AgriSustain-An International Journal ISSN: 3139-2598 Agriculture

Review

Organic Waste Recycling for Soil Amendments : Advancing Circular Bioeconomy and Soil Health Restoration

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Abstract

The recycling of organic waste into soil supplements is an essential component of the circular bio economy, providing a long-term and regenerative solution to a range of environmental issues. With growing global worries about soil degradation, decreased agricultural output, and an increasing volume of organic waste, this technique offers a way to convert trash into a valuable resource. Organic resources such as food scraps, agricultural residues, animal manure, and green waste can be turned into nutrient-rich soil amendments by composting, vermicomposting, anaerobic digestion, or biochar synthesis. These additives improve soil structure, fertility, microbial diversity, and water-holding capacity, while also contributing significantly to carbon sequestration and climate change mitigation. This strategy not only decreases the need for chemical fertilizers, but it also diverts biodegradable trash from landfills, lowering methane emissions and contributing to a more sustainable waste management system. This closed-loop system, which is part of a circular bio economy, recycles biological resources, supports sustainable agriculture, and promotes local economic development by providing green jobs and lowering farmers' input costs. By incorporating organic waste recycling into agricultural and urban design, we can recover degraded soils, boost food security, and transition to a more resilient, low-carbon future. This strategy offers a comprehensive, scalable, and effective answer to sustainable land use and environmental regeneration.

Keywords: Soil Amendments, Organic Waste, Soil Fertility, Nutrient Recycling and Microbial Diversity

OPEN ACCESS

CITATION

Kumar, S.; Dhyani, B.P.; Shahi, U.P.; Kumar, S.; Singh, S.P.; Kumar, Y.; Pathak, D.; Pal, R. Organic Waste Recycling for Soil Amendments: Advancing Circular Bioeconomy and Soil Health Restoration. *AgriSustain -an International Journal,* 2026, 04(2), 17-25.

ARTICLE INFORMATION

Received: 20 May 2026

Accepted: 10 June 2026

Published: 01 July 2026

DOI: 10.5281/zenodo.21767851

Introduction

The term organic waste describes biodegradable materials derived from plants, animals, and other natural sources. Crop residues, weeds, straw, and husk are examples of agricultural materials; manure, bedding soaked in urine, and chicken litter are examples of animal wastes; leftover food, tea leaves, vegetable peels, and fruit trash are examples of kitchen scraps (Adegbeye *et al.*, 2020).

Along with agro-industrial wastes like press mud, bagasse, rice bran, and molasses, organic waste also includes items from gardens and landscapes such leaves, grass clippings, and small branches. Through the action of microbes, these wastes naturally break down into valuable organic materials. Organic waste can be a valuable resource for improving soil if it is properly managed and recycled.

It promotes microbial activity, improves soil structure, increases soil organic carbon, supplies vital nutrients, and fosters long-term soil fertility (Ahmad *et al.*, 2007). By transforming materials into nutrient-rich soil amendments that promote

Organic Waste as Soil Amendments

Recycling organic waste into soil amendments is essential for boosting sustainable agricultural systems, enhancing soil fertility, and restoring soil health (Scotti *et al.*, 2015). Crop residue, animal dung, kitchen litter, and agro-industrial byproducts are examples of organic waste that contribute useful organic matter to the soil, improving its chemical, biological, and physical characteristics. Humus, which is created when organic waste breaks down, increases aggregation, decreases bulk density, and enhances porosity, all of which lead to improved aeration, root penetration, and water infiltration (Ibrrahim *et al.*, 2016). Adding organic matter improves the soil's ability to retain water, increasing its resistance to drought and lowering the requirement for irrigation. Chemically derived organic amendments improve nutrient availability and decrease dependency on synthetic fertilizers by acting as a slow-release source of vital nutrients like nitrogen, phosphorus, potassium and micronutrients (Kumar *et al.*, 2025 & Pandey *et al.*, 2023a).

In terms of biology, recycled organic waste encourages the development of earthworms, beneficial bacteria, and other soil organisms which drive natural decomposition and nutrient cycling. These organisms help in the transformation of complicated organic compounds into forms that are easily absorbed by plants (Chatterjee *et al.*, 2017).

Additionally, using organic amendments promotes long-term ecological balance, increases soil resilience, and enhances soil biodiversity. Recycling organic waste also avoids environmental issues including greenhouse gas emissions, landfill buildup, and residue burning (Yoshida *et al.*, 2012). It lowers pollution, encourages the conversion of waste to resources, and supports a circular agricultural economy. Organic amendments also reduce the soil erosion, degradation, and fertility loss by increasing soil organic carbon. In general, adding organic waste to soil amendments is crucial for long-term agricultural sustainability, improving crop output, maintaining soil health, and protecting the environment (Singh *et al.*, 2022). In recent years, the idea of a circular bioeconomy is generated a lot of interest as a practical way to solve healthy plant growth and sustain ecological balance, recycling organic waste not only reduces environmental pollution and the load on landfills, but it also plays a critical role in sustainable agriculture (Biswas *et al.*, 2024).

environmental problems and promote sustainable development. Recycling organic waste into beneficial assets that support economies and ecosystems is one of the main foundations of this approach. Converting organic waste into soil amendments is one of the most promising ways to use it. These amendments are essential for improving agricultural production, restoring soil health, and reducing climate change (Urra *et al.*, 2019).

Bio-Economy

An economic system focused on the sustainable production of food, energy, substances, and other products from biological resources such as plants, animals, microbes, and organic waste is known as the bioeconomy. The bioeconomy combines renewable biological resources and modern technologies like biotechnology, bioengineering, and bioprocessing to produce ecologically friendly solutions rather than depending on fossil fuels or non-renewable resources. Natural materials are effectively recycled and reused in a bioeconomy, which reduces waste, pollution, and promotes long-term ecological balance (Aguilar *et al.*, 2019). Biofuels, bioplastics, organic fertilizers, bio-based chemicals, compost made from organic waste, and biodegradable materials are a few examples of items from the bioeconomy (Yusuf *et al.*, 2024). Promoting sustainable development, lowering reliance on fossil fuels, saving natural ecosystems, and generating renewable employment are the objectives of the bioeconomy. In general, it promotes a circular system that ensures economic progress while protecting the environment through careful application and regeneration of biological resources.

The Circular Bioeconomy Concept

A circular bioeconomy ensures that organic resources are recycled and utilized instead of being thrown away by emphasizing the ongoing cycle of materials. A circular bioeconomy places more emphasis on sustainability, waste reduction, and the economical use of natural resources than the conventional linear economy, which adheres to a "take, make, dispose" approach. By using this strategy, organic waste can be reintegrated into the food chain, improving soil health, lowering carbon emissions, and producing goods with additional value for both rural and urban areas (Muscat *et al.*, 2021).

Bioeconomy Strategy and Its Relation to Soil

A national or international approach that encourages the sustainable use of biological resources- such as plants, microbes, animals, forests, and organic waste-to promote social well-being, economic growth, and environmental protection is known as a bioeconomy strategy. The strategy's main objectives are encouraging green technologies, replacing non-renewable resources with renewable bio-based materials, improve recycling systems, and advancing biotechnology, bioenergy, bioproducts, and sustainable agriculture. Because it is one of the most significant biological resources supporting food production, nutrient cycling, carbon storage, and ecosystem stability, soil is crucial to this framework. A robust bioeconomy strategy acknowledges that biomass production, biodiversity preservation, and the long-term viability of industrial and agricultural systems all depend on healthy soils. There is a close connection between soil and the bioeconomy. Crop growth, biofuel production, forestry support, and the production of other bio-based raw materials are all made possible by healthy soils (Yusuf & Ojedokun, 2024). A bioeconomy strategy encourages recycling organic waste, composting, the use of biofertilizers, conservation farming, and regenerative agriculture. These methods improve soil organic matter, nutrient availability, water-holding capacity, and microbial diversity (Prashar *et al*., 2025). These methods lessen the need for chemical fertilizers, improve soil carbon sequestration, and lessen soil degradation all of which contribute to the mitigation of climate change. Additionally, the policy promotes the use of bio-based goods, such as bioplastics and bioenergy, which lessen pollution of the environment and soil ecosystems. By encouraging sustainable land management, recycling biological resources, restoring degraded lands, and increasing soil biodiversity, the bioeconomy strategy improves soil health (Anikwe & Ife., 2023). Thus, a steady supply of biomass, food security, environmental resilience, and long-term economic gains are all guaranteed by healthy soils. Because soil sustains the bioeconomy and the bioeconomy strengthens soils for future generations, the relationship is circular and mutually beneficial.

Need to Convert Organic Waste into Soil Amendments

The need to transform organic waste into soil supplements originates from the increasing issues of soil degradation, decreased soil fertility, environmental contamination, and higher demands on agricultural systems. Organic waste, including agricultural residues, livestock manure, food scraps, and agro-industrial byproducts, is generated in vast quantities, and if not properly managed, it leads to landfill accumulation, greenhouse gas emissions, unpleasant odors, and water contamination. Instead of allowing this trash to become an environmental burden, recycling it into soil amendments supports soil health and sustainable agriculture. Organic amendments improve soil structure, boost organic carbon, increase water retention, and promote nutrient cycling (Tiwari *et al*., 2024). They provide critical nutrients in a slow-release manner, increasing soil fertility without relying on synthetic fertilizers (Alvarenga *et al*., 2017). Converting organic waste into compost, vermicompost, biofertilizers, or biochar increases microbial diversity and soil biological activity, which is essential for good plant growth (Kumar et al., 2025). This recycling process additionally conforms to the ideas of a circular economy, in which waste is converted into a valuable resource while decreasing pollution and protecting natural habitats. As a result, turning organic waste to soil amendments is critical not just for sustainable agriculture, but also for protecting the environment, climatic resilience, and long-term soil productivity (Masullo *et al*., 2017).

Impact of Organic Waste on Soil Health

Improvement of Soil Fertility

Soil fertility improvement is critical for long-term agricultural productivity and crop production durability (Shang *et al*., 2014). Organic waste, when turned into soil amendments, offers vital nutrients, including nitrogen, phosphorus, potassium, and micronutrients in a slow-release form, assuring a consistent supply for plants. Organic matter boosts soil organic carbon, increases cation exchange capacity, and improves nutrient retention (Kumar & Pathak, 2025). This reduces nitrogen losses owing to leaching while increasing fertilizer efficiency. Organic amendments also help to build humus, which enriches the soil and increases its buffering ability. As a result, plants thrive, yields rise, and the soil remains productive for future cropping seasons (Hiranmai *et al*., 2024 & Pal *et al*., 2025).

Enhancement of Soil Biological Activity

Boosting soil biological activity serves as essential for a healthy and functional soil environment. When organic waste is recycled into soil amendments, it delivers nourishment to beneficial living things like bacteria, fungus, actinomycetes, and earthworms (Chatterjee *et al*., 2017). These organisms use natural processes to decompose organic materials, release nutrients, and enhance soil structure. Their activities promote nutrient cycling, humus formation, and disease suppression by competing with dangerous pathogens. Increased microbial diversity improves soil resilience and increases plant development (Pedrinho *et al*., 2024). Active soil life also aids in residue decomposition, which improves soil aeration and aggregation. Overall, increased biological activity promotes soil health and productivity (Pandey *et al*., 2023b).

Minimize the Dependency of Chemical Fertilizers

By delivering a sustainable and natural supply of nutrients, turning organic waste into soil amendments significantly reduces the need for synthetic nutrients. By releasing nutrients gradually, organic materials ensure long-term availability and minimize the frequency of fertilizer treatments (Kumar *et al*., 2025). In addition to saving farmers money on inputs, this reduces the possibility of nutrient imbalances and soil deterioration brought on by overuse of chemicals. Reduced reliance on artificial fertilizers avoids salinity, acidity, and the loss of helpful microbes in the soil. Additionally, it reduces pollution in the environment, supports integrated nutrient management, and advances environmentally friendly farming methods (Kumar & Pathak, 2025). Ultimately, while preserving soil productivity, organic additions promote sustainable agriculture (Ansari *et al*., 2019).

Environmental Protection

As reducing pollution and preserving natural resources, recycling organic waste into soil supplements is essential to environmental protection. Composting and vermicomposting turn trash into useful inputs instead of burning crop residues or disposing of organic waste in landfills (Singh *et al*., 2011). This reduces groundwater contamination, unpleasant odors, and greenhouse gas emissions. By enhancing soil carbon sequestration, organic amendments help slow down global warming and repair degraded areas (Sachan *et al*., 2024). Additionally, they lessen the use of chemical fertilizers, which stops dangerous materials from running off into rivers and lakes. Organic waste recycling promotes a cleaner environment and better ecosystems by lowering trash creation and encouraging natural nutrient cycling (Singh *et al*., 2024).

Improved Soil Structure and Water-Holding Capacity

Soil structure and moisture retention are significantly enhanced by organic fertilizers made from recovered trash. Organic matter increases porosity and decreases compaction by binding soil particles into stable aggregates (Kumar *et al*., 2024). Aeration, microbiological activity, and root penetration are all improved by improved soil structure. Additionally, better aggregation lessens surface crusting and erosion. The soil's ability to keep water is increased by organic components acting as sponges, which is crucial during dry spells. This lessens the need for watering and gives plants access to moisture for longer periods of time. Organic amendments make soil more resilient and productive by improving both structure and moisture balance (Singh *et al*., 2023).

Promotion of Circular Economy

By transforming waste into a useful resource, the circular economy is greatly supported by the conversion of organic waste into soil supplements. Recycling techniques including composting, vermicomposting, and biochar synthesis restore nutrients to the soil rather than burning or disposing of organic matter in landfills. This lessens reliance on outside inputs and closes the nutrition loop. A circular system encourages sustainable farming methods, reduces waste, and preserves natural resources. It promotes green jobs, lessens pollution in the environment, and improves ecological equilibrium. The circular economy enhances food systems, safeguards the environment, and fosters long-term sustainability by guaranteeing the ongoing reuse of biological elements (Alonso *et al*., 2020).

Common Organic Waste Recycling Methods

There are several methods to recycle organic waste into soil amendments, each with its unique benefits:

Composting

Composting is an environmentally responsible way to improve soil fertility since it encourages sustainable agriculture and reduces reliance on chemical fertilizers by recycling organic materials. In the natural biological process of composting, microorganisms like bacteria and fungi convert organic waste-such as crop leftovers, kitchen scraps, leaves, and animal manure-into humus that is rich in nutrients (Bashi *et al*., 2025). In order to sustain microbial activity, this process needs sufficient oxygen, moisture, and temperature. In addition to decreasing waste volume, effectively managed composting turns it into a stable soil supplement that is high in vital nutrients like potassium, phosphate, and nitrogen. Compost boosts microbial activity, strengthens the soil's ability to hold water, and helps prevent plant diseases. Additionally, it helps reduce greenhouse gas emissions by sequestering carbon (Odlare *et al.*, 2011).

Vermicomposting

Earthworms, typically species like *Eisenia fetida* or *Eudrilus eugeniae*, are used in vermicomposting to break down organic waste into fine, nutrient-rich vermicast. Compared to conventional compost, earthworms' castings have a better nutrient availability since they eat organic matter. Vermicompost is an excellent organic fertilizer because it is full of helpful microorganisms, enzymes, and compounds that promote plant growth (Lim *et al.*, 2015 & Kumar et al., 2024). Worm survival is favoured by this mechanism, which functions best in damp, dark, and aerated environments. Vermicomposting stimulates soil biological activity, root development, nutrient cycling, and soil aeration(Kumar *et al.*, 2024 and Kumar *et al.*, 2025). Additionally, it offers quicker decomposition than traditional composting. Vermicomposting is commonly used by farmers to effectively manage farm waste and create a useful amendment that enhances crop output and soil health in a sustainable manner (Kumar *et al.*, 2025).

Biochar Production

Pyrolysis is a method that produces biochar by heating biomass, such as wood chips, crop leftovers, or manure, in the absence or almost absence of oxygen. While doing this, organic matter is transformed into biochar, a stable solid that is rich in carbon. Biochar improves soil structure, boosts water-holding capacity, and improves nutrient retention (Fu *et al.*, 2019). Its porous nature fosters the biological health of the soil by providing dwellings for helpful microorganisms (Khan *et al.*, 2024), Additionally, biochar helps lessen nutrient leaching and can increase fertilizer effectiveness. It is a useful technique for mitigating climate change because, crucially, it keeps carbon in a stable state for hundreds to thousands of years (Alkharabsheh *et al.*, 2021). Biochar is produce using waste biomass, which promotes trash recycling and sustainable agriculture.

Liquid Fertilizer Production

The process of creating nutrient-rich liquid formulations from organic materials like compost, plant wastes, animal manure, and kitchen trash is known as liquid fertilizer. Fermentation, aerobic digestion, and nutrient extraction from vermicompost or compost are common techniques (Kalita *et al.*, 2025). Nutrients including nitrogen, potassium, micronutrients, amino acids, and compounds that promote plant growth are easily accessible when using liquid fertilizers. They are simple to administer using drip irrigation or foliar sprays, guaranteeing rapid nutrient absorption and enhanced plant growth. Liquid organic fertilizers promote microbial activity, improve root development, and quickly address vitamin deficiencies (Varshini & Jayanthi, 2020). They help lessen reliance on chemical fertilizers and are inexpensive to grow on farms. This technique recycles trash into useful inputs for crop production, enhances nutrient-use efficiency, and promotes sustainable agriculture (Brichi *et al.*, 2023).

Environmental and Economic Benefits of Recycling Organic Waste

Organic waste recycling has several economic and environmental benefits that promote resource-efficient development, healthy ecosystems, and sustainable agriculture. Large amounts of biodegradable waste are kept out of landfills by recycling techniques like composting, vermicomposting, anaerobic digestion, and biochar synthesis (Sharma *et al.*, 2019). Methane, a major greenhouse gas that contributes to climate change, is produced when organic waste breaks down in landfills (Kiehbadroudinezhad *et al.*, 2024).

Methane emissions are greatly decreased by treating the waste using specified techniques. Recycling organic matter also improves soil structure, water-holding capacity, and aeration by adding stable carbon to the soil (Bashir *et al.*, 2021). This promotes the growth of roots and strengthens the soil's resistance to drought and heavy precipitation. In addition to increasing beneficial microbial activity and decreasing the demand for chemical fertilizers, the return of organic matter also lowers soil and water pollution (Dixit *et al.*, 2024). Compost, vermicompost, liquid fertilizers, fermented matter, and biochar are just a few of the valuable products that may be produced economically by recycling organic waste (Dey *et al.*, 2026). These products increase long-term soil production and lessen farmers' dependency on expensive synthetic fertilizers. Additionally, anaerobic digestion systems produce biogas, which can be utilized for heating, cooking, or the generation of power, providing extra revenue or savings. Organic amendments are produced and sold locally, boosting rural economies and generating jobs (Masullo, 2017). Organic waste recycling promotes resource efficiency and lowers waste disposal costs, which helps farmers, communities, and the environment (Matisic *et al.*, 2024).

Some crucial actions must be done to fully exploit the potential of recycling organic waste for soil restoration:

1. ***Infrastructure Development:*** Both urban and rural areas need to have efficient waste collection, sorting, and processing systems. This entails establishing facilities specifically for composting and encouraging localized recycling initiatives.
2. ***Policy Support and Subsidies:*** By establishing laws that promote sustainable waste management techniques and provide benefits for the recycling of organic waste, governments can play a significant role. This can involve requiring the diversion of organic waste from landfills or providing incentives for composting companies.
3. ***Public Education and Awareness:*** Educating the public about the advantages of recycling organic waste and applying soil amendments is essential for fostering community involvement. Educational initiatives can encourage businesses and individuals to take initiative, cutting waste and promoting sustainable local agriculture.
4. ***Cooperation Between Sectors:*** To promote innovation and investment in organic waste recycling technologies, cooperation between governments, corporations, non-governmental organizations, and local communities is essential. We can build a more effective and long-lasting circular bioeconomy by coordinating our efforts.

Conclusion

A key element of the circular bioeconomy, recycling organic waste into soil amendments has significant beneficial impacts on the environment and the economy. This method turns trash into a useful resource by turning materials like crop leftovers, food waste, and animal manure into valuable products like compost, vermicompost, biochar, and microbial digestate. These additives contribute to healthier and more resilient soils by increasing microbial activity, improving soil fertility, and improving nutrient availability. Higher agricultural yields are supported by healthier soils, which also reduce the demand for artificial fertilizers, saving farmers money and reducing pollution. In terms of the environment, recycling organic waste maintains a lot of biodegradable materials out of waste dumps, in which they normally emit the powerful greenhouse gas methane. alternative methods like the creation of biochar and composting aid in the sequestration of carbon, which helps to mitigate climate change. By enhancing soil structure, boosting water-holding capacity, and promoting biodiversity, this technique also increases ecosystem resilience.
Economically speaking, turning compost into useful soil inputs lowers waste management costs, generates new revenue streams, and encourages sustainable farming methods. Recycling organic waste will be essential to promoting circular economies, lowering environmental pressures, and promoting long-term sustainability in food production as societies move toward greener and more resource-efficient systems.

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