IQRO JURNALI , IQRO JOURNAL, ИКРО ЖУРНАЛИ
ISSN:2181-4341| wordlyknowledge.uz/index.php/iqro
Volume 24. Issue 01. Oktabr, 2026

EFFECTS OF RECYCLED ORGANIC WASTE-BASED FERTILIZERS ON PLANT GROWTH, NUTRIENT UPTAKE, AND CROP YIELD

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https://doi.org/10.5281/zenodo.23371777

Abstract. The growing volume of urban, agricultural, and agro-industrial organic waste creates both an environmental burden and an opportunity for nutrient recycling. This narrative review synthesizes peer-reviewed evidence on the effects of fertilizers produced from recycled organic waste, namely compost, vermicompost, anaerobic digestate, and biochar-based materials, on plant growth, nutrient uptake, and crop yield. The reviewed literature indicates that properly stabilized materials generally increase soil organic matter, nutrient supply, and microbial activity, and can sustain yields comparable to, and in some cases higher than, those obtained with mineral fertilizers, especially when both are used in combination. Responses, however, depend strongly on feedstock, processing, application rate, soil properties, and crop species. Immaturity, salinity, heavy metals, ammonia losses, and nutrient imbalance remain important constraints. Standardized quality control and site-specific dosing, supported by precision agriculture tools, are recommended to make recycled organic fertilizers a reliable component of sustainable crop production.

Keywords: organic waste recycling; compost; vermicompost; digestate; biochar; nutrient uptake; crop yield; sustainable agriculture

1. Introduction

Agricultural production must expand to meet rising food demand. The Food and Agriculture Organization estimated that global food production would need to increase by roughly 60% between 2005/07 and 2050 (Alexandratos & Bruinsma, 2012). Intensive production with mineral fertilizers has been central to past yield gains, but it has also been associated with nutrient losses, soil degradation, and environmental costs (Tilman et al., 2002). Finding nutrient sources that support yields while protecting soil resources is therefore a priority for sustainable agriculture.

At the same time, societies generate very large quantities of organic waste. Global municipal solid waste was estimated at 2.01 billion tonnes in 2016 and is projected to reach 3.40 billion tonnes by 2050, with food and green waste forming the largest single fraction at about 44% (Kaza et al., 2018). When landfilled or left untreated, this material contributes to

greenhouse gas emissions, leachate, and loss of nutrients. Agriculture and food processing add further streams of manure, crop residues, and by-products.

Converting these streams into fertilizers through composting, vermicomposting, anaerobic digestion, or pyrolysis returns carbon and nutrients to soil and fits the logic of a circular economy. Organic amendments are known to improve soil fertility, structure, and biological activity (Diacono & Montemurro, 2010; Scotti et al., 2015). However, recycled organic fertilizers are chemically and biologically heterogeneous, and their agronomic performance is not uniform across studies. A consolidated view of their effects on plant performance is needed to guide practice.

The aim of this review is to summarize the evidence on how recycled organic waste-based fertilizers affect (i) plant growth, (ii) nutrient uptake, and (iii) crop yield, to identify the factors that explain variability among studies, and to outline practical recommendations and research gaps.

2. Research Methodology

2.1 Review design

A narrative review was conducted. Its reporting was guided by the transparency principles of the PRISMA 2020 statement (Page et al., 2021), although no formal meta-analysis was performed by the present authors. Quantitative statements in this article are taken from published meta-analyses or primary studies and are cited accordingly.

2.2 Literature search and selection

Relevant publications were searched in Scopus, Web of Science, and Google Scholar using combinations of the terms “recycled organic waste”, “compost”, “vermicompost”, “anaerobic digestate”, “biochar”, “organic fertilizer”, “plant growth”, “nutrient uptake”, and “crop yield”. Peer-reviewed articles, review papers, and authoritative institutional reports were considered. Studies were retained if they evaluated fertilizers derived from recycled organic materials and reported at least one plant-related outcome (growth, nutrient uptake, or yield). Studies on non-recycled amendments, or without a clearly described material, were excluded.

2.3 Data extraction and synthesis

From each source, the fertilizer type and feedstock, crop, application rate, soil context, and reported outcomes were recorded. Because experimental designs and units differ widely, findings were synthesized qualitatively and grouped by fertilizer type and by outcome. Where meta-analytic estimates were available, they were preferred over single-study results.

3. Results

3.1 Main types of recycled organic waste-based fertilizers

Four groups of materials dominate the literature. Table 1 summarizes their feedstocks, reported effects, and main constraints.

Table 1. Main types of recycled organic waste-based fertilizers and their reported agronomic effects

Fertilizer type	Typical feedstock	Main effects reported	Main constraints	Key sources
Compost	Green and food waste, manure, crop residues	Raises soil organic matter; slow-release N, P, K; better structure and water retention	Immaturity, N immobilization, salinity, heavy metals (MSW compost)	Hargreaves et al. (2008); Bernal et al. (2009)
Vermicompost	Manure, food and plant waste processed by earthworms	Improved growth and marketable yield at moderate rates; bioactive compounds	Variable quality; high rates may reduce growth	Atiyeh et al. (2000); Arancon et al. (2004)
Anaerobic digestate	Manure, food waste, agro-industrial residues	High share of plant-available ammonium N; fertilizer value comparable to mineral N	Ammonia losses, high moisture, contaminant control	Möller & Müller (2012); Alburquerque et al. (2012)
Biochar-based materials	Pyrolyzed woody and crop residues, often co-composted	Liming effect, water retention; average yield gain of about 10% in meta-analysis	Effect depends on soil and feedstock; low nutrient content alone	Jeffery et al. (2011); Lehmann & Joseph (2015)

3.2 Effects on plant growth

Composts supply nutrients gradually and improve the physical environment of the root zone, including porosity, aggregate stability, and water retention (Diacono & Montemurro, 2010; Hargreaves et al., 2008). Vermicomposts have attracted particular attention because they often stimulate germination, seedling growth, and flowering at moderate application rates. In horticultural container media and soil, vermicompost improved plant growth, and the response frequently peaked when it formed a relatively small proportion of the substrate (Atiyeh et al., 2000). In a field study on strawberry, vermicompost increased plant growth and marketable yield compared with inorganic fertilizer alone (Arancon et al., 2004). Such effects are attributed not only to nutrients but also to plant growth-regulating substances and humic fractions in the material (Edwards et al., 2011).

Growth responses to biochar are more conditional. Biochar can raise soil pH, increase water retention, and improve nutrient retention, which benefits crops on acidic or coarse-textured soils (Lehmann & Joseph, 2015). Its effect on growth is therefore strongly soil-dependent.

3.3 Effects on nutrient uptake

Nutrient availability differs markedly among materials. In composts, a large part of nitrogen is in organic forms and is released slowly, so mineralization may not match crop demand in the first season. Immature compost may even cause temporary nitrogen immobilization, which is why maturity criteria are essential for quality assurance (Bernal et al., 2009). Anaerobic digestate behaves differently: digestion converts a considerable share of organic nitrogen into ammonium, so digestate is a faster-acting nitrogen source, and its nitrogen fertilizer value can approach that

of mineral fertilizer when ammonia losses are controlled (Möller & Müller, 2012). Field and pot studies of digestates from farm and agro-industrial residues similarly confirm their fertilizing potential, with performance depending on the feedstock and on dry matter and ammonium content (Alburquerque et al., 2012).

Beyond direct nutrient supply, organic fertilizers can improve nutrient uptake indirectly by increasing cation exchange capacity, stimulating root development, and supporting the microbial processes that mobilize phosphorus and other elements (Scotti et al., 2015). Phosphorus and potassium in composts and digestates are largely plant-available, which allows partial replacement of mineral sources.

3.4 Effects on soil microbial communities

Microbial biomass and enzyme activities are widely used as sensitive indicators of soil quality, although their interpretation requires care (Bünemann et al., 2018). Repeated additions of organic amendments generally increase soil organic carbon and microbial activity, which supports nutrient cycling (Diacono & Montemurro, 2010). In addition, mature composts can suppress several soil-borne plant diseases through the activity of a diverse microbial community, an effect that depends on the compost substrate and on the degree of stabilization (Hoitink & Boehm, 1999). This biological component helps explain why plant responses to organic fertilizers sometimes exceed what their nutrient content alone would predict.

3.5 Effects on crop yield

Reviews of long-term experiments show that organic amendments tend to increase crop yields, with the strongest benefits appearing after several years of repeated application as soil organic matter accumulates (Diacono & Montemurro, 2010). Studies of composted municipal solid waste report increased yields in many crops, together with improvements in soil organic matter and nutrient status (Hargreaves et al., 2008). For biochar, a meta-analysis found an average yield increase of about 10%, with the largest responses on acidic and coarse-textured soils and smaller or no responses on fertile soils (Jeffery et al., 2011). Digestate can replace a substantial part of mineral nitrogen without yield loss when application is well timed and losses are limited (Möller & Müller, 2012).

Most evidence indicates that the best results are often obtained when organic and mineral sources are combined, because the mineral component meets early crop demand while the organic component builds soil fertility and supplies nutrients later (Scotti et al., 2015).

4. Discussion

The reviewed studies converge on a consistent picture: recycled organic waste-based fertilizers can support plant growth, nutrient uptake, and yield, but the magnitude of the effect is conditional. Three groups of factors explain most of the variability. First, the feedstock and the treatment process determine nutrient concentration, carbon-to-nitrogen ratio, stability, and contaminant load. Second, the application rate and timing determine whether nutrient release matches crop demand. Third, soil and climate determine how the amendment interacts with existing fertility; benefits are generally larger in degraded, acidic, sandy, or low-organic-matter soils than in already fertile ones.

Several risks must be managed. Composts from mixed municipal waste may contain heavy metals or other contaminants, and soluble salts can harm sensitive crops, particularly in arid and

semi-arid regions where soils are already saline (Hargreaves et al., 2008). Immature materials may inhibit germination or immobilize nitrogen (Bernal et al., 2009). Digestate is vulnerable to ammonia volatilization if surface-applied without incorporation (Möller & Müller, 2012). High rates of vermicompost or compost may not improve, and may even reduce, plant growth (Atiyeh et al., 2000). These risks argue for routine laboratory characterization of each batch and for compliance with quality standards.

Compared with mineral fertilizers, recycled organic fertilizers act more slowly and have more variable nutrient content, so they are seldom a complete one-to-one substitute in the short term. Their value lies in combining nutrient supply with soil improvement and in closing nutrient loops. Integrated nutrient management that blends organic and mineral inputs therefore appears the most practical strategy.

This review has limitations. As a narrative synthesis it does not provide a pooled quantitative estimate across fertilizer types, and published studies are biased toward positive results and toward short-term experiments. Comparisons are also hampered by inconsistent reporting of material properties. Future work should include long-term field trials, standardized reporting of fertilizer characteristics, assessment of food-safety and contaminant dynamics, and economic and life-cycle analysis. Sensor-based soil mapping and variable-rate application, which are central to precision agriculture, could allow organic fertilizers to be dosed according to within-field variability and so reduce the risks of over- or under-application.

5. Conclusions and Recommendations

Fertilizers derived from recycled organic waste are a credible and sustainable complement to mineral fertilization. When properly stabilized and applied, compost, vermicompost, digestate, and biochar-based materials improve soil properties, support nutrient uptake and plant growth, and can maintain or increase crop yields. Their effectiveness depends on material quality, dose, and soil context.

Based on the evidence reviewed, the following recommendations are proposed: (1) use only stabilized and mature materials and test each batch for nutrients, salinity, and contaminants; (2) match application rates to crop demand and soil analysis rather than applying fixed doses; (3) combine organic and mineral sources to balance early nutrient supply and long-term soil improvement; (4) incorporate digestate or apply it with low-emission techniques to limit ammonia losses; and (5) support adoption through quality standards, farmer training, and long-term field monitoring.

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