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Compost as a sustainable tool for greenhouse horticultural productivity: benefits, limitations, and state of the art

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Greenhouse horticulture plays a vital role in modern agriculture, offering a controlled environment for the cultivation of high-value crops while mitigating the adverse effects of climate variability. However, its intensive nature requires sustainable soil management strategies to maintain productivity and long-term fertility. This review, conducted following a PRISMA-based systematic methodology and synthesizing peer-reviewed studies published between 2015 and 2025, evaluates the role of compost as a sustainable soil amendment in greenhouse systems. Quantitative evidence indicates that compost application can enhance crop yield (up to 20–40%), improve soil health, and increase nutrient availability. In addition to these benefits, compost contributes to circular economy principles through organic waste valorization and reduced reliance on synthetic inputs. Nevertheless, limitations such as variability in composition, salinity risks, and nutrient imbalances are critically discussed, highlighting the need for optimized management strategies. Particular emphasis is placed on application rate, compost maturity, and incorporation methods to maximize agro-nomic benefits while minimizing environmental risks. Overall, compost represents a promising pathway for sustainable intensification in greenhouse horticulture, with strong global relevance for food security under climate change and resource constrained conditions.

KEYWORDS

circular economy, fertility, nutrient dynamics, ornamental crops, sustainable agriculture, vegetables

1 Introduction

Climate change poses a significant challenge to global agriculture, affecting crop production and threatening food supply, especially in regions with inherent agricultural constraints, such as arid and semi-arid areas (Goddek et al., 2023). Greenhouse horticulture is a key driver of global food security, enabling intensive crop production under controlled environmental conditions while reducing crop losses associated with extreme climate events and fluctuations. With the global population estimated to reach 9.7 billion by 2050, food demand is expected to increase by approximately 35–55% (Hussain et al., 2025). In this context, greenhouse cultivation offers a viable solution by significantly enhancing agricultural productivity and allowing

year-round production, ensuring a stable food supply and reducing seasonal market fluctuations (Koukounaras, 2021). Additionally, greenhouse technologies support diversification by facilitating cultivation of high-value crops in regions where farming is constrained by poor soil conditions and limited water availability (Argento et al., 2024).

In recent years, the global greenhouse horticulture market has been experiencing a rapid expansion. In many countries, particularly within the European Union, greenhouse production is a key contributor to national economies (Koukounaras, 2021). The Netherlands is a global leader in greenhouse horticulture, particularly in the export of high-value ornamental and greenhouse-grown horticultural products, while Spain and Italy are the principal Mediterranean producers, accounting for 5.6 and 4.1% of the global greenhouse area, respectively (Malabadi et al., 2024).

Recently, the agricultural industry has been increasingly seeking sustainable and eco-friendly alternative strategies to promote plant growth, enhance crop production, and preserve soil quality and fertility over the long term (Pilla et al., 2023). At the same time, consumer demand for certified organic products continues to rise, driven by growing awareness of environmental and health benefits. Accordingly, government incentives are further encouraging the transition of agricultural production toward the organic farming. Greenhouse horticulture, however, entails high nutrient requirements within short growing cycles, coupled with significant nutrient removal through the harvested products (Tittarelli, 2020). As a result, meeting the nutritional needs of crops while ensuring long-term sustainability in organic systems is a considerable challenge.

In greenhouse horticulture, the integration of organic amendments, particularly compost, plays a pivotal role in enhancing soil fertility, improving crop yield, and promoting sustainable agricultural practices (EL-Mogy et al., 2024). Particularly, the intensification of greenhouse monoculture in horticultural production adversely impacts soil fertility, leading to a significant decline in soil organic matter (OM) and nutrient content, a degradation that ultimately diminishes crop productivity and threatens the long-term sustainability of intensive agricultural practices (Huang et al., 2023).

Compost, derived from the decomposition of organic materials, serves as a rich source of nutrients and as a suitable growth substrate for beneficial microorganisms, thereby improving soil structure and fertility (Manhou et al., 2026). The application of composts in greenhouse has been shown to increase nutrient availability, enhance soil microbial activity, and improve soil structure, leading to better water retention, balanced aeration, and root development (Huang et al., 2023). Hence, compost represents a viable and eco-friendly alternative to synthetic fertilizers (Hajam et al., 2023). By recycling organic waste into valuable soil conditioners, composting not only reduces the reliance on chemical fertilizers but also supports circular economy principles within the horticulture industry (Bergstrand, 2022).

This review aims at summarise the role of compost in greenhouse horticulture by examining its impact on soil fertility, nutrient availability, and overall plant growth and productivity. Additionally, the review explores optimal compost application strategies, including appropriate rates, maturity stages, and incorporation methods, to maximize agronomic benefits while ensuring long-term soil health. Furthermore, it highlights the environmental advantages of compost use, emphasizing its role in reducing agricultural waste, promoting circular economy (Domene et al., 2025), and mitigating environmental degradation.

2 Methods for literature selection and analysis

A systematic literature review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure transparency, reproducibility, and methodological rigor in the identification, screening, and selection of relevant scientific literature. The review focused exclusively on peer-reviewed publications published between 2015 and 2025 in order to capture the most recent advances in compost applications for greenhouse horticulture. A comprehensive bibliographic search was carried out across five major scientific databases: Web of Science, Scopus, ScienceDirect, Google Scholar, and ResearchGate. To maximize retrieval accuracy and relevance, advanced search filters were applied, restricting results to English-language journal articles with full-text availability. The search strategy was based on keywords, including: 'compost', 'greenhouse production', 'sustainable agriculture', 'soil health', 'organic waste recycling', 'horticulture', 'circular economy', 'agroecosystem safety' and 'soilless growing media'.

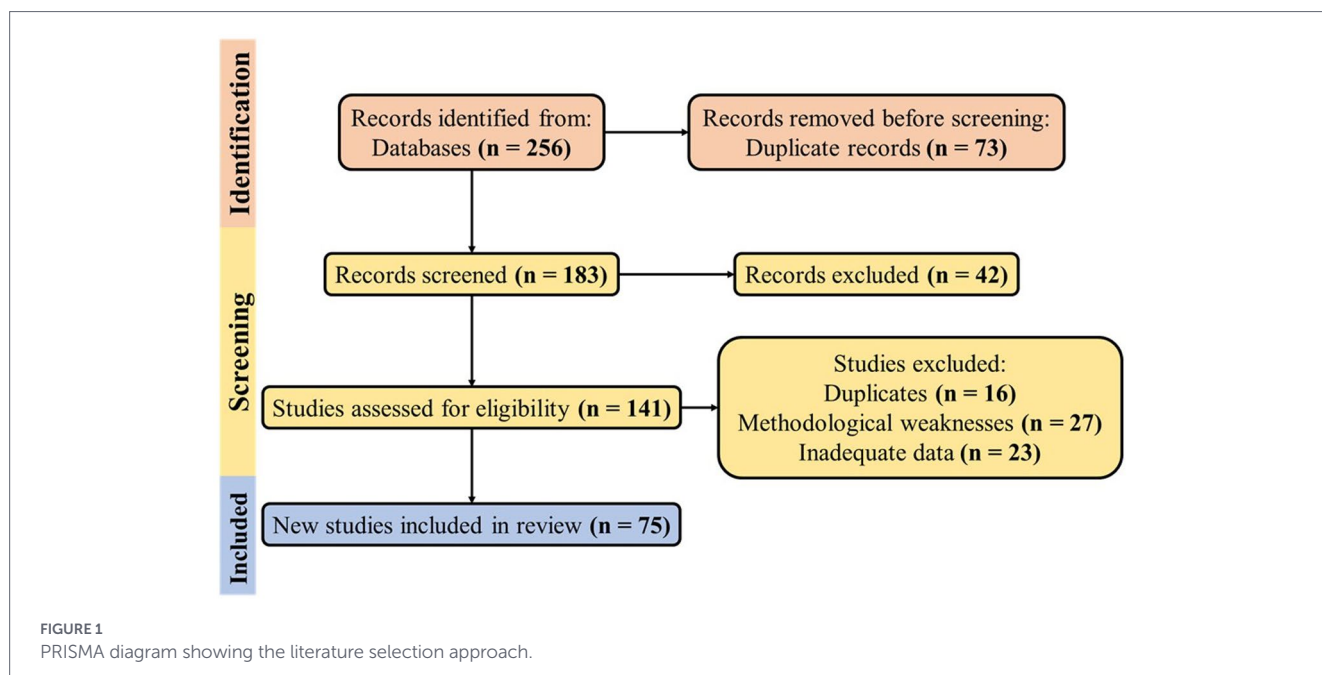
The initial search yielded 256 records. After duplicate removal ($n = 73$), 183 articles remained for title and abstract screening. A further 42 records were excluded because they were unrelated to greenhouse horticulture, focused exclusively on non-transferable open-field systems, or lacked sufficient methodological clarity. The remaining 141 full-text articles were assessed for eligibility, of which 66 were excluded due to insufficient experimental detail, lack of direct relevance to compost use in horticultural production systems, or absence of measurable agronomic, physiological, or environmental outcomes. Consequently, 75 studies were retained for final qualitative synthesis (Figure 1).

The inclusion criteria comprised studies that: (i) were published in peer-reviewed journals indexed in Scopus or Web of Science; (ii) were written in English with full text accessible online; and (iii) directly addressed compost use in horticultural systems, particularly under greenhouse or controlled cultivation conditions, with measurable outcomes related to plant growth, yield, nutrient dynamics, soil/substrate properties, or sustainability indicators. Exclusion criteria included non-peer-reviewed publications, duplicated records, grey literature, conference abstracts without full papers, studies lacking methodological transparency, and articles not directly relevant to compost applications in horticultural production.

The final dataset included 75 articles, consisting of 59 original research papers and 16 review articles. Among the experimental studies, 55 were conducted under greenhouse conditions and 4 in open-field systems explicitly retained for their comparative relevance to greenhouse compost management. Regarding crop categories, 15 studies focused on fruit crops, 31 on vegetable crops, 12 on ornamental plants, and 1 on mushroom cultivation. This structured and selective approach ensured that only scientifically robust and thematically aligned studies were included, thereby strengthening the reliability and reproducibility of the review.

2.1 Functional attributes of major compost types for greenhouse applications

Compost is a stabilized organic product resulting from the controlled aerobic biological decomposition of biodegradable materials, including agricultural residues (Waqas et al., 2023), food waste (Wang et al., 2022), and animal manure (Ji et al., 2023). This transformation,



driven by microbial communities, leads to the production of a humus-like substance rich in essential nutrients, OM, and beneficial microorganisms, which can serve as a valuable soil amendment in horticulture. Indeed, compost significantly improves soil structure by enhancing its porosity, water-holding capacity, and aeration, which are essential for optimal root development and plant growth (Bomfim et al., 2023; Sanad et al., 2026a). Moreover, compost application replenishes soil organic carbon stocks and stimulates microbial activity, fostering the proliferation of beneficial bacteria and fungi that contribute to nutrient cycling and disease suppression (Singh et al., 2024).

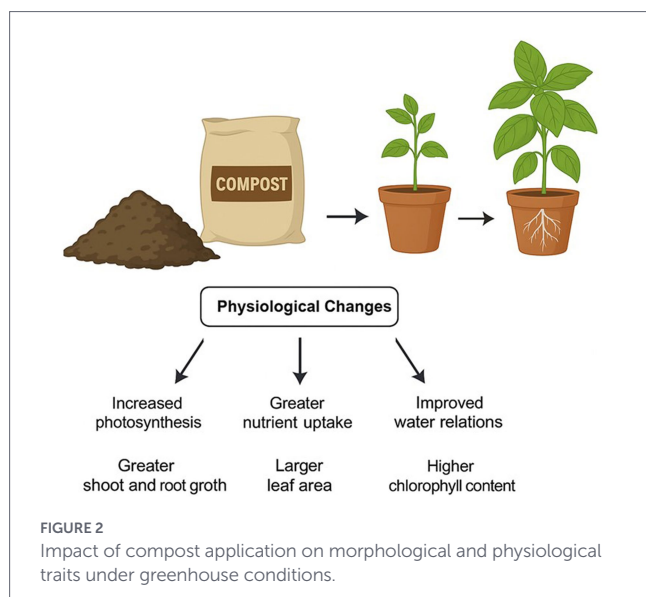
Various compost types are employed in horticulture, each offering distinct benefits tailored to specific crop requirements. Green Waste Compost (GWC), derived from plant residues such as leaves, grass clippings, and pruning materials, is rich in OM and essential nutrients. Its application has been shown to improve soil structure and water retention, leading to enhanced plant growth (Hussein et al., 2022). A study demonstrated that incorporating GWC into potting media resulted in well-developed root systems in baby leaf species (De Falco et al., 2021). Manure-based compost produced from animal manure, is rich in nitrogen and other nutrients essential for plant nutrition (Wei et al., 2022). However, its elevated salinity and high contaminant content require careful management to mitigate potential adverse effects on sensitive crops, and these factors represent significant limitations for horticultural applications (Zikeli et al., 2017). Consistently, compost derived from horse bedding showed lower performance compared to food-residual compost and fertilized peat-based media, primarily due to its higher salinity (Isaka et al., 2021). Vermicompost (VC) from non-thermophilic decomposition results from the breakdown of organic materials by earthworms and microorganisms, yielding a product rich in plant growth-promoting enzymes, hormones, and regulators (Rehman et al., 2023). The VC has been associated with improved seed germination, and plant growth and yield across various horticultural crops, and its fine texture and high nutrient content make it particularly suitable for greenhouse application (Kiyasudeen et al., 2016).

2.2 Traditional applications of compost

In greenhouse, several methods can be used for compost application to enhance the soil fertility and structure, thereby promoting the optimal plant growth. Integrating compost into the soil, a practice known as soil incorporation, enhances soil fertility by increasing OM content, improving soil structure, and optimizing nutrient availability for plant growth (Figure 2) (Sayara et al., 2020). This method improves soil aeration, water retention, and root penetration, leading to increased crop yields (Dong et al., 2022).

Another essential soil management practice is mulching (top-dressing), which involves the surface application of compost to protect and enhance soil fertility. Using compost as a mulch layer helps conserve soil moisture by minimizing water evaporation (El-Beltagi et al., 2022), regulate temperature fluctuations (Jiang et al., 2016), suppress weed growth and maintains a stable microenvironment favourable for plant health (Blanco et al., 2024). Additionally, compost mulching promotes soil microbial activity, enhancing nutrient cycling and overall soil fertility (Ni et al., 2016). However, proper management is crucial, as excessive application rates may lead to nutrient leaching, particularly of nitrates, which can pose environmental risks if not carefully monitored (Horgan et al., 2023; Sanad et al., 2026c).

Across the studies summarized in Table 1, these traditional compost application strategies consistently enhanced soil physicochemical properties and crop performance in a wide range of greenhouse grown vegetables and aromatic species. Compost incorporation improved yield, photosynthetic efficiency, and nutritional quality in tomato (*Solanum lycopersicum* L.) and pepper (*Capsicum annuum*) systems, while also modifying substrate pH and electrical conductivity (EC), underscoring the importance of rate optimization (Tortosa et al., 2018; Ouelid Lhaj et al., 2026a). Synergistic effects were reported when compost was combined with complementary amendments or management practices, such as biochar addition or regulated irrigation, resulting in improved fruit quality and nutrient uptake (Al-Harbi et al., 2020). Floricultural and aromatic crops similarly benefited from compost inputs, with enhanced biomass accumulation, flowering



dynamics, essential oil content, and water-use efficiency observed in carnation (*Dianthus caryophyllus* L.) and basil (*Ocimum basilicum* L.) production systems (Al-Mizory and Hammo, 2022; Ouelid Lhaj et al., 2025). Moreover, biologically active compost derivatives, including VC and compost tea (CT), promoted yield, fruit quality, and nutrient acquisition while supporting microbial-mediated processes and disease suppression under reduced mineral fertilization regimes (Kilic et al., 2021; Tavalı et al., 2021; Verrillo et al., 2021).

2.3 Innovative techniques

While traditional compost application methods remain prevalent in greenhouse cultivation, ongoing research has led to the development of innovative techniques that optimize nutrient efficiency and sustainability.

2.3.1 Compost-based application in soilless systems

Hydroponics systems, in which plants are grown without soil, supported by inert substrates or with their roots submerged in a nutrient solution (Fussy and Papenbrock, 2022), have emerged over the past three decades as modern cultivation technology, in areas with issues associated with greenhouse soil, including poor fertility, salinity, sodicity, soil-borne diseases, and degradation from monocropping systems (Savvas and Gruda, 2018). Europe is one of the largest markets for hydroponic systems, with France, the Netherlands, and Spain leading as the top three producers (Jan et al., 2020).

Being independent from soil, hydroponics can mitigate these problems and result in higher production, reduced use of chemical inputs such as pesticides, and increased efficiency of water and fertilizer use and the produce quality (Gonnella and Renna, 2021), minimizing water and nutrient losses (Szekely et al., 2023). It has been reported that hydroponically grown plants can grow 30–50% faster than their soil-grown counterparts, due to optimized nutrient availability and better root environment (Mofatteh et al., 2024). The integration of compost-derived extracts and CT further enhances these systems by serving as organic nutrient sources, fostering microbial diversity, and improving nutrient uptake efficiency (Giménez et al., 2020).

Studies have demonstrated that compost-based nutrient solutions can effectively replace synthetic fertilizers, either partially or entirely, without compromising crop yield, particularly for leafy greens and high-value vegetables (Table 2). For instance, Arancon et al. (2019) found that applying VC tea at concentrations of 1.6 and 3.2% in volume of nutrient solution significantly boosted lettuce (*Lactuca sativa*) yield when the nutrient solution concentration was reduced to 25% or 50% of the recommended rate. Similarly, for tomato, even lower concentrations ($\leq 0.56\%$) led to improved yields when combined with a 50% reduced nutrient solution. These findings suggest that VC tea can reduce dependency on synthetic fertilizers in hydroponics while maintaining or enhancing crop productivity, offering a more sustainable and cost-effective alternative. Additionally, the application of compost extract was found to reduce *Pythium irregulare* populations in hydroponic water, demonstrating its potential for biological disease control (Giménez et al., 2020).

Although soilless systems offer significant advantages in terms of water and nutrient management, their agronomic performance largely depends on the quality and functionality of the growing media, thereby highlighting the importance of substrate enrichment strategies using compost-based amendments.

2.3.2 Substrate enrichment

Mature compost functions as a slow-release fertilizer, supplying essential nutrients over time and improving soil fertility. Its inclusion in growth media has been linked to increased plant productivity while reducing dependence on non-renewable substrate components, thereby promoting more sustainable horticultural practices (Martins et al., 2023). In this context, reliable assessment of compost maturity is essential to ensure substrate safety and agronomic performance. In addition to conventional physicochemical indicators such as pH, EC, temperature, and C/N ratio, Pfeiffer chromatography has emerged as a practical and low-cost complementary tool for evaluating compost biological stability. This qualitative technique, based on chromatographic pattern formation, allows rapid visual assessment of humification degree, microbial activity, and stabilization level, offering an accessible field-based method for farmers and technicians, particularly in low-resource greenhouse production systems (Villalba and Acosta, 2025).

The combination of compost with other organic materials, such as peat, and coco coir, and inorganic materials, like perlite, has been shown to enhance the physical, chemical, and biological properties of growing media, thereby improving the seedling and plant performance (Adamczewska-Sowińska et al., 2021; Su and Zhang, 2024; Erdal and Aktaş, 2025). In the Mediterranean region, numerous studies have examined the effects of incorporating compost into growing media, emphasizing its positive impact on soil health and plant growth. A study conducted in Italy evaluated two organic substrates, pure compost and a compost-poultry manure mixture, as growth media for Mediterranean native species on degraded sites. Seedlings grown in the compost-poultry manure mixture, consistently showed superior performance, exhibiting higher photosynthetic rates, increased height and stem diameter, and greater biomass accumulation compared to those grown in pure compost. During summer drought, plants cultivated in the mixture maintained carbon assimilation rates up to 37% higher, demonstrating enhanced physiological resilience. Furthermore, the compost-poultry manure mixture provided improved water retention and nutrient availability,

TABLE 1 Overview of studies on compost application in different crops in Mediterranean greenhouse horticulture.

Species	Soil type	Compost composition	Application conditions	Plant growth and yield, effects on soil		Reference
				Increase	Decrease	
<i>Capsicum annuum</i>	Soilless growing media [vermiculite/perlite (1:1, v/v)]	Alperujo olive-mill and sheep manure co-compost at rates of 8, 17, and 33% (v/v) + 14.92 mM nitrate.	Compost incorporation	Vitamin C in fruit, antioxidant activity (at 33% compost), soil C and nutrients		Tortosa et al. (2018)
	Sandy Loam soil	Compost (1–2–4% v/v) + biochar (1–2–4% v/v) under PRD irrigation	Mixing compost and biochar with the soil	TSS, sugars, vitamin C, fruit N, P, Ca		Al-Harbi et al. (2020)
<i>Dianthus caryophyllus</i> L.	Sandy clay loam soil (River soil)	River soil +/– local compost (30 and 60% v/v)	Compost incorporation	Plant height, flower size, diameter, substrate nutrients	Anthesis (from 179.9 to 163.3 days)	Al-Mizory and Hammo (2022)
<i>Fragaria × ananassa</i>	Clay loam soil	VC, humic-fulvic acid, farm manure (v/v)	VC placed as a base fertilizer	Yield (190.6 g/plant), fruit size (18.8 g), TSS/acid ratio, leaf nutrient content		Kilic et al. (2021)
<i>Solanum lycopersicum</i> L.	Soil mixed with sand at 2:1 ratio	MSW compost blended at 5, 10, 20, 40% (v/v)	Substrate mixture, compost incorporation	Yield (20%), fruit quality, EC, pH, organic C	Photosynthesis at 40% compost	Tzortzakis et al. (2020)
<i>Ocimum basilicum</i> L.	Sandy loam soil	Co-composting green waste + sheep manure at 10 20 30 and 40% (v/v)	Compost incorporation	Plant height, oil %, seed weight, SOM, WHC, RWC		Oued Lhaj et al. (2025)
	Clay loamy soil	CT from vinasse at 0.5 (t/ha) and 1 (t/ha) with/without chemical fertilizer at 1 (t/ha)	Surface irrigation	Biomass (compost + chemical fertilizer), plant height, branches, fresh/dry mass, growth, oil yield, disease suppression, microbial activity		Tavali et al. (2021)
	Clay loamy soil	Humic extracts from composted artichoke residues (v/v)	Mulching	Biomass, oil, enzyme activity, soil biochemical traits		Verrillo et al. (2021)

supporting sustained growth and efficient OM uptake ([Maisto et al., 2025](#)). Other study concluded that, compost-enriched technosols improved soil properties, enhancing the photosynthetic efficiency and health status of Mediterranean tree species like green olive (*Phillyrea angustifolia*) and holm oak (*Quercus ilex*) ([Vitale et al., 2024](#)). These benefits were linked to the better soil moisture and nutrient availability, underscoring the role of compost in supporting sustainable urban greening.

In Spain, a recent study highlighted the positive impact of maize residual compost on the incorporation dynamics of carbon into a Mediterranean agricultural soil, in presence of various crops ([San-Emeterio et al., 2023](#)). The authors demonstrated that compost application enhanced soil OM content, improving nutrient availability and, at higher doses, it also contributed to a more stable soil structure,

fostering root growth and overall plant health ([Figure 3](#)). Additionally, the study suggested that compost plays a role in long-term carbon sequestration.

In Morocco, composting of green waste and phosphate washing sludge, achieving a mature compost with a C/N ratio of 12.39, was tested in greenhouse tomato ([Rahou et al., 2021](#)). When incorporated at 5, 10, and 20% (v/v) in garden soil, the 5% compost significantly improved plant growth after 9 weeks compared to the control. Another study showed that combining compost with arbuscular mycorrhizal fungi (AMF) enhanced tomato growth, including plant height, flower and fruit numbers, and biomass, even under saline conditions ([Mekkaoui et al., 2024](#)). In the same experiment, compost also improved photosynthetic efficiency and nitrogen content, mitigating the adverse effects of salinity.

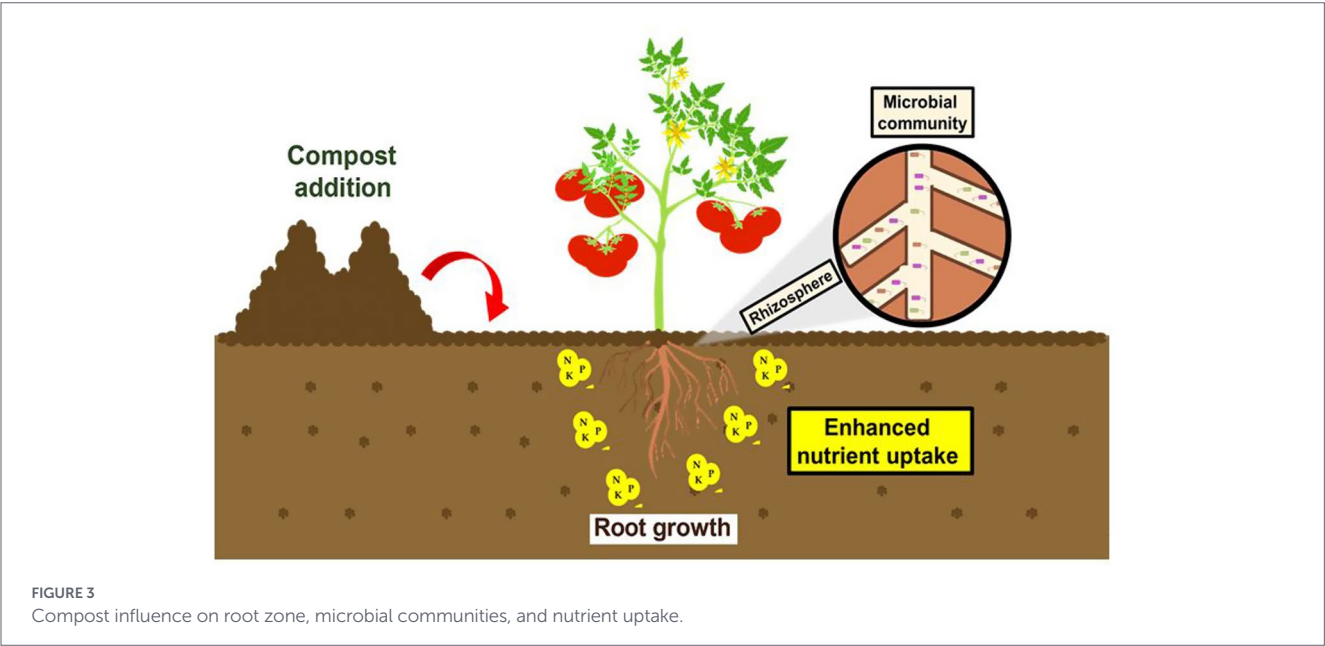
TABLE 2 Effects of compost enrichment on plant performance and productivity in greenhouse hydroponic systems.

Species	System type	Compost composition	Plant growth and yield		Country	Reference
			Increase	Decrease		
<i>Lactuca sativa</i> L.	Soilless/substrate growing media trial	Municipal solid waste compost blended into coir-based growing media Coir + municipal compost + biochar combinations (acacia biochar)	Seedling growth (12% compost +10% biochar), emergence rate		Portugal	Martins et al. (2023)
	Floating soilless cultivation system	3 composts from agro-industrial residues: tomato, leek, grape, and olive mill wastes, each with commercial peat at a 75:25 (v/v) ratio to create three growing media (GM)	Total phenolic content and antioxidant capacity, suppressive activity against <i>Pythium irregulare</i> , nitrate in leaves		Spain	Giménez et al. (2020)
<i>Lactuca sativa</i> L., <i>Solanum lycopersicum</i> L.	Static hydroponics	VC tea (from food waste-derived VC), 1.6 and 3.2% (v/v) for lettuce, 0.14, 0.28, and 0.56% (v/v) for tomato	Tomato and lettuce yield	Concentration of nutrient solution	USA	Arancon et al. (2019)
<i>Quercus pubescens</i>	Soilless/potting mix experiment	M1: 50% (municipal + green organic residues) + 35% perlite + 15% sand + Osmocote. M2: 50% (green organic residues from pruning and mowing) + 35% perlite +15% sand + Osmocote	M2: mycorrhization (59.7%), seedling survival (Mix 2: >90%), root length, number of root tips and forks, shoot diameter	Mix 1: lower survival, likely linked to phytotoxic compounds in municipal compost	Italy	Pagliarani et al. (2023)
<i>Quercus ilex</i> L., <i>Phillyrea angustifolia</i> L., <i>Laurus nobilis</i> L.	Mesocosm open-air substrate system	(1) C compost from municipal organic waste and green pruning, (2) CP a blend of the same compost mixed with poultry manure. Both substrates + clay pellets and applied above limestone debris.	CP: Photosynthetic rates, height and trunk diameter, carbon fixation (22 to 37%), nutrient availability, WHC, OM depletion, photochemical efficiency, stress resilience, transpiration rates and stomatal conductance		Italy	Maisto et al. (2025)
<i>Solanum lycopersicum</i> L., <i>Lactuca sativa</i> L., <i>Beta vulgaris</i> var. <i>cicla</i> L.	Soilless media in Urban Rooftop	3 organic feedstocks (spent coffee grounds, coffee silverskin, and seaweed biomass) composted with and without added biochar	Nutrient retention	Uptake and leaching of trace elements, P and N losses	Spain	Veliu et al. (2025)

(Continued)

TABLE 2 (Continued)

Species	System type	Compost composition	Plant growth and yield		Country	Reference
			Increase	Decrease		
<i>Pisum sativum</i> var. <i>arvense</i> L.	Static hydroponics cultivation system	VC tea prepared from VC	Overall biomass, stem length, K content, and N uptake in maple peas		China	Jiang et al. (2023)



Integrating compost into soilless systems promotes the development of microbial community, fostering distinct bacterial communities, which in turn facilitates nutrient uptake compared to non-amended substrates. Specifically, the addition of compost influenced the relative abundance of various bacterial *phyla* over time, indicating that the amendment can shape microbial communities in soilless substrates, potentially enhancing nutrient cycling processes (Valles-Ramirez et al., 2023).

The studies summarized in Table 2 confirm that compost-enriched substrates consistently improve physiological activity, nutrient retention, and crop productivity in both soilless and hydroponic systems. In baby leaf lettuce, municipal compost blended with coir enhanced emergence and growth stability (Martins et al., 2023), while agro-industrial compost–peat mixtures improved antioxidant capacity and suppressed parasitic oomycetes in floating hydroponics (Giménez et al., 2020). The VC tea increased lettuce and tomato yield even under reduced nutrient solutions, indicating improved nutrient use efficiency (Arancon et al., 2019). In woody Mediterranean species, compost-based substrates enhanced mycorrhization, survival, and drought-related carbon fixation, although municipal compost required quality control to prevent phytotoxicity (Pagliarani et al., 2023; Maisto et al., 2025). Urban rooftop substrates reduced N and P losses and improved trace element dynamics (Velu et al., 2025), while hydroponic pea systems showed improved biomass and ion uptake following VC tea application (Jiang et al., 2023).

Beyond improving the physicochemical properties of solid substrates, compost can also be valorized in liquid form, where compost-derived extracts such as compost tea provide an additional pathway to

enhance nutrient availability, microbial activity, and plant resilience in greenhouse systems.

2.3.3 Compost tea

The CT is a liquid extract derived from mature compost, enriched in soluble nutrients, humic and fulvic acids, amino acids, secondary metabolites, and diverse microbial mixes, making it a potent bio-stimulant for greenhouse horticulture (Pilla et al., 2023; Badagliacca et al., 2024). Mechanistically, CT enhances plant growth through multiple, interrelated pathways. First, the readily available nutrients and organic chelating compounds improve nutrient acquisition at the root-soil interface, accelerating ion uptake and supporting metabolic activity. Second, its rich microbial consortia promote beneficial rhizosphere processes, including nitrogen mineralization, phosphorus solubilization, and phytohormone production, which enhance root development and water uptake capacity. Third, bioactive compounds such as phenolics and organic acids can trigger systemic resistance responses, increasing plant tolerance to abiotic stresses and suppressing pathogens through competitive exclusion, antibiotic release, and enzymatic degradation (Bergstrand, 2022). The effectiveness of CT depends on several factors such as the quality of the source compost, extraction method, and microbial composition, which collectively influence its nutrient bioavailability and biocontrol potential (Singh et al., 2024).

As shown in Table 3, CT can significantly improve yield, nutrient uptake, and plant resilience in greenhouse and hydroponic systems. In Mediterranean soils, weekly applications increased lettuce, onion,

TABLE 3 CT applications in soilless and hydroponic systems: impact on crop yield, microbial activity, and disease suppression in greenhouse horticulture.

Species	Soil type/ system	Compost composition	Application conditions	Plant growth and yield, effects on soil		Reference
				Increase	Decrease	
<i>Allium cepa</i> , <i>Beta vulgaris</i> , <i>Lactuca sativa</i>	Mediterranean volcanic soils	Commercial CT from plant residues + grass straw + nitrogen-fixing hay +composted cow manure	Weekly CT applied at defined concentrations (2% w/v, diluted 1:50) under controlled greenhouse conditions	Yield ($\geq 21\%$ in lettuce), ($\geq 58\%$ onion), ($\geq 110\%$ chard)	CT microbiome dominated by <i>Pseudomonadota</i> (<i>Pseudomonas</i> , <i>Massilia</i> , <i>Sphingomonas</i>), reduced slug damage, longer shelf life	Bonanomi et al. (2025)
<i>Gossypium hirsutum</i> L.	Calcareous agricultural soil	Organic chicken manure compost amended with phosphoric acid to produce a low-pH liquid (acidic CT)	CT was topdressing the soil under drip irrigation conditions.	Root growth, total root length (18.9%), Surface area (19.9%), and root volume (20.7%)		Luo et al. (2022)
<i>Lactuca sativa</i> L., <i>Solanum lycopersicum</i>	Non-circulating hydroponics system	VC tea from food waste	Added to nutrient solutions at low concentrations (1.6–3.2% for lettuce; 0.14–0.56% for tomato) in static hydroponics	Yields when nutrient strength was (25–50%), biomass		Arancon et al. (2019)
<i>Lactuca sativa</i> L.	Hydroponics floating system	Directly brewed compost extract (agroindustrial compost)	2 methods tested: Compost extract added directly into the nutrient solution. Compost extract applied via microsprinkler (foliar/aqueous spray)	Yield and quality metrics, fresh weight and leaf biomass	Nitrate content in leaves, <i>Pythium irregulare</i> incidence in the hydroponic solution.	Giménez et al. (2020)
<i>Solanum melongena</i> L., <i>Cucumis sativus</i> L.	Greenhouse soil	CT applied via Partial Root-Zone Drying (PRD) irrigation	Weekly/seasonal irrigation with CT + PRD	Yields, well-developed plants, fruit quality		Aly et al. (2024)
<i>Portulaca oleracea</i> L.	Pots in a growth substrate composed of a mixture of native soil + sand + vermiculite	CT (Compost derived from vine pruning, leek waste, and olive mill waste)	Weekly direct application to soil with inorganic fertilizer controls	Shoot biomass, soil enzymatic activities		Carrascosa et al. (2023)

and chard yields while promoting beneficial microbial dominance and reducing pest pressure ([Bonanomi et al., 2025](#)). The application of CT resulted in a significant improvement of crop outputs, associated with better water status (i.e., increased leaf turgor), higher nutrient accumulation in plant tissues, and improved soil OM turnover, reflecting more active microbial dynamics and better soil structure. Acidified CT enhanced cotton root morphology under drip irrigation ([Luo et al., 2022](#)). In hydroponics, VC tea sustained lettuce and tomato biomass under reduced nutrient strength ([Arancon et al., 2019](#)), while compost extracts reduced nitrate accumulation and suppressed *Pythium* spp. ([Giménez et al., 2020](#)). Under partial root-zone drying,

CT increased productivity and fruit quality in eggplant (*Solanum melongena* L.) and cucumber (*Cucumis sativus* L.). The combined treatment resulted in well-developed plants, high yield and improved fruit quality, all while preserving soil nutrient levels. The authors attributed these improvements to synergistic effects between irrigation strategy and CT fertilization, which enhanced nutrient uptake efficiency while maintaining soil nutrient status ([Aly et al., 2024](#)), and in purslane it stimulated biomass and soil enzymatic activity ([Carrascosa et al., 2023](#)). Such findings are particularly relevant for Mediterranean horticulture, where declining soil fertility, reduced rainfall, and rising temperatures pose major constraints to crop productivity.

2.4 Optimization strategies

Optimizing compost application dosage and frequency is crucial to maximize their promoting effects in soil fertility and crop productivity (Isaka et al., 2021). Indeed, the impact of compost on soil structure, nutrient availability, and microbial activity depend on the rate of supply. Excessive doses can lead to nutrient imbalance and potential environmental risks (Tsai and Chang, 2020), whereas insufficient amounts may not provide the desired results on fertility (Brock et al., 2021). Ortiz-Liébaña et al. (2023) reported that the application of a formulated compost + biochar enhanced maize (*Zea mays* L.) biomass production and soil microbial activity compared to only compost, with optimal results achieved at 6% biochar and 2–5 t/ha of the final blended product, highlighting the synergistic effects of a balanced amendment. Similarly, researchers in Turkey found that applying kitchen waste compost at 0.8% (v/v) significantly increased spinach (*Spinacia oleracea* L.) growth, in terms of leaf width, stem length, and fresh and dry weight, especially when combined with chemical fertilization (15-15-15 NPK at 150 kg/ha), in greenhouse conditions. The experiment evaluated a gradient of kitchen waste compost application rates (0, 0.4, 0.8, 1.2, and 1.6% v/v) under fertilized and non-fertilized conditions, demonstrating that the combined organic–mineral strategy outperformed single-input treatments (Gürel, 2024). This further demonstrates the positive impact of compost on enhancing crop productivity in greenhouse settings.

A recent study by Anthony et al. (2024) demonstrated that even a single compost application could significantly improve plant growth, particularly of annual grasses such as *Bromus* spp. and *Avena* spp., while also increasing soil carbon stocks, suggesting that infrequent compost applications can have lasting positive effects. In Egypt, a field experiment on snap beans (*Phaseolus vulgaris* L.) showed that the recommended mineral fertilizer (MF) and 9.52 t/ha of compost applied in two equal splits at soil preparation and 30 days after sowing

produced the highest total yield, while the compost after sowing excelled in early yield. Other treatments included natural fertilizer (NF), 9.52, 14.29, and 19.05 t/ha of compost applied once at soil preparation, and 14.29 and 19.05 t/ha applied in two equal splits, which generally resulted in lower yields or nutrient content compared to the optimal MF and 9.52 t/ha compost after sowing treatments (Shehata et al., 2011). Additionally, observations over 3 years assessing soil and nutrient management practices in high tunnels revealed that yard waste-based compost (22.4 t/ha) combined with weekly liquid fish fertigation (organic liquid fertilizer from fish or fish by-products, rich in N, P, K and organic compounds) determined the highest marketable yield of pac choi (*Brassica rapa* var. *chinensis* 'Mei Qing Choi'). This increased by 11.6% compared to control without compost, and also respect to other treatments including cow manure-based compost (22.4 t/ha), VC (5.6 t/ha), and preplant application of granular organic fertilizer, generally resulting in lower yield and/or leaf nutrient content (Tian et al., 2023).

2.5 Integration with other sustainable practices

2.5.1 Combining compost with biofertilizers

Integrating compost with biofertilizers has been shown to enhance soil health and improve plant growth and productivity, making it a promising strategy for sustainable agriculture (Figure 4). This synergistic approach improves nutrient availability, strengthens plant tolerance to biotic and abiotic stresses, and improves overall soil fertility (Bergstrand, 2022; Khan et al., 2024). The experimental evidence summarized in Table 4 confirms that the combined application of composted agricultural residues and biofertilizers can markedly improve crop performance. For example, the integration of plant waste compost with microbial inoculants

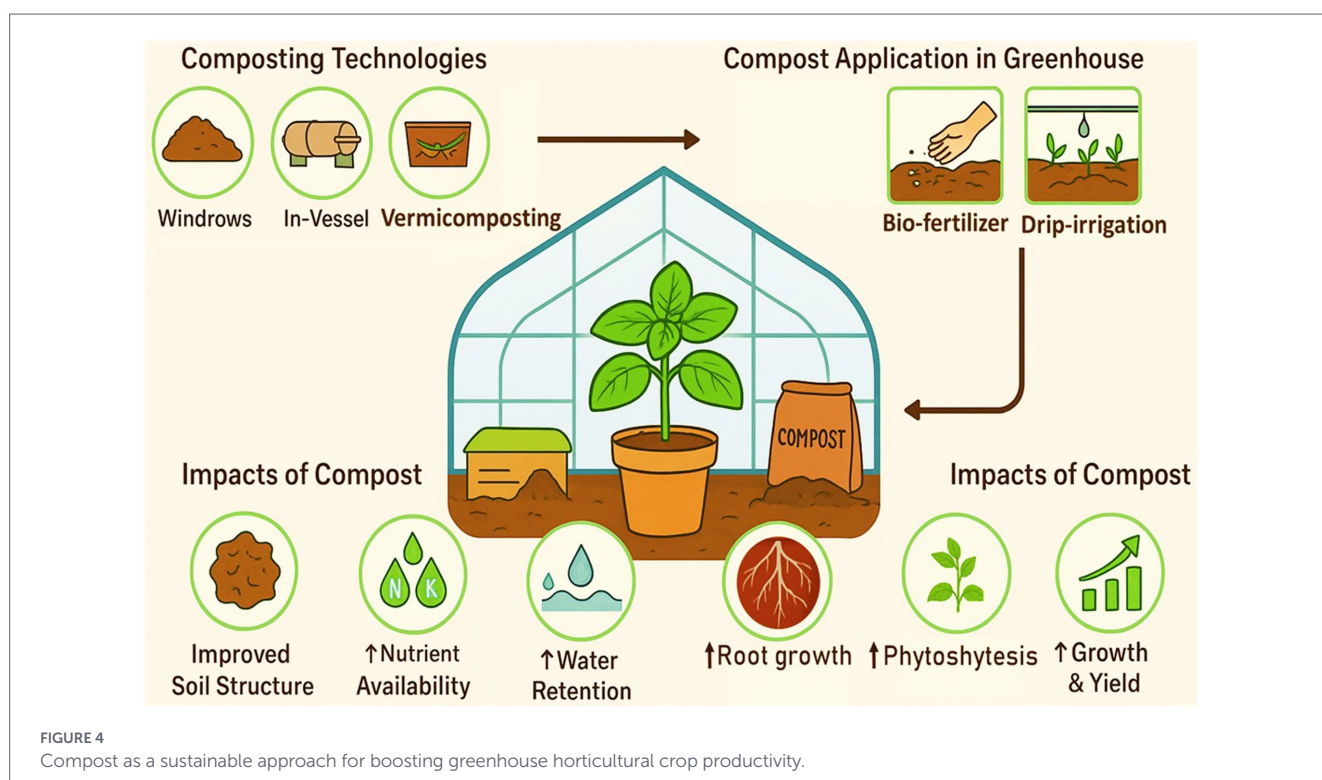


TABLE 4 Synergistic effects of compost and biofertilizers on plant performance, soil health, and stress resilience across open-field and greenhouse systems.

Species	System type	Compost composition	Application conditions	Impact on plant growth and yield		Reference
				Increase	Decrease	
<i>Capsicum annuum</i>	Open field	Agricultural waste (Spent substrate of <i>Pleurotus ostreatus</i> , spent substrate of <i>Volvariella volvacea</i> , Chicken manure) + biofertilizer	Compost incorporated into soil with microbial biofertilizer at transplanting phase.	Yield, nutrient uptake, soil fertility	Pathogen propagation (up to 81%)	Yu et al. (2019)
<i>Ceratonia siliqua</i>	Greenhouse / controlled pot experiment under drought stress	Mature organic compost (typical OM from plant residues / farm waste) + AMF	Compost combined with AMF under drought stress and recovery + mixed into soil as an amendment	Plant growth, chlorophyll content, photosynthetic efficiency, and drought resilience		Boutasknit et al. (2021)
<i>Hibiscus sabdariffa</i> L.	Pot experiment (controlled greenhouse/pot trial)	Co-composting (wheat straw and palm leaves) + household wastes + one of the three (poultry, cow, and mixed sheep and camel)	Compost combined with biofertilizer under clay-loam soil	Yield, fresh/dry sepal weight, anthocyanins and flavonoids, CO ₂ flux, microbial activity, nutrient availability (N, P, K)		Al-Sayed et al. (2023)
<i>Oryza sativa</i>	Controlled/field-like rice growing system (paddy-style substrate)	Organic fertilizer (compost-based) + biofertilizer (OF+BF)	Integrated nutrient treatments: control, organic fertilizer only, biofertilizer only, OF+BF; applied throughout growth cycle	Plant height (31%), tillers (135%), chlorophyll content (42%)		Mthiyane et al. (2024)
<i>Solanum lycopersicum</i> L.	Pot experiment with controlled salinity treatments + biostimulants applied under non-stress + salt-stress conditions.	GWC (plants and industrial wastes)	Compost (5%) and AMF applied to the soil under salt stress	Salt tolerance, biomass, PSII efficiency, water status, antioxidant activity		Mekkaoui et al. (2024)
<i>Solanum melongena</i> L., <i>Cucumis sativus</i> L.	Greenhouse horticultural system, using combined irrigation and organic fertilization techniques	CT + microbial activity	CT applied via partial root-zone drying irrigation	Crops productivity, nutrient availability, water-use efficiency		Aly et al. (2024)
<i>Zea mays</i> L.	Open field in arid agro-ecosystem	Agricultural wastes [cow manure, poultry manure, and sheep + camel manure; mixture of all three at varying rates (5–20 t/ha) + biofertilizers]	Integrated compost + biofertilizer + reduced mineral fertilizer	Biomass, grain yield, and quality, nutrient use efficiency, soil biological activity		Al-Suhaibani et al. (2021)

significantly boosted pepper yield, enhanced nutrient retention, and achieved up to 81% disease suppression compared with the control, with the strongest effects observed when the compost derived from spent mushroom substrate (Yu et al., 2019). Compost with AMF improved drought tolerance and photosynthetic efficiency in carob (*Ceratonia siliqua*) (Boutasknit et al., 2021), and enhanced salt

tolerance and antioxidant defense in tomato (Mekkaoui et al., 2024). In maize, integrated organic and biofertilizer management enhanced yield, nutrient use efficiency, and soil biological activity under arid agroecosystems (Al-Suhaibani et al., 2021). CT integrated with microbial activity also improved productivity and water-use efficiency in greenhouse vegetables (Aly et al., 2024).

Similarly, in the ornamental plant roselle (*Hibiscus sabdariffa* L.) grown in clay loam soil, the integration of compost with biofertilizers (*Azotobacter chroococcum* and *Azospirillum brasiliense*) led to increased soil CO₂ flux, improved nutrient availability (N, P, K), and resulted in superior plant performance. These improvements resulted in higher fresh and dry sepal biomass, as well as higher anthocyanin and flavonol concentration (Al-Sayed et al., 2023). Further research supported this approach on the aromatic species lavender (*Lavandula officinalis* L.) grown in clay soil, revealing that combining compost with biofertilizers (i.e., *Azospirillum* spp., *Azotobacter* spp.) and active dry yeast significantly improved plant height, branch number, biomass accumulation, and nutrient uptake (Shoeip et al., 2022). Additionally, it enhanced chlorophyll content, secondary metabolite production (phenolics, flavonoids, and other antioxidants), and endogenous hormone levels, ultimately increasing both essential oil yield and quality.

Although limited studies focused specifically on compost and biofertilizer integration in Mediterranean greenhouse horticulture, research in other contexts demonstrates its effectiveness in improving soil fertility and crop performance. The incorporation of biofertilizers such as *Rhizobium*, *Azotobacter*, and mycorrhizal fungi with compost has been shown to enhance nutrient soil availability and plant uptake, leading to greater plant growth. Recent work on rice revealed that this combination improved photosynthetic activity and regulated genes associated with chlorophyll production, further emphasizing the potential of compost-biofertilizer mixture in sustainable farming (Mthiyane et al., 2024). Consistently, a study conducted in Morocco investigated the combined effects of AMF and compost on carob seedlings under drought stress. Results showed that this combination significantly increased the leaf chlorophyll content and improved the maximum photochemical efficiency of photosystem II in treated plants compared to the untreated control. In addition to the synergic effects observed with AMF, compost-amended plants showed greater shoot height, root development, and higher shoot and root dry biomass compared to untreated controls. These improvements were associated with enhanced mineral nutrient uptake, improved soil water retention, and better photosynthetic performance (Boutasknit et al., 2021).

The development of compost-based biofertilizers, enriched with beneficial microorganisms, represents a promising, environmentally sound alternative to synthetic fertilizers, contributing to improved soil biological functioning, crop resilience, and long-term agricultural sustainability (Temoor et al., 2023).

2.5.2 Integration with cover crops

Integrating compost with cover crops is an effective strategy for fostering more resilient agroecosystems while reducing input costs, particularly under increasingly variable climate. A review on organic fertilizers and crop diversification highlighted the positive effects of combining compost and cover crops on soil fertility and crop productivity, emphasizing its potential as a sustainable agricultural practice (Khan et al., 2024). A long-term study investigating the combined effects of composted poultry litter and cover crops on soil chemistry, bacterial communities, and foodborne pathogens demonstrated significant benefits for soil health. Over 27 years, the research showed that compost amendments alongside cover crops enhanced soil microbial diversity and increased macronutrient availability, while simultaneously reducing the survival of some foodborne pathogens

like *Salmonella enterica* and *Listeria monocytogenes*. Indeed, compost-amended soils had fewer pathogens compared to non-amended soils, underscoring the potential of this combination in improving both soil health and food safety (Devarajan et al., 2021).

Further research on sustainable management in semiarid Mediterranean almond orchards demonstrated the benefits of combining compost and cover crops for soil organic carbon and nitrogen stabilization (Fernández-Soler et al., 2024). Reduced tillage with seeded or native cover crops revealed that integrating compost and cover crops significantly increased soil organic carbon and total nitrogen sequestration. Moreover, results suggested that this practice is most effective when tailored to local environmental conditions, with compost or mulching further enhancing soil quality in compacted soils, especially when combined with no-till farming techniques.

2.5.3 Integrated nutrient management

Integrating compost into nutrient management in greenhouse, particularly in the Mediterranean regions, has proven to significantly improve both soil health and crop productivity. The approach aligns with the principles of Integrated Nutrient Management (INM), which aim to reduce dependence on chemical fertilizers through the incorporation of organic amendments (Ghanbari and Khajoei-Nejad, 2021). By improving soil structure and enhancing nutrient cycling, incorporating compost into INM strategies contributes to sustained crop yields over time (Antil and Raj, 2020). Several studies have demonstrated that this not only boosts nutrient use efficiency but also supports long-term productivity (Mthiyane et al., 2024).

One study on INM strategies highlighted the positive impact of replacing a portion of chemical fertilizers with organic compost, showing that it mitigated soil degradation while improving crop production (Al-Suhaibani et al., 2021). Likewise, a long-term study conducted in Turkey examined the effects of various fertilization treatments, including compost application, on soil organic carbon and the agronomic performance of pepper, wheat, and maize (Ortas and Lal, 2014). The study found that organic fertilizers like compost increased soil organic carbon concentration and resulted in superior plant performance over time. Notably, the combination of compost and mycorrhizal inoculation yielded favourable outcomes for both soil quality and crop productivity.

In Morocco's arid regions, evaluation of nitrogen use efficiency and broccoli yield under compost and synthetic fertilizer application (200 kg N/ha) indicated that combining both inputs significantly enhanced plant growth and productivity, giving the highest yield (13.5 t/ha) among all treatments tested (Aouass and Kenny, 2023). Additionally, another study in Morocco investigated the effects of organic and inorganic fertilizers on nitrogen use efficiency and fruit yield in greenhouse organic cultivation of melon, reporting that compost resulted in high agronomic efficiency, particularly in sandy loam soils, leading to higher yield and improved nitrogen utilization (Aouass et al., 2020). In a related arid agroecosystem study on maize, integrated nutrient management combining composted agricultural waste, chemical fertilizers, and biofertilizers produced the best results when either 20 t/ha of mixed manure compost (cow, poultry, and sheep/camel manure) was applied alone, or when half-dose NPK was combined with 10 t/ha compost and biofertilizers (Al-Suhaibani et al., 2021).

3 Compost and crop performance in greenhouse systems

3.1 Seed germination and early growth

The impact of compost on seed germination and seedling vigour is influenced by several factors, including compost composition, maturity, and plant species. Studies have shown that co-composted garden waste with sheep manure, especially mixtures enriched with fallen leaves, can significantly enhance germination rate, early root growth, and seedling development, but its effectiveness depends on the above-mentioned factors (Ouelid Lhaj et al., 2024). For instance, a study evaluating the suitability of on-farm green compost for baby leaf production found that its application significantly enhanced seed germination and early root growth, leading to increased shoot and root dry weight, mainly through the enhanced nutrient availability and microbial activity (De Falco et al., 2021). However, the quality and maturity of compost play a critical role in its effects on seedling vigour. Immature composts, which may contain phytotoxic compounds, can severely inhibit seed germination and root development (Domene et al., 2025). This underscores the importance of using mature compost to maximize its benefits for plant growth and health (Savvas and Gruda, 2018).

Furthermore, in cucumber the composition of compost critically influenced seedling vigour (Zapałowska et al., 2023). Specifically, a substrate comprising 25% compost from sewage sludge, sawdust, and biodegradable waste combined with 75% peat produced the most vigorous seedlings, exhibiting superior growth parameters. In contrast, substrates containing other compost types, such as those richer in sewage sludge and sawdust or VC from green waste or higher compost proportions (50–75%) generally impaired growth, likely because of suboptimal physical properties and heightened physiological stress. In parallel, the use of compost and biochar as partial substitutes for peat in growing media indicated that incorporating the inclusion of compost positively affected microbial activity and lettuce seedling development (Rozas et al., 2023). In addition, a study on compost content in substrates found that mixtures containing more than 50% compost led to a higher number of seedlings, promoting seedling vigour, particularly in greenhouse beet (*Beta vulgaris* L.) and tomato (Isaka et al., 2021).

In Morocco, compost derived from organic household waste and olive pomace enhanced the seed germination rate and promoted the early growth of fenugreek plants (*Trigonella foenum-graceum* L.) (Doughmi et al., 2023). Likewise, in Spain using compost from kitchen waste and pet faeces, germination rate was influenced by compost concentration, with the highest rate at 25% compost and a decrease in both germination and growth beyond this point, likely due to the elevated EC and potential water retention issues (Carbonel and Luciano, 2023).

3.2 Vegetative growth and biomass accumulation

As described, the application of compost has been widely recognized for its positive effects on vegetative growth parameters in various crops. A study on maize demonstrated that supplementing soil with compost and NPK fertilizer led to significant increases in plant height (up to 26%), the number of leaves per plant (up to 20%), and stem diameter (up to 22%) compared to control. Furthermore, it increased chlorophyll content (by approximately 15%), suggesting an improvement in photosynthetic capacity (Zapałowska and Jarecki,

2024). Similarly, in tomato cultivation, compost application has been shown to substantially enhance plant growth and productivity. Cozzolino et al. (2023) reported that compost incorporation increased biomass accumulation by more than 23% compared with mineral fertilization. Likewise, Durmuş and Kızılkaya (2022) found that the application of 6% compost resulted in tomato yields exceeding those obtained under only chemical fertilization by more than 15.66%. Under saline conditions, further evidence from Italy demonstrated that compost-treated tomato plants exhibited superior growth performance, including higher biomass production and fruit yield, relative to mineral-fertilized plants exposed to the same salt stress. These improvements were primarily associated with enhanced nutrient uptake efficiency and favorable metabolic adjustments induced by compost application (Savy et al., 2022).

The co-application of compost with biochar and VC has been shown to further enhance plant growth and biomass production. A study on sweet pepper grown in greenhouse found that integrating these amendments significantly increased the plant height, number of branches, leaf area, and SPAD values (EL-Mogy et al., 2024). These effects were linked to the improvement in soil physicochemical and microbial properties, leading to enhanced nutrient availability and uptake. Similarly, the application of 3% VC improved photosynthetic efficiency in tomato plants, resulting in a 32.6% increase in yield (Liu et al., 2022). The addition of GWC increased soil OM, thereby boosting microbial activity, both of which contributed to improved nutrient cycling and availability, which in turn fosters better plant growth and biomass accumulation (LeBlanc and Harrigan, 2024).

An additional Italian study assessed the influence of different organic amendments, including compost from animal waste, on Swiss chard (*Beta vulgaris* L. var. *cycla*) (Libutti et al., 2020). The study found that compost application resulted in increased plant height, fresh weight, leaf number, and leaf area. Moreover, chlorophyll content was significantly elevated, indicating improved photosynthetic capacity.

4 Environmental benefits, challenges and limitations of compost use in greenhouse

The integration of composting into greenhouse agriculture offers numerous environmental benefits, with a primary focus on improving soil health, and promoting sustainable nutrient recycling. Additionally, composting helps reduce the need for chemical fertilizers and manure, the application of which can have possible effects on global warming (Jeong et al., 2019). Beyond soil health and temperature, composting plays a pivotal role in climate change mitigation by enhancing soil carbon sequestration. When compost is incorporated into soil, it not only improves fertility but also stabilizes carbon within the soil matrix, effectively acting as a carbon sink (Manea et al., 2024; Sanad et al., 2025). Research indicates that compost amendments can bolster carbon sequestration in various ecosystems, further contributing to the mitigation of climate change impact (Goddek et al., 2023). For example, in 2023 a study investigating the compost amendment in rangeland ecosystems found that it improved the aboveground plant production by over 40% and increased the belowground carbon content by 50%, highlighting its potential in the rangeland resilience to climate change (Kutos et al., 2023).

By stabilizing organic carbon during decomposition, compost contributes significantly to greenhouse gas mitigation, as the application of composted manure has been shown to generate lower net emissions than direct application of raw fresh manure, particularly in rice production systems (Jeong et al., 2019). A comprehensive analysis of 93 studies in China revealed that compost application significantly increased soil organic carbon in croplands sequestering approximately 85 teragrams of carbon per year in topsoil, contributing about 4.4% toward the nation's carbon neutrality goals between 2021 and 2060 (Chen et al., 2023). In Southern Togo, a study assessed the carbon sequestration potential of croplands amended with varying doses of compost from solid household waste. The study found that compost application led to increased soil carbon accumulation, with sequestration rates ranging from 0.105 to 0.573 tons of carbon per hectare per year under maize cultivation, and 0.048 to 0.492 tons under tomato cultivation (Mawussi et al., 2021). These findings suggest that household waste compost can significantly contribute to carbon accumulation in soil. Several studies have further examined the role of compost in enhancing soil carbon sequestration and reducing greenhouse gas emissions in agricultural systems (Chen et al., 2023). For instance, in Spain, maize compost amendment significantly improved soil organic carbon content, leading to a rapid improvement in soil quality and supporting enhanced plant growth and productivity (San-Emeterio et al., 2023).

Another important environmental benefit of composting is the indirect reduction of methane emissions, a potent greenhouse gas generated from organic waste decomposition in anaerobic landfill conditions. By diverting organic waste from landfills to composting systems, methane emissions can be significantly reduced, thereby lowering the overall environmental footprint of agricultural waste management (Nordahl et al., 2023).

On this basis, composting not only enhances soil fertility but also improves the overall ecosystem sustainability (Adugna, 2018). In this respect, composting has been linked to improvements in soil microbial diversity, supporting beneficial microbial communities and promoting a more resilient and balanced soil ecosystem (Ayilara et al., 2020).

By fostering soil biodiversity and improving nutrient cycling, compost contributes to the long-term sustainability of greenhouse agriculture. However, despite the above-mentioned possible advantages, integrating compost into greenhouse systems in the Mediterranean region, remains constrained by several technical, chemical, biological, and economic limitations that require careful management for safe and effective use. One of the primary constraints is the inconsistency in compost physiochemical and nutritional composition, which directly affects its suitability as a growing medium (Vandecasteele et al., 2022). Properties such as pH, EC, salinity and nutrient content may fluctuate significantly depending on the feedstock composition and processing methods (López et al., 2021). These variations can impact seed germination, seedling development, and nutrient balance, making the use of compost in horticulture difficult to standardize (Gavilanes-Terán et al., 2017; Manhou et al., 2025, 2026). Moreover, nutrient mineralization from compost is often slower and less predictable than that of synthetic fertilizers, which may create temporal mismatches between nutrient release and crop demand, particularly during critical growth stages in intensive greenhouse cropping systems. Therefore, systematic quality assessment and, when necessary, supplementation with mineral fertilizers remain essential to ensure agronomic reliability and crop performance (Ayilara et al., 2020).

Another critical factor is the presence in compost of soluble salts, which can pose risks of plant toxicity, particularly for sensitive crops (Ho et al., 2022). Some composts and digestates show high EC levels that may

negatively affect plant growth if not properly managed (Gondek et al., 2020). Nevertheless, research suggests that compost-based growing media can effectively reduce the dependence on peat, aligning with sustainability objectives by promoting resource recycling and minimizing environmental impact (Greco et al., 2021). However, careful monitoring and control of salt content are essential to prevent adverse effects in plants (Ho et al., 2022). Studies have indicated that optimal plant growth and nutritional quality are achieved when EC values range between 1.8 and 2.1 dS/m, while deviations from this range lead to suboptimal growth and reduced nutrient content (Yang et al., 2024). Findings suggest that plant biomass production, chlorophyll content, and total soluble proteins initially increase with rising EC but decline sharply when EC exceeds 4.0 dS/m (Bhoi et al., 2022).

At the same time, an important factor driving compost adoption in greenhouse horticulture is the scarcity of natural resources such as peat, a common component in traditional growing media. As peat extraction becomes increasingly unsustainable, composted materials have emerged as viable alternatives (Hirschler and Thrän, 2023). However, the limited availability of high-quality organic waste suitable for composting presents a significant challenge (Chen et al., 2020). Addressing this issue requires the exploration of alternative organic feedstocks and the development of more efficient composting techniques to meet the rising demand for sustainable growing media (Isaka et al., 2021).

In Spain, efforts have been made to develop composts that can partially replace peat or perlite in soilless. A study on sage (*Salvia officinalis* L.) cultivation demonstrated that compost, VC, and digestate can partially replace peat (at a 40% ratio) without negatively impacting plant nutrient uptake, essential oil yield, and leaf nutrient composition (Greco et al., 2021). Similarly, Yang and Zhang (2022) demonstrated the potential of compost-based growing media but suggested that modifications with biochar and organic fertilizers can optimize their properties, making compost more suitable for horticultural applications.

Another concern is the potential presence of pathogens in compost, which can lead to the spread of diseases in greenhouse environments, and pose risks in terms of produce safety (Ouelid Lhaj et al., 2026b). Ensuring that composting processes reach sufficiently high temperatures to eliminate pathogens is crucial, yet maintaining consistent thermophilic conditions can be difficult (Liu et al., 2023). Without proper composting protocols, there is also a risk of pathogen survival, increasing the likelihood of disease outbreaks in controlled growing conditions (Manga et al., 2023). Furthermore, compost derived from contaminated feedstocks may contain heavy metals or other harmful substances, potentially dangerous for both plant and consumer health (Abdelrahman et al., 2022; Sanad et al., 2026b).

The composting process itself presents a significant challenge, as it requires several months to produce mature compost suitable as cultivation substrate. This prolonged decomposition period can limit the timely availability of compost, particularly during peak planting seasons, necessitating the development of optimized composting methods to accelerate the process while maintaining quality. In addition, insufficiently stabilized immature compost may contain phytotoxic compounds, including ammonia, volatile organic acids, and phenolic substances, which can inhibit seed germination and impair early seedling establishment.

Furthermore, compost production demands technical expertise and infrastructure, which may not be readily accessible to all greenhouse operators (Pergola et al., 2020). Implementing proper composting techniques is essential for ensuring high-quality compost, but the complexity and resource requirements can act as barriers for some producers (Waqas

et al., 2023). Beyond production challenges, transportation costs represent a significant economic constraint in the use of compost in greenhouse horticulture. The high bulk density and moisture content of compost contribute to increased transportation costs, reducing its economic viability for some growers (Pergola et al., 2018, 2020). Despite these challenges, integrating compost into greenhouse systems offers notable benefits, including improved plant growth, soil fertility and structure. Addressing the issues of compost quality variability, nutrient inconsistency, and pathogen risks through standardized production methods and thorough nutrient management can enhance its effectiveness in greenhouse horticulture. The continued development of efficient composting strategies and the identification of alternative organic materials will be key to promote sustainable and resilient greenhouse agriculture.

5 Conclusion

Compost can enhance the growth and productivity of greenhouse crops by improving soil health and fertility, while offering a viable alternative to synthetic fertilizers. Besides, it contributes to circular economy principles through organic waste valorisation, resource recycling, and reduced reliance on non-renewable agricultural inputs, thereby supporting climate-resilient greenhouse production systems. The present review, based on the analysis of peer-reviewed studies published between 2015 and 2025, highlights that compost application can substantially improve soil structure, moisture retention, and microbial activity. However, several limitations continue to constrain its widespread adoption, including variability in compost quality, salinity-related phytotoxicity risks, potential pathogen contamination, and economic barriers linked to production and transportation costs. To maximize compost effectiveness, optimized application strategies tailored to specific crop requirements, soil types, and environmental conditions. Factors such as compost maturity application timing and rate, significantly influence its effectiveness in promoting plant performance.

In the context of increasing climate change pressures, integrating compost into greenhouse horticultural systems represents a strategic approach to promoting sustainable agriculture, strengthening food security, and enhancing environmental resilience. Although current research provides valuable insights for the rational use of compost, further efforts are still required to standardize compost quality, refine crop-specific application protocols, improve safety measures, and reinforce knowledge transfer mechanisms that facilitate the effective adoption of scientifically validated practices by farmers.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

MO: Validation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing, Resources. RM: Writing – review & editing, Funding acquisition. LM: Writing – review & editing,

Supervision, Writing – original draft. HS: Writing – original draft, Methodology, Software, Writing – review & editing. AZ: Supervision, Writing – review & editing. RS: Validation, Supervision, Writing – review & editing. RP: Writing – original draft, Methodology, Writing – review & editing, Formal analysis, Supervision.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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