fertilizers and biofertilizers in managing organic waste and advancing organic agriculture. It offers a summary of worldwide organic waste generation and the difficulties related to its management. It also underscores the progress in recent studies regarding the bioconversion of diverse organic waste into biofertilizers and their utilization as agricultural amendments.

## **2. Global production of organic waste: current trends and future projections**

Globally, the amount of organic waste continues to increase and remains the largest fraction of municipal solid waste. According to World Bank data, global municipal solid waste production is estimated to be around two billion tons per year. The output of this could increase to 3.40 billion tons by 2050. Thus, municipal organic waste can account for 40-70% of municipal solid waste, with a particularly high proportion in developing countries (Kaza *et al.*, 2018, Shi *et al.*, 2024).

However, food and agriculture is an important sectoral source of organic waste. Indeed, the agro-industrial sector generates annually about 250 million tons of waste worldwide from non-edible plants; for example, Asia alone produces about 475 tonnes of agricultural residues (Maalout and Mavropoulos, 2023). Statistics from the United Nations Environment Programme (UNEP) show that annual production of agricultural biomass waste is estimated at around 140 billion tonnes. This quantity could increase by about 60% by 2050, in line with the increase in agricultural productivity (Marciniuk and Kluska, 2025). Thus, in its report of March 27, 2024, UNEP indicated that 1.05 billion tonnes of food waste had been produced in 2022. This quantity of waste constitutes 20% of the food designated for consumption. Households are the predominant sources of organic waste, succeeded by catering services and commercial enterprises. Indeed, 44% of municipal solid waste generated globally and 56% in low-income nations is readily compostable. The present circumstances yield a composting rate of under 6% of the total waste produced globally (Kaza *et al.*, 2018).

Generally, the composition of municipal waste varies according to countries' income levels. Low-income countries produce a significant share of organic waste that can exceed 50% of their total waste stream. By contrast, high-income countries produce a high share of dry recyclable materials, where the share of organic waste can account for only 30% of total production (Kaza *et al.*, 2018; Machado and Hettiarachchi, 2020).

### **3. Constraints related to the management of organic waste**

The processes of urbanization and alterations in consumption patterns are contributing to an increase in global organic waste generation. The management of this waste poses a considerable challenge for numerous societies, especially in developing nations. A salient example is the rapid expansion of African cities, which is resulting in a significant increase in waste, thereby adversely impacting cleanliness, water and soil quality, and public health (Bodjona *et al.*, 2022). In addition, the lack of necessary infrastructure and the absence of effective policies are obstacles that can limit proper management of organic waste (Koné *et al.*, 2021).

Despite the initiatives already in place, some countries still face various difficulties related to the management of organic waste. Indeed, the management systems in place remain ineffective in eliminating all the waste produced, which leads to their accumulation, particularly in public spaces. There is also the lack of interest in collecting this waste (Bodjona *et al.*, 2022). In addition, organic waste can certainly contain pollutants including plastics and other non-biodegradable materials, calling for the strengthening of their management technique (Saïdi-Boulahia *et al.*, 2018).

Moreover, disasters such as floods or hurricanes are also challenges most often observed in certain regions that can lead to their production in huge quantities (Beraud *et al.*, 2019). Furthermore, socio-economic and political factors significantly influence the management of organic waste. In numerous instances, waste management policies are inadequately defined or absent in many developing countries, thereby complicating the implementation of effective management systems (Nikiema *et al.*, 2016).

### **4. Technological approaches for converting organic waste into organic fertilizers and biofertilizers**

Research on organic fertilizers and biofertilizers continues to advance in response to some of the challenges mentioned above, with studies exploring their potential in different crop types and soil conditions, strengthening their role in sustainable agriculture. Several recent studies have focused on converting organic waste into organic fertilizers through biological processes and evaluating their agronomic properties. In order to achieve this, many strategies that tackle waste management from the standpoint of the circular economy have been extensively and in-depth examined. Table 1 delineates various technological processes employed to transform organic waste into organic fertilizers and biofertilizers. Each of these processes possesses unique advantages, limitations, and effects on nutrient composition and soil health. The selection of method is contingent upon factors including cost, time, and environmental impact.

Table 1: Comparison of main technological processes and methods for organic waste conversion

Conversion process	General principle	Type of fertilizer obtained	Main benefits	References
Aerobic composting (windrows, piles, silos)	Controlled aerobic degradation (temperature, humidity, C/N ratio)	stabilized solid compost	Low cost, simplicity, reduction of pathogens, improvement of soil structure	Ayilara <i>et al.</i> , 2020 ; Dieng <i>et al.</i> , 2019 ; Hidalgo <i>et al.</i> , 2025
Mechanized dynamic composting	Composting accelerated in controlled reactors	Compost/stabilized organic matter	Reduced residence time, better control of emissions, odors, and sanitary quality;	Martinez <i>et al.</i> , 2022 ; Finore <i>et al.</i> , 2023 ; Tan <i>et al.</i> , 2025
Vermicomposting	Fragmentation and digestion organic matter by worms	Very fine vermicompost, rich in nutrients, enzymes, and beneficial microorganisms (PGPR, PSB, etc.).	Significant enrichment in NPK and micronutrients, high microbiological activity, presence of growth hormones	Kaur, 2020, Ayilara <i>et al.</i> , 2020 ; Bhatt <i>et al.</i> , 2025
Anaerobic digestion	Degradation of organic matter in the absence of oxygen, producing biogas + liquid/solid digestate	Solid/liquid digestate + biogas	Double valorization (energy and fertilizer) efficient recycling of nutrients	Diacono <i>et al.</i> , 2019 ; Jamison <i>et al.</i> , 2021 ; Artola <i>et al.</i> , 2024
Liquid fermentation	Liquid phase fermentation to produce inoculants, metabolites, or nutrient-rich digestate/sludge stabilizers	Liquid biofertilizers (inoculants, fermented extracts) or liquid fractions concentrated in N, P, K	Easy-to-apply formulations (fertigation, seed coating), high density of microbes/metabolites possibility of fast-release products	Jennifer <i>et al.</i> , 2023 ; Abidin <i>et al.</i> , 2024 ; Gao <i>et al.</i> , 2021 ; Admi <i>et al.</i> , 2024

Conversion process	General principle	Type of fertilizer obtained	Main benefits	References
Solid-state fermentation (SSF)	Growth of microorganisms on slightly moist solid substrates (fungi, bacteria) for bioconversion and functional enrichment	Bio-organic fertilizers enriched with functional microbes (PGPR, PSB, lignin/chitin degraders, etc.)	Valorization of difficult substrates (lignocellulose), joint production of enzymes and microbial consortia, and nutrient availability	Lim & Matu, 2015 ; Areeshi, 2022 ; Bibi <i>et al.</i> , 2022 ; Sharma <i>et al.</i> , 2023 ; Xie <i>et al.</i> 2023
Bokashi fermentation	Rapid fermentation by effective microorganisms (lactobacilli, yeasts, etc.) under quasi-anaerobic conditions.	Partially decomposed organic amendment, rich in organic acids and microorganisms.	Fast process, low odor, reduced N losses, suitable for small areas, improved microbial activity	Oiza <i>et al.</i> 2022 ; Zaini <i>et al.</i> , 2023 ; Admi <i>et al.</i> , 2024
Targeted microbial inoculation (PGPR, PSB, N-fixers)	Application of selected strains or consortia to solubilize P/K, fix N, produce hormones or pathogen antagonists	Microbial biofertilizers (solid or liquid), often combined with an organic matrix (bio-organic fertilizers)	Improved nutrient utilization, stimulation of growth and stress resistance, possible reduction in mineral fertilizer doses	Jenniffer N <i>et al.</i> , 2022, Zielinska <i>et al.</i> , 2024, Mia & ZZaman, 2025,

Among the valorization processes, composting remains the most popular technique for managing organic waste worldwide due to its technical simplicity and accessibility, low cost, versatility, and environmental benefits. This process implies the aerobic decomposition of organic matter by involving a population of microorganisms to produce a compost rich in nutrients. On the other hand, anaerobic digestion, although providing a double benefit (biofertilizers and biogas), remains less frequent due to its very demanding technicality in terms of infrastructure. Nevertheless, processes such as enzymatic fermentation or microbial degradation, although more specialized, also remain less common.

### **5. Impact of organic and biofertilizers on soil fertility improvement and crop productivity**

The application of organic fertilizers and biofertilizers improves soil fertility while promoting microbial life essential to nutrient cycles. Soil bacteria and fungi ensure the decomposition of organic matter while releasing essential minerals such as potassium, phosphorus and nitrogen (Bhardwaj *et al.*, 2014). As reported by Li *et al.* (2023), soil amendment using bio-fertilizer increases the health index and carbon concentration, derived from microbial biomass. A study conducted by Djaouga *et al.*

(2020) demonstrated the effectiveness of biochar in improving the restoration of chemical properties such as pH and the content of nutrients essential for fertility. Kumar et al. (2022) reported that the application of biofertilizer promotes crop growth through hormone production, disease elimination and improved nutrient uptake.

However, the microorganisms present in organic amendments promote soil microbial life. As indicated by Diaw et al. (2018), rhizobacteria such as *Pseudomonas* spp., may be desired to improve nutrient absorption and abiotic stress resistance of crops. Similar observations were also reported in the work of Nosheen et al. (2021); Aliyat et al. (2022) and Omar et al. (2025). Research has shown that these bacteria can substantially influence crop yields, particularly in maize, by increasing the concentrations of essential macronutrients such as potassium, phosphorus, and nitrogen (Adjanohoun *et al.*, 2012). All findings in this section corroborate previous research by Brar et al. (2017), Ravanachandar et al. (2020), and Wu et al. (2025), which assert that the application of biofertilizers enhances soil microbial activity as well as biomass. These microorganisms are essential for regulating crop productivity and soil health.

Furthermore, the utilization of organic fertilizers and biofertilizers systematically enhances both final yield and various crop growth parameters. Several studies have been conducted to date demonstrating that the nutrient composition of growing media is important for increasing agricultural production. Table 2 summarizes different results concerning the effects of organic fertilizers and biofertilizer formulations on crop yields.

Table 2. Effects of different organic fertilizers and biofertilizers formulations on crop yields

Treatment/main formulation	Crops	Production		Rate of yield increase	Reference
		Witness Yield	Yield-treatment		
Manure + Biofertilizer (PSB+BGA)	Rice ( <i>Oryza sativa</i> L.)	2625 kg ha <sup>-1</sup>	3100- 4625 kha <sup>-1</sup>	~18 - 76%	Singh <i>et al.</i> , 2023
Compost (straw + manure) + Trichoderma	-Soybean -Quinoa	1.8 t/ha 2.5 t/ha	2.2 t/ha 2.9 t/ha	+22% +16%	El-Gamal ,2020
<i>Tithonia diversifolia</i> (organic contribution)	Maize	-885.5 kg/ha	-1398.1 kg/ha	40-80%	Mukendi <i>et al.</i> , 2017
Mycorrhizal fungi	Broad bean ( <i>Vicia faba</i> L.)	5296 t/ha	5874 t/ha	+10.9%	Al-Zubaidi <i>et al.</i> , 2024
Algae extracts + Rhizobium + Trichoderma	Maize	-	-	11.8%	Alvarez <i>et al.</i> , 2024
Azospirillum or Azotobacter + Manure	Maize	-	-	20-30%	Fadalla <i>et al.</i> , 2016

Treatment/main formulation	Crops	Production		Rate of yield increase	Reference
		Witness Yield	Yield-treatment		
Biofertilizer Consortium + Trichoderma	Rice	7.1 t/ha	7.9 -10.1 t/ha	11.3 - 42.3%	Simarmata <i>et al.</i> , 2016
Strains of <i>Bradyrhizobium japonicum</i>	Soybean	5535 kg/ha	9207 kg/ha	66.4%	Argaw <i>et al.</i> , 2014
Control (without fertilizer) and Bio-organic (agricultural waste) 100% substitution of CF	Winter wheat	3241.05 t /ha	5629.15 t/ha	+42.4 %	Duan <i>et al.</i> , 2023
Green manure ( <i>Sesbania</i> ) + Biofertilizers	Rice Basmati	3.64 t/ha	5.24- 5.43 t/ha	25.8- 49.2%	Kumawat <i>et al.</i> , 2023
Compost from household waste (20 t/ha)	Tomato	22.4 t/ha	38.7 t/ha	72.7%	Basheer <i>et al.</i> , 2023
Azotobacter + Soil inoculation and FYM inoculation	Maize	Stover : 3.83 t ha-1 Grain : 2.83 t ha-1	-Stover : 6.39- 11.92 t ha-1 -Grain : 4.06- 6.62 t ha-1	-15 to 35%	Baral & Adhikari 2014
Chemical fertilization with combined chemical and BOF treatment ( <i>Bacillus amyloliquefaciens</i> )	Cotton	-	-	19.82– 28.17%	Yu <i>et al.</i> , 2025
Organic + biochar + straw return	Black weat			17.3% over F	Zou <i>et al.</i> , 2025
Inoculation with Rhizobium + Various doses of nitrogen +Phosphorus from TSP	Soybean variety Belessa-95	-	-	-75 - 76.8% (vs control)	Getachew & Abeble ,2020
Control = 100% chemical fertilizer, 75% chemical + bio-organic (Trichoderma)	Tomate	82.85 (kg/plot)	86.78 (kg/plot)	+4.7	Ye <i>et al.</i> , 2020
Control = 100% chemical fertilizer, High organic + chemical dose	Maize (albic soil)	12000	1 4 370	+19.7%	Ma <i>et al.</i> , 2025
Bio-organic + amendment (fulvic acid, etc.)	Rice	-	-	(4 %-15 %) compare to CK	Xiao <i>et al.</i> , 2025

RDF: recommended dose of chemical fertilizer, PSB: phosphate solubilizing bacteria, TSP: triple Superphosphate, NT: no-till system, FS: Fallow soil, MOP: muriate of potash, CB: consortia of biofertilizers, CB-T: consortia of biofertilizers combined with *Trichoderma sp.*, CS: composted straw, CF: Chemical fertilizer, CK: no fertilization as a control, bio-organic fertilizers (BOFs)

The analysis of the results presented in the above table shows that the increase in yield results from the simultaneous effect of nutrients and microbial activity on the assimilation of mineral elements. Treatments combining both manure or compost and microbial agents such as *Trichoderma*, PSB specifically for rice and tomato, have a high productivity performance in grains and straw. Additional performance metrics documented include dry matter, plant height, stem diameter, leaf area index, pod count per plant, and seed count per pod. Crop-specific responses also have an important influence on yields. Indeed, some crops such as rice and soybeans show a rate of increase that can reach more than 60%, while maize and quinoa show moderate increases ranging from 10 to 40%.

## **6. Impact of organic fertilizers and biofertilizers on the nutritional quality of crops**

The utilization of biofertilizers and organic fertilizers enhances both soil characteristics and the quality of biomass harvested. This substantial enhancement in the physicochemical and nutritional quality of the soil accounts for the rise in macro- and micro-nutrient levels in crops. Many crops with free and symbiotic nitrogen-fixing bacteria can enhance crop quality by augmenting protein content and improving the bioavailability of micronutrients for human absorption (Bargaz *et al.*, 2018). Conversely, phosphorus-mobilizing microorganisms are acknowledged and efficient instruments for enhancing the mineral nutrition, aroma, and flavor profile of tomatoes (Bíró *et al.*, 2018).

Furthermore, El-Gamal (2020) asserts that organic fertilizers and biofertilizers enhance the concentration and uptake of nutrients, including nitrogen, phosphorus, and potassium, in the grains and straw of crops such as soybeans, corn, and quinoa, in contrast to mineral fertilizers. Kumawat *et al.* (2023) demonstrated that the application of these integrated biological inputs, such as *Azospirillum*, *Azotobacter*, *Rhizobium*, phosphate-solubilizing bacteria (PSB), potassium-solubilizing bacteria (KSB), and cellulolytic fungi (*Aspergillus awamori*, *Trichoderma viride*, *Phanerochaete chrysosporum*, and *Aspergillus wolulens*), enhanced the protein content and concentrations of macro- and micronutrients in rice, wheat, and mung bean grains. Comparable findings have been documented by other researchers, particularly Borna *et al.* (2025) and Ferreira *et al.* (2025).

Negi *et al.* (2021) demonstrated the efficacy of farmyard manure (FYM) and vermicompost, in conjunction with biofertilizers, to enhance the nutritional quality of strawberries. Such treatments have contributed to the improvement of their phenolic compound content, total soluble solids and total sugars content as well as their antioxidant capacity. Similarly, various results confirming the improvement in nutritional quality, including increased protein levels, were reported by Zayed *et al.* (2012) and Sadafzadeh *et al.* (2023).

## **7. Organic fertilizers and biofertilizers as a pillar of organic farming systems**

Organic soil amendments are an effective strategy to reduce dependence on chemical inputs. Their application increases crop productivity by giving yields comparable or even superior to those of chemical fertilizers. They contribute to maintaining ecological balance while mitigating pollution (Corrado *et al.*, 2018) and preserving beneficial soil microorganisms (Mahmud *et al.*, 2021).

However, various studies already carried out show that the use of biofertilizers offers a financial advantage because it reduces the production costs to be incurred compared to inorganic fertilizers (Corrado *et al.*, 2018; Elias *et al.*, 2022). Apart from immediate interest, their use reduces future needs and inputs, leading to better health and increased productivity in the long term (Corrado *et al.*, 2018; Li *et al.*, 2023).

Another significant importance is that organic fertilization strengthens the resilience of agricultural systems to various environmental challenges (Yadav and Sarkar, 2019; Tiwari *et al.*, 2023). Moreover, it is an effective strategy for improving global food security while preserving ecosystems. Thus, their integration into agricultural practices allows farmers to improve management and optimize the use of available resources (Nosheen *et al.*, 2021; Asad and Ahamed, 2024).

## **CONCLUSIONS**

This study highlights the dual function of converting organic waste into soil nutrient sources. It highlights that this strategy allows on the one hand to manage the waste produced and on the other hand to promote organic farming. Indeed, this strategy is part of a circular economy approach because it starts from the production, the recovery of organic waste, and the use of fertilizers to increase crop productivity. Despite the technological advances already implemented, challenges related to the transformation of organic waste into sources of fertilizers and their application remain observable. To overcome these challenges, future research on organic fertilization could advance towards a technological integration of nanoscience, microbial ecology and polymer engineering.

## **ACKNOWLEDGMENT**

The authors express their deep gratitude to the scientific publication support center of Ibn Tofail University in Kenitra for their support in the success of this article.

## **CONFLICT OF INTEREST**

The authors have declared that no competing interests exist.

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