Chapter

Compost Tea Quality and Fertility

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Abstract

The water extract of compost termed "compost tea" retains all the beneficial soluble bioactive components, making it a potent source of plant stimulatory and defensive compounds. The exact nature and extent of these features are, however, modified by composting system, feedstock quality, tea preparation and resultant use and management, including application dynamics of the compost tea. Compost teas contain a significant quantity of total nutrients with the majority being primary macronutrients. Secondary and micronutrient concentrations are more variable, but contents are generally insufficient to satisfy crop requirements. Noting this, compost tea use in agriculture and horticulture supports crop nutrition directly and indirectly. Improvements in soil quality have been widely reported for a range of soils and compost teas. A key feature of compost tea-amended soils is the increase in soil organic matter and microbial diversity and its associated benefits. Research on appropriates rates for field and container use show large variability associated with edapho-climatic factors and crop species. However, foliar application seems best suited to maximising the dual nutrition and phytopathogenic effects of compost tea. Regardless of the purpose of compost tea use, its positive effects on crop growth and soil fertility, whilst controlling pest and disease, make it a contemporary sustainable tool aligned to organic agriculture.

Keywords: compost tea, substrate quality, soil fertility, crop nutrition, phytostimulation

1. Introduction

Composting and vermicomposting as bioengineering processes provide dual environmental and human health benefits through the reuse and recycling of biodegradable waste as well as the production for use of a biochemically stable compost and vermicompost, respectively. Thermophilic compost and vermicompost compared to other organic amendments sequester mineral nutrients whilst allowing release in a slow to controlled manner. The material once matured is pathogen free and phytotoxicity free, containing phytostimulatory biocompounds including humic substances, plant growth regulators (PGR) and other biomolecules that have been proven to enhance crop growth and development [1]. Doan et al. [2] reported better performance of vermicompost relative to compost and manure over a 3-year corn trial. They concluded that the combination of vermicompost and biochar further improved corn yield and water availability. The superior effects of vermicompost were also reported by Goswami et al. [3] who reported a substantial improvement in soil health and nutrient availability, physical stability and microbial diversity due to compost and vermicompost application. They noted interestingly that heavy metal contamination was less significant in vermicompost-treated soils.

Research evidence supports the positive influence of composts and vermicomposts as amendments and substrate components on plant performance and soil fertility and quality. Martínez-Blanco et al. [4], Doan et al. [2], Hubbe et al. [5] and Erhart and Hartl [6] reviewed the effects of composts on plant and soil properties and summarised key mechanisms by which the positive effects may be manifested. Erhart and Hartl [6] noted that the most important benefit of using compost is the increased soil organic matter content. This assertion is functionally more important under tropical humid climates where degradation is accelerated. Composts directly supply plant-available macronutrients, with lesser amounts of micronutrients depending on substrate and composting system and conditions. Indirectly either active biocompounds or soil microbial enhancement stimulates plant performance. Improvements and sustained plant health via suppression of disease agents also add to the list of secondary mechanisms.

Compost application to soil whilst effective in addressing soil fertility and soilborne diseases is limited in responding to direct plant diseases and acute nutritional deficiencies. A derivative of compost, compost tea, provides an opportunity to expand the reach and benefit of soluble compost components. Zaccardelli et al. [7] defined compost tea as an organic liquid product derived through extraction with water from quality compost carrying useful microorganisms and moieties capable of protecting and stimulating the growth of plants. Moieties include essential nutrients that can correct nutritional deficiencies during crop production. Compost teas have been shown to contain bioactive concentrations of extractable compounds of composts. The range and concentration of extractable compounds are dependent on compost substrates, composting method and extraction protocols [8]. Xu et al. [9] studied the effects of increasing aeration on compost tea chemical properties and reported increased nutrient contents and humification with increasing aeration. Islam et al. [8] reported significant decreases in total N, organic C and organic matter and slight decreases of bacterial and fungal communities of compost teas with increasing extraction time to 6 days. Contrastingly, Hegazy et al. [10] reported increasing microbial populations with increasing extraction time although exceeding 48 h did not show significant improvement. They also found decreased microbial concentration with dilution and temperatures above 28°C. In another study on compost tea properties, Remedios Morales-Corts et al. [11] stated greater nutritional content, humic acids, salicylic acid and indole acetic acid (IAA) for aerated compost tea vs. aerated vermicompost tea, but the effect on tomato performance was non-significant.

Compost tea has evolved to include variants such as leachates, washes and extractants from other organic sources (e.g. manure) and biodynamic preparations. The application and use of compost teas in organic systems require technical clarification to ensure that the quality associated with the amendment cum fertiliser is not compromised. One key distinction is the controlled ratio of compost to water which separates compost teas from organic leachates and washes. Additionally, the incorporation of additives including molasses to boost microbial activity may or may not improve compost tea properties and provide positive effects on plant and soil health. Palmer et al. [12] inoculated compost teas with *Escherichia coli* (*E. coli*) at the start of the extraction and noted that when teas were supplemented with 1% molasses, there was a significant increase in *E. coli*. The same was not true for treatments devoid of molasses.

Non-supplement compost teas have been shown to serve as a nutrient source, improving soil fertility and crop nutrition through direct and indirect mechanisms. Taha et al. [13] observed that application of compost tea significantly increased soil bacteria (including N_2 fixing) and fungi populations along with increasing N, P and K uptake of radish leaves by 150, 90 and 253%, respectively, compared to the control. These findings were supported by Mohd Din et al. [14] who reported non-consequential effects between aerated and non-aerated extraction of compost tea on pak choi performance. Increasing yields and plant performance traits from foliar and soil application of compost teas were further reported for pepper [7], navel orange [15], tomato [16] and cucumber [17]. The occurrence of combined suppressive and biostimulatory mechanisms, sustained by microbial communities, nutrient supply and carbon-based bioactive compounds, is assumed to underlie the positive effects [16]. Molecular characterisation through NMR suggests that supramolecular organic structures contained in compost tea may be associated with the biostimulatory response [16].

The duality of compost teas makes them ideally suited as organic fertilisers with the advantage of stimulating further organic nutrient release from inherent soil organic matter. This chapter covers the nature and behaviour of this nutrient source and provides an analysis of effects and mechanisms. It intends to showcase the range of possibilities of compost teas, even to the domain of hydroponics [17], which has been dominated by inorganic nutrient sources.

2. Definitions and standards

The term "compost tea" when used in the literature covers a wide range of aqueous solutions and/or suspensions made from different organic materials via a range of processes. The lack of consensus in definition and standards supports the need for clarification and distinction in reporting on compost tea, especially where claims are purported. St. Martin [18] reported that the terms compost tea and compost extract are typically used interchangeably but argued that they should be differentiated. Scheuerell and Mahaffee [19] defined compost extracts as the filtered products of composts mixed with any solvent (usually water), but not fermented or brewed, whilst Litterick et al. [20] defined compost tea as the filtered product of compost fermented in water. As such, tea differs from extract based on steeping period, with tea associated with a significantly longer brewing time. For either extract or tea, specific concentrations are prepared primarily on a mass to volume basis. This prescribed dilution allows distinction between compost leachate and tea. Zhou et al. [21] stated that composting leachate is a complex type of organic waste water originating during the composting process as a result of the constant application of water to maintain the substrate moisture content in the range of 65–70% [22]. The fact that compost leachate is collected throughout the process further distinguishes it from compost tea, which is an extraction product of mature compost. It is expected that compost leachate may present greater phytotoxic concern. The concentration of compost leachate also remains a mystery limiting standardisation.

Compost leachate, extract and tea can be produced from either vermicompost or thermophilic compost. Edwards et al. [23] noted that the superior biochemical and physical properties of vermicompost over thermophilic compost are reflected in tea quality and subsequent plant growth, although other factors including concentration, substrate, additives and brewing methods modify the response [24]. Reported differences in the performance of vermicompost and thermophilic compost may warrant specific terminology. Vermicompost usually causes little to no phytotoxic effect on plants; therefore, it is ready for use following harvesting. Remedios Morales-Corts et al. [11] reported vermicompost tea having an EC value that was approximately fivefold lower than thermophilic compost tea from the same feedstock, inferring lower potential phytotoxicity. Thermophilic compost tends to require a prolonged mesophilic (curing) phase to ensure proper humification and reduction in phytotoxicity. The production of compost tea for use as an organic fertiliser would require greater attention to final compost quality. Hegde et al. [25] specifically mentioned that vermiwash (worm tea) contained a mixture of excretory products and mucus secretions of earthworms along with essential nutrients. Such differentiation is also important as other organic amendments apart from composts are used to produce "teas". Zarei et al. [26] compared the quality of vermicompost tea versus vermiwash from different compost sources including leaf meal and cow manure. Results indicated a significantly greater nutrient content for a 1:10 m/v aerated vermicompost tea brewed for 24 h.

Manure tea is another variant of the concept of compost tea, made from a solution that contains animal manure. Azeez et al. [27] defined manure tea as the liquid extract from manure or a solution made by soaking manure in water in order to ease the decomposition process and enhance the release of nutrients. Although similar processes may be used, there is concern over the possible presence of pathogens in manure tea [28]. There are also commercially available microbial sources such as "effective microorganisms" that may replace compost as an inoculant, if teas are primarily aimed at increasing microbial content. The practice of fortifying compost and their tea extracts has grown among composters. Some of the common additives used include kelp, molasses, fish hydrolysate, rock dust, humic acid and carrot juice along with biodynamic extracts of plants such as "comfrey" [24, 29, 30]. The primary aim of this practice is to stimulate beneficial microbes by enriching their environment with a source of food and oxygen with the expectation of increased crop protection and a general boost in plant health. Naidu et al. [30] reported a 10–100-fold increase for total bacteria, fungi and actinomycetes for enriched compost tea relative to the control (pure compost tea). The authors also further reported that the enriched compost tea remained stable for up to 4 months. On the contrary, the use of kelp and molasses favoured the growth of *E. coli* in spiked compost teas. Strict sanitation practices can therefore act as a preventative measure to compost tea contamination by pathogens. It is noteworthy that several authors, Palmer et al. [12], Kannangara et al. [31] and Brinton et al. [29], reported the absence or minor presence of human pathogens in matured composts and their teas. Carrot juice acted as an inhibitor to the proliferation of *E. coli* in compost tea [31]. The use of additives during the brewing process has a lesser effect on tea mineral nutrient content. Compost maturity is a stronger determinant of tea nutritional quality [32]. A mature compost refers to decomposed organic matter that has no phytotoxic effects on plants [33]. Griffin and Hutchinson [34] stated that mature compost generally releases higher levels of soluble nutrients and fewer phytotoxic organic acids and heavy metals than immature material. The nutrient composition of finished compost is based on initial substrate quality as well as compost maturity. Immature composts can negatively affect compost tea quality and encourage anaerobic conditions [24, 29]. Careful management of the factors controlling the composting process is therefore important in ensuring an effective compost tea is derived. Observing some key maturity indices such as C/N ratio, pH and EC can help improve decision-making on final compost quality.

Similar to the distinctions previously discussed, which focused on organic material source, compost tea may be extracted under aerated or non-aerated conditions. During aerated extraction, air is pumped through water containing compost to maintain the O_2 level above 5 mg l^{-1} [24]. St. Martin [18] noted that most of the reported literature does not identify the O_2 concentration during preparation of aerated compost tea (ACT), which may imply that wide variability exists in process standards. For passive extraction, compost is placed in a certain volume of water and allowed to steep for several days, with or without occasional stirring [35]. The term fermentation has been strongly associated with the production of non-aerated compost tea (NCT) as a consequence of the presumed anaerobic conditions. However, St. Martin [18] explained that the term "brewing" is better suited to describe the process and implies a steeping process of compost in any solvent, which lasts for more than 1 h [36]. Considering the product and the process, a more appropriate terminology might be "compost infusion". Both terms, brewing and tea, imply the use of hot water [37]. Kevin [36] provides the best definition of compost tea which encapsulates the previous discussion. Compost tea is a commercially and anecdotally popularised term for an "infusion" where compost is steeped in water for a period of time with the aim of transferring soluble organic matter, beneficial microbes and nutrients in solution.

Greater effort is required by the scientific community and compost enthusiasts to define the product and process when referring to compost infusions and related extracts. This would improve standardisation and clarity among researchers and users.

3. Compost tea as a nutrient source

3.1 Growth, development, crop nutritional status and soil fertility

Relative to their use for disease suppression or control, research into the use of compost teas and other bio-fertilisers (phytohormones and humic substances) as sources of plant essential nutrients is limited. This fact is more evident when considering effects on field-grown crops [30]. **Table 1** identifies a short but comprehensive list of research reports focused on the effects of compost tea on plant performance characteristics, crop nutritional status and soil fertility. Special attention was directed to distinguishing among treatment effects that will assist in better understanding the reported variability. Most research used either non-aerated or aerated compost teas, whilst other studies reported on manure or microbial teas, whilst still a few others used commercial mixtures labelled as compost teas. Both thermophilic compost and vermicompost were used and compared (in a few studies). Application methods, rates and frequencies as well as crops, season and soils varied across studies, making any general inference anecdotal at most.

Seminal works by Hargreaves et al. [38] investigating the comparative use of compost teas, soil-incorporated compost of the same substrates and inorganic fertiliser showed similar responses in soil fertility and plant nutritional status across treatments. Compost tea applied at 150–300 ml/2.4 m^2 weekly as a foliar spray resulted in leaf tissue N and K content of strawberries similar to plants treated with soil-incorporated compost and mineral fertiliser. N and K tissue content further correlated well in both trial years to mineralised N. At rates applied NCT was able to maintain plant nutrient status within the sufficiency range. However, the authors were concerned over the low soil test K levels under compost tea. In a previous study, Hargreaves et al. [39] reported similar nutrient-supplying potential of foliar-applied NCT on raspberry growth and development and nutrition. Lower tissue K

Compost feedstock	Brewing method/ concentration*	Crop plant	Summarised effects	Reference
Not specified	ACT, conc. not specified	Canada yew	Increases in plant biomass similar for compost tea and inorganic fertiliser. Fertiliser resulted in greater biomass allocation to shoots	Smith et al. [40]
Agro-waste compost	ACT and NCT, 10% m/v	Pak choi	Increased yield, mineral nutrient content and antioxidant levels in leaves for NCT + mineral fertiliser	Mohd Din et al. [14]
Cow dung, urine and palm sugar, milk	NCT and ACT Drench application not specified. Foliar 10%	Broccoli	Inclusion of compost tea, especially at higher doses, increased crop yield and quality. Compost + compost tea maintained soil fertility similar to mineral fertiliser	Sanwal et al. [41]
Cow manure, molasses (MT) Commercial EM	ACT and NCT 5% m/v and v/v for MT and EM, respectively	Collard and spinach	Application of MT or EM did not improve short-term yield or soil fertility	Knewtson et al. [28]
Ruminant compost MSWC	NCT 10% m/v	Strawberries	Compost teas provided equivalent levels of nutrients to strawberries compared with inorganic fertiliser Soil K levels decreased with compost tea application	Hargreaves et al. [42]
Ruminant compost MSWC	NCT 10% m/v	Strawberries	Compost teas did not improve the fruit quality and total antioxidant capacity compared to inorganic fertiliser	Hargreaves et al. [43]
MSWC	ACT 20% m/v	Strawberries	Foliar application of compost teas provided sufficient nutrients to strawberries for growth and resulted in equal yield compared to compost applications to soil	Hargreaves et al. [38]
Chicken manure vermicompost	ACT 5 and 10% m/v	Pak choi	Greatest plant response was observed with 5 and 10% tea Magnitude of response was greater under chicken manure fertilisation	Pant et al. [32]

Compost feedstock	Brewing method/ concentration*	Crop plant	Summarised effects	Reference
Not specified	Not specified	Borage	Higher rate of compost tea significantly increases plant growth and productivity	Ezz El-Din and Hendawy [44]
Manure compost	ACT 10% m/v	Water spinach	Under aquaponic conditions, yield of water spinach was significantly increased via foliar application	Bethe et al. [45]
MSWC	NCT 20% m/v	Brussels sprouts	Yields of all treatments were similar to where conventional fertiliser was used. Tea may only be useful as a supplemental fertility source applied to foliage	Radin and Warman [37]
Ruminant compost MSWC	NCT 10% m/v	Raspberries	Yield, total antioxidant capacity of fruit and vitamin C content were not affected by treatment. Compost tea supplied less K to raspberries compared to compost	Hargreaves et al. [39]
Not specified	Brew not specified 25% m/v	Basil	Compost tea in conjunction with compost improved vegetative growth and essential oils but decreased N content	Khalid et al. [46]
Not specified	Not specified	Sugar beet	Sugar yield and juice quality of increased with compost tea. Combination of compost tea with mineral N fertiliser further increased yield and quality properties	El-Gizawy et al. [47]
Farm refuse compost	ACT 10% w/v	Pomegranate	Foliar application gave greater leaf mineral and pigment content, yield and fruit parameters than soil drenching	Fayed [48]
Cow manure vermicompost	Direct leachate used	Sorghum	Leachate can be used directly without dilution. Stimulated plant development but NPK was required for maximum growth	Gutiérrez-Miceli et al. [49]
Not specified	Direct leachate 50% v/v	Curry leaf	Foliar spray increased yield over the control, especially when combined with fertiliser and manure application	Hedge et al. [25]

Compost feedstock	Brewing method/ concentration*	Crop plant	Summarised effects	Reference
Rice straw and animal manure	Brew not specified 3% m/v	Onion	Foliar application increased yield and quality when used in combination with mineral N	Mahmoud et al. [50]
Palm fruit and oil effluent (ME)	ACT, 20%	Muskmelon	Fertigation + foliar compost tea significantly increased fresh weight, TSS and other quality indices	Naidu et al. [30]
Tomato, escarole residue and wood chips	ACT, 20%	Tomato	Largest yields were showed by compost tea-managed plants, significantly exceeding those of control plots	Pane et al. [16]
Not specified	Not specified	Peppers, cucumber and sweet corn	Treatment did not affect responses	Russo and Fish [51]
Agricultural waste compost	Not specified	*Atriplex* and mesquite	Compost tea increased morphological traits and further improves soil fertility when combined with compost	Shourije et al. [52]
Cow dung, vegetable waste and 1:2 ratio mixture	Direct leachate	Strawberries	Foliar application increased marketable fruit yield of firmer fruit with improved quality attributes. Also reduced physiological disorders like albinism and malformation	Singh et al. [53]
Town refuse compost	ACT, 5% m/v	Radish	Compost tea + mineral N increased growth and yield and improved soil biochemical properties and microbial population	Taha et al. [13]
Not specified	Not specified	Cucumber	Under hydroponic production compost tea had significantly lower yield but higher antioxidant content	Santiago-López et al. [17]

**ACT, aerated compost tea; NCT, non-aerated compost tea; MT, manure tea; EM, effective microbes; ACTME, aerated compost tea with microbial enhancer; MSWC, municipal solid waste compost; ME, microbial-enriched.*

Table 1.
Summary of studies examining the effects of compost tea on crop performance and nutrient status.

content in 2 out of 3 growth years with associated lower soil K test levels suggested a lower uptake potential of K through plant leaves as K concentration in the compost teas was fairly high. The inability of foliar-applied compost teas to supplement soil available nutrient levels may pose productivity risks, especially where foliar uptake may be hindered by morphological or biochemical mechanisms. Consideration should be given to increasing frequency of application. Hargreaves et al. [42] also reported increased Na content of raspberry leaves attributed to enhanced foliar uptake. This may be an issue for compost tea foliar use in Na-sensitive plants. Lazcano and Domínguez [1] noted that the use of vermicompost tea reduces the probability of phytotoxic effects arising from elevated EC and specific ion concentrations. However, variations in compost tea quality will determine the nature and extent of plant effects.

Radin and Warman [37] reported that foliar application of compost tea showed similar pH and soil K levels to other treatments, except for higher K under organic fertiliser. Doubling the application rate of compost tea had no significant effect on tissue nutrient content and soil fertility. The lower application rate of 450 ml/5.3 m^2, similar to [38, 39], resulted in comparable P, K, Ca and S contents. Tissue Na content was similar across compost tea treatments. However, these were significantly lower than the incorporated compost treatment, which contrast findings from [42]. Both studies utilised municipal solid waste compost (MSWC) from the same source. This highlights the extent of variability reported in compost tea effects and provides a rationale to continued interest in this area. In a study on Canada yew, Smith et al. [40] reported comparable biomass as well as morphological traits (plant height) between the biodynamic compost tea and inorganic fertiliser. The authors concluded that compost tea was capable of producing similar growth characteristics with lower nutrient input than inorganic fertiliser. They noted that compost tea influenced partitioning and allocation of biomass with a favourable allocation to roots relative to shoots. The opposite was observed for inorganic fertiliser. Naidu et al. [30] suggested that biodynamic compost tea can result in improved microbial populations and stability. Mahmoud et al. [50] and Pant et al. [54] reported enhanced overall root development accompanied with better nutrient uptake by tea-treated plants than mineral fertiliser. Although Smith et al. [40] did not report tissue nutrient contents, others have indicated similar tissue nutrient contents between compost tea and mineral fertiliser [37, 39], suggestive of either favourable root allocation of nutrients or positive effects of other tea bioactive components affecting biomass accumulation. Lazcano and Dominguez [1] suggested that improvements in plant growth and productivity seem less related to the amount of nutrients available, as plant tissue nutrient content varies non-significantly between doses. Other bioactive components of compost teas clearly stimulate and enhance plant performance beyond nutrient availability. Suggestions of the presence and action of phytohormones and humic substances have been reported [55].

Compost tea use as the sole or primary nutrient source may provide adequate nutrients to maintain plant growth and development, but that depend on application rate and frequency, strength (concentration) and crop species. Santiago-López et al. [17], in one of the only studies utilising compost tea as a hydroponic fertigation solution, reported, significantly lower yields for cucumber fertigated with either compost or vermicompost tea relative to Steiner's solution. The lower yields were reflective of lower nutrient contents of the teas and, probably more critically, imbalances among nutrient concentrations. The literature supports foliar application, which seems to have a positive effect on nutrient uptake. Relative to its use as a primary nutrient source, application of compost tea in conjunction with other fertilisers or plant additives results in a superior performance. Pant et al. [32] investigated the effects of increasing dilution of compost tea on pak choi grown on soil amended with organic or inorganic fertiliser. The addition of vermicompost tea increased pak choi height as well as base diameter across all fertiliser sources. N accumulation in plant leaves followed a similar trend. This study differed in respect to nutrient uptake compared to trials where compost tea was the primary nutrient source. Similar increases in plant nutrient content, especially N, have been reported [14] with analogous explanations put forward. The influence of compost tea on N availability and uptake is an important effect that has not been fully understood and evaluated. Reviewed studies failed to investigate N use efficiency under compost tea application, an area that has tremendous global significance. Keeling et al. [56] noted with interest that compost water extracts had no effect on shoot and root development of field bean compared to oilseed rape. This finding suggests that constituents of compost tea influence N uptake and possibly assimilation and may respond to chemical equilibrium. Further, Khan et al. [57] investigating the combinatory effects of compost tea and AMF stated that nutrient stoichiometry revealed that there was a greater uptake of N under vermicompost tea than P, whilst the opposite occurred with AMF.

It is notable that compost tea application resulted in positive effects when combined with either soil-incorporated mineral fertiliser or compost across crop species. For borage [44], basil [46], sugar beet [47], curry [25], onion [50] and peppers, cucumbers and sweet corn [51], supplementation with foliar-applied compost or vermicompost tea improved aboveground morphological traits, plant nutrient content and soil fertility above control treatments. This effect was in most cases more apparent when compost tea was applied in soils amended with compost. The literature on compost tea as a nutrient source speculates that compost tea improves nutrient use efficiency. However, there has not been any study that directly measured nutrient uptake and use efficiency. Different methods have traditionally been employed in investigating nutrient effects, but these are limited by priming effects [58]. Stable isotope techniques or other direct measurement protocols need to be employed to verify the effects of compost tea on nutrient uptake and use efficiency.

Many microbial water-based extracts are commercially available or can be made following simple instructions. These extracts are sometimes not differentiated in the literature from compost teas. Such terms, which may lead to misconception, are discussed in the preceding section on definitions and standards. Reports of neutral or negative effects of compost tea on plant growth and nutrition all had one common thread. Water extracts (not brewed) were made from organic sources other than compost. Knewtson et al. [28] investigated the effects of manure tea and commercial EM on collard greens and spinach as well as soil biological properties. Results of this study showed that tea application had non-significant effects across fertiliser source for plant biomass and soil biochemical properties, applied at rates and frequencies corresponding to previous reports showing positive benefits. Sanwal et al. [41] using a homemade microbial tea (made mainly from manure) reported no improvement in the use of compost tea over compost-only treatments, with both treatments outperforming synthetic fertiliser. Broccoli height, number of leaves, weight of leaves, head weight and diameter were all similar across compost and compost + compost tea treatments. No information was reported about the application methodology or the tea properties limiting an objective assessment. Variability in the depth of reporting of compost tea properties and application methodologies limits any meta-analysis or objective evaluation of results on plant growth and development. Greater attention needs to be paid by authors and publishers to ensure that such relevant information is provided.

3.2 Yield, yield components and quality

Single application of compost teas failed to result in a similar positive effect of increasing crop yield and quality likened to the effects on growth parameters [37–39]. Radin and Warman [37] reported lower but significantly similar yields of Brussels sprouts for foliar-applied compost tea than organic fertiliser and

MSWC. Hargreaves et al. [39], Hargreaves et al. [42] and Hargreaves et al. [43] using a similar MSWC all reported similar yields for strawberries and raspberries across compost tea and compost treatments. Both Radin and Warman [37] and Hargreaves et al. [42] further highlighted that yields were below average with plants showing visible nutrient deficiency symptoms. The former authors inferred through correlation analysis that reduced tissue nutrient concentrations may have resulted in lower yields for tea treatments and concluded that compost tea as a nutrient source does not provide sufficient plant nutrition. Remarkably, Hargreaves et al. [42] used rates 4–8 times greater than Radin and Warman [37] and at twice the frequency, with analogous results, although in this case compost tea values were similar to compost treatments. Contrastingly, Singh et al. [53] working on strawberries showed an increase in yield, fruit nutrient content and quality attributes compared to the control. However, the control was a no-nutrient water control. A notable difference between Singh et al. [54] and Radin and Warman [37] and Hargreaves et al. [42] is the use of vermicompost tea versus thermophilic compost tea. Whilst composts can be defined from a quality perspective in terms of stability and maturity, the processes resulting in the production of vermicompost and compost are vastly different, inferring differences in their bioactive components [59] and overall effects on crop performance.

Khalid et al. [46] and Ezz El-Din et al. [44] both investigated the combinatory effects of increasing compost tea concentration together with compost or fertiliser, respectively, on herb yields and quality. Inclusion of compost tea resulted in a significantly greater yield than the control, with the extent of increase directly related to increasing rate of compost tea supplementation [44]. Both studies showed that the concentration of essential oils and flavonoids [46] increased significantly for compost tea treatments. Increased yield has been correlated to improved growth characteristics and plant nutrient contents. However, the question remains; what mechanisms are responsible for these responses, especially where inorganic sources are applied? Are fertiliser nutrients temporarily immobilised or transformed, reducing potential loss? Or are they quickly absorbed by enhanced root systems? What is certain is that compost tea cannot supply the requisite amount of essential nutrients under field production systems; hence, the bulk of nutrients originate from the primary source when combined.

Works of El-Gizawy et al. [47] on sugar beet support the previous findings. Increased sugar yields and juice quality were aligned with increasing frequency of foliar-applied compost tea. The relative increase in sugar yield ranged from 6.5% for a one-time soil drench application to 36% with soil drenching followed by three monthly applications of compost tea. Juice quality measured by purity, sugar content and K content was significantly higher in plants treated with medium N (75 kg N/fad) and the highest frequency of compost tea. Sifola and Barbieri [60] reported that organic N sources and the combination with inorganic sources significantly improved plant height, root and shoot dry weight and oil yield of basil compared to inorganic N only. Hegde et al. [25] and Mahmoud et al. [50] showed identical findings for curry leaves and onion yield and oil content respectively. The combination of mineral fertiliser + organic manure + compost tea resulted in significantly higher yield attributes.

Akin to earlier discussed neutral and reduced effects of compost tea on plant performance, these studies reported the same for crop yield and quality components. Russo and Fish [51] investigated a commercial compost tea (PMSLA and EO-12) on peppers, cucumbers and sweet corn, Knewtson et al. [28] studied effects of commercial EM and manure tea on collard greens and spinach, and Sanwal et al. [41] investigated a traditional fresh cow manure-based tea on broccoli. Similar yields were reported across crops for comparative treatments with and without compost tea. Only for Sanwal et al. [41], who employed a fertiliser only control, did compost tea treatments show significantly higher yield and quality, but the effect was lessened by statistically similar values to compost-only treatments. A critical evaluation deciphering underlying mechanisms by which compost tea improves plant performance and specifically nutrient use efficiency will considerably add to better synthesis and use of compost tea.

4. Mechanisms of action of compost tea as nutrient sources

Similar to compost, compost tea is a microbiologically active, nutrient-rich extract, which when used to irrigate crops (foliar or soil drench) influences growth, yield, nutrition and quality directly or indirectly through chemical and/or biological mechanisms. Direct modalities involve increased nutrient supply and action of microbial bioactive compounds including humic acids and phytohormones. Indirect mechanisms operate principally on the effect of microorganisms within the compost tea on pest suppression and enhancement of microbial communities that affect direct mechanisms of nutrient uptake or production of bioactive compounds. **Table 2** provides a synthesis of reported studies elucidating mechanisms of action of compost teas.

4.1 Direct mechanisms

4.1.1 Nutrient content

Analysis of compost tea has revealed varying concentrations of plant mineral elements based on compost source, brewing methods and dilution. Pant et al. [32] investigated the effects of compost tea strength on pak choi growth and yield and reported that increasing vermicompost tea concentrations linearly and positively influenced plant growth resulting from increased concentration of mineral nutrients. Increasing amounts of available nutrients in compost tea and their relationship with crop growth have also been confirmed by [42, 61]. It has been postulated that the increased presence of soluble mineral nutrients can enhance nutrient uptake from soil and increase foliar uptake of nutrients [32]. However, this effect seems conjunctive with other chemical and possibly biological components within compost tea. Mahmoud et al. [50] claimed that the availability of mineral nutrients is greater for foliar versus drench applications. They inferred that compost tea increased the time stomata stay open, reducing loss from the leaf surface. Schönherr [62] identified polar aqueous pores which facilitate the absorption of charged ions into epidermal cells. This capability was further confirmed and explained by Kaya et al. [63] who stated that compost tea increased permeability of cellular membranes in plants to minerals which increased plant growth. In addition to the direct effects that foliar feeding has on nutrient assimilation, Fayed [48] asserted that it also has a positive priming effect and may actually promote root absorption of the same and other nutrients. Of the few studies that investigated compost tea use across different soils, Pant et al. [54] showed that soil properties modify nutrient absorption under compost tea fertilisation, with poor aeration and drainage limiting nutrient uptake. Increased nutrient uptake through compost tea has been reported to increase leaf area, which relatedly improves light interception, photosynthesis, water and nutrient use and dry matter production [64]. The importance of compost tea nutrient content to growth was reported by [49]. The authors showed that vermicompost tea explained ~50% of the growth parameters for sorghum and significantly affected total macronutrient content

Compost feedstock	Brewing method/ concentration	Compost tea properties	Summarised mechanisms	Reference
Grape pomace and manure biodynamic compost	Brewed for 8 h (aeration not confirmed) 5% m/v)	Nutrients	Direct effect of nutrients but more plausible effect of phytohormones, even though not determined	Reeve et al. [61]
Garden waste compost and vermicompost	ACT/AVT 5% v/v	Nutrients, humic acids, phytohormones, heavy metals, pathogens	Nutrient composition, humic acids, the presence of phytohormones	Remedios Morales-Corts et al. [11]
Ruminant compost MSWC	NCT 10% m/v	Nutrients	Positive effect associated with nutrient content	Hargreaves et al. [42]
Chicken manure vermicompost	ACT, NCT and augmented ACT 10% m/v	Nutrients, microbial content	Microbial and hormonal contributions along with nutritional effects	Pant et al. [54]
MSWC	ACT 20% m/v	Nutrient	Less effective in building SOM, nutrient availability, but insufficient N	Hargreaves et al. [38]
Chicken manure compost and vermicompost Green waste compost Food waste vermicompost	ACT 5 and 10% m/v	Macronutrients, humic acids, phytohormones	Positive effects largely associated with mineral N and GA_4	Pant et al. [65]
Not specified	Not specified	Nutrients and microbial content	Supply of nutrients and microbial function	Ezz El-Din and Hendawy [44]
MSWC	NCT 20% m/v	Nutrients and heavy metals	Low N availability affected P uptake inferring inadequate nutrient in tea	Radin and Warman [37]
Ruminant compost MSWC	NCT 10% m/v	Raspberries	Increased uptake of Na leading to nutrient toxicity	Hargreaves et al. [42]
Vegetable waste compost	ACT 25% v/v	Nutrients, microbial content	Physiological and nutritional biostimulation	Zaccardelli et al. [7]
Not specified	Brew not specified 25% m/v	Nutrients	Induced systemic response allowing for better growth	Khalid et al. [46]
Not specified	Not specified	Nutrients and bacterial content	Synergistic effect of beneficial microorganisms and essential micronutrients and other bioactive compounds	El-Gizawy et al. [47]

Compost feedstock	Brewing method/ concentration	Compost tea properties	Summarised mechanisms	Reference
Farm refuse compost	ACT 10% w/v	Nutrients	Nutrient availability and plant root physiological response increasing nutrient uptake	Fayed [48]
Fruit bunch and chicken manure compost	Brew not specified 20% m/v	Nutrients, microbial content	Beneficial microbes, presence of essential micronutrients and bioactive compounds	Siddiqui et al. [66]
Cow manure vermicompost	Direct leachate used	Nutrients, humic acids, microbial content	Specific mention of micronutrient stimulate in tandem with humic acids and phytohormones	Gutiérrez-Miceli et al. [49]
Rice straw and animal manure	Brew not specified 3% m/v	Nutrients, microbial content	Supply of nutrients and microbial function Asserted plant physiological effect increasing leaf nutrient absorption	Mahmoud et al. [50]
Palm fruit and oil effluent (ME)	ACT 20%	Nutrients and heavy metals	Availability of macro- and micronutrients and improved fertility of soilless media, presence of chelating agents	Naidu et al. [30]
Tomato, escarole residue and wood chips	ACT 20%	13C NMR, nutrients, Microbial content	Plant disease suppressiveness, supply of chelated nutrients and the action of humic acids and phytohormones	Pane et al. [16]
Agricultural waste compost	Not specified	Not reported	Mechanism not described	Shourije et al. [52]
Cow dung, vegetable waste and 1:2 ratio mixture	Direct leachate	Nutrients	Increased nutrient and growth regulator including humic acids	Singh et al. [53]
Biodynamic preparation (several components including compost)	Aerated ratio not specified	Chemical properties	Retention of root tip border cells which serves as bacterial trap and physical protection against pathogens	Tollefson et al. [67]

Compost feedstock	Brewing method/ concentration	Compost tea properties	Summarised mechanisms	Reference
SMC	ACT, 10% + K_H	Not reported	Improved nutrient availability and soil quality evidenced by greater CEC, OM and nutrient content	Taha et al. [13]
Rice straw compost and vermicompost, Cyprus bark compost	ACT, 10%	Chemical properties, microbial diversity	Foliar application increases speed and efficiency of nutrient uptake relative to soil drenching	Kim et al. [68]
Agro-waste compost	ACT and NCT, 10% m/v	Nutrients, microbial content	Interactive stimulatory effect of compost tea on uptake of mineral nutrients	Mohd Din et al. [14]

ACT, aerated compost tea; NCT, non-aerated compost tea; MT, manure tea; EM, effective microbes; ACTME, aerated compost tea with microbial enhancer; MSWC, municipal solid waste compost; ME, microbial-enriched; K_H, potassium humate; SMC, substrate mushroom compost.

Table 2.
Summary of reported mechanisms of action of compost tea on crop performance and nutrient status.

of plants. Due to the relatively small amount of nutrients in compost tea present in organic form, the possibility of slow release mechanisms is low. However, the presence of chelated nutrients increases availability to plants [44]. Complimentary to the supply of readily available essential nutrients, Hargreaves et al. [39] noted that compost tea produced from municipal solid waste compost (MSWC) contained high concentrations of Na^+ which when applied to leaves correlated with increased tissue Na content of raspberries. Whilst the concentration of beneficial mineral nutrients has been shown to increase through compost tea use, attention is warranted towards the presence of other soluble ions that may be harmful or toxic to plants. Characterisation of composts and compost teas should be a prerequisite to use, which can influence dilution and application rate and frequency.

4.1.2 Bioactive metabolites

There is a paucity of information on the chemical and biological properties of compost extracts, but many authors have identified and to some extent confirmed the presence of water-extractable mineral elements and biologically active metabolites such as humic acids and plant growth regulators (PGR). These latter compounds may enhance initial root development, nutrient uptake and plant growth. Keeling et al. [56] analysed compost tea by liquid chromatography mass spectrometry and identified the presence of hundreds of low (<20 kDa) molecular weight organic compounds, which may be involved in plant responses. Humic acids have been identified as an important component of compost teas, especially vermicompost teas. de Sanfilippo et al. [69] suggested that earthworm activity accelerated humification of organic matter and their influence in increasing microbial populations enhances the presence of humic acids. Humic acid stimulatory effect on plants has been explained by direct action, which is hormonal in nature, together with an indirect action on the metabolism of soil microbes and the uptake of soil nutrients by plants [70, 71]. This effect is greater on roots, resulting in increased proliferation of root hairs and enhancement of root initiation [70]. Valdrighi et al. [72] and Cacco et al. [73] reported increased N uptake associated with humic acids. The latter increases the permeability of membranes of root cells and or switch on NO_3^- transport genes in roots. There remains an open debate on the exact mechanisms of increased nutrient uptake with Panuccio et al. [74] suggesting that humic substances only stimulated NH_4^+ uptake. Consensus exists on the fact that there is activity at the cellular level. Keeling et al. [56] in their study on compost tea effects on field bean seedling performance provided strong support for the N transport mechanism effect. They reported that neither root nor shoot development was stimulated by compost tea, consistent with the notion that compost components modify transport of inorganic N compounds within roots and that N-fixing legumes are insensitive to the process. Humic acids have been also associated with increased stress tolerance and produced similar endogenous levels of osmoprotectants as exogenous levels of PGR [75].

Spaccini et al. [76] reported that ACT contained low molecular weight bioactive compounds of microbial origin. In addition to humic acids, phytohormones and other metabolites have been identified in compost teas. Arancon et al. [77] reported a small quantity (198 ng/L) of GA4 in a chicken manure-based compost tea, which resulted in significantly greater root growth. Garcia Martinez et al. [78] also found that compost aqueous extracts contained compounds with molecular structure and biological activity analogous to auxins. The range of concentrations of phytohormones in compost teas varies much like its mineral nutrient content and is reported to also have a concentration-based effect. Studies on pak choi by Pant et al. [65] showed nonquantifiable amounts of phytohormones in a range of compost teas but improved growth and yield in treatments receiving compost tea. Notwithstanding the probable effect of other bioactive compounds, it can be reasoned that only trace levels of PGRs are required to initiate a plant response. In the same study, the authors detected traces of GA4 in a mature thermophilic compost associated with specific fungal families. The specific nature of bioactive metabolic compounds in compost tea still remains unresolved. However, there is strong evidence that suggests the major effect is expressed on plant roots both at the cellular and phenotypic levels, which serves as a system for increased nutrient uptake. Further research into biochemical pathways triggered by isolated compounds from compost teas will aid in elucidating these mechanisms.

4.2 Indirect effects

4.2.1 Disease suppression

St. Martin [18] provides an extensive review of the effects and mechanisms, whereby compost tea suppresses microbial diseases, insect pests and other plant pathogens. Suppression has been attributed to direct suppression of pathogens or to the induction of systemic resistance. Other authors have suggested that improved plant health provides an indirect effect on plant growth and nutrition. Healthy plants with thick cuticles are better able to resist attack from piercing and biting insects as well as microbial infections. Hargreaves et al. [42] noted the complimentary effects of compost tea suppression of diseases on overall plant growth and nutrient uptake. Khalid et al. [46] working with basil stated that foliar-applied biotic extracts are believed to initiate a systematic response known as "induced resistance", which may act as a repellent or reduce the severity of pest and disease. The nature of this induction is uncertain, but Ezz El-Din and Hendawy [44] inferred that foliar application of compost tea provides useful microbes that colonise leaf surfaces, which probably competes with pathogens.

The nature, diversity and concentration of microorganisms present in compost tea may influence its ability to suppress pathogens or inoculate the receiving plant with beneficial microbes. The concentration and diversity of microorganisms in compost tea differ and in most instances are lower relative to the compost source. Arancon et al. [79] determined that vermicompost teas had about 1/3 of the microbial activity and diversity of the solid vermicompost (v/v). However, there was little diminution of the influence on tomato and cucumber seedling growth over the trial period. No specific family of microbes present in compost teas has been shown to have a critical role in nutrient uptake and growth of treated plants. Compost tea-related changes in soil and tissue microbial biodiversity have been reported to increase the range of biocontrol agents [80] and increase the production of defensive substances by the plant [7]. Compost tea may also impart a physical, morphological defence in plant roots through altered dispersal of border cells, which have a high affinity to trap bacteria. Tollefson et al. [69] investigating several plant species noted retention of root border cells under compost tea treatment compared to water even at high agitation.

4.2.2 Microbial inoculants

Soil application of compost tea resulted in greater presence of N fixers, actinomycetes and spore formers [81]. This supports the previous discussion on compost tea positive effect on N availability and plant uptake. Carpenter-Boggs [82] contested that compost tea is thought to act more as a microbial inoculant that stimulates soil and foliar microbial production effectiveness than as a direct nutrient source. The inoculation potential of compost tea has not been extensively researched, and it seems less likely that reported concentrations of microorganisms applied at typical dilutions and rates would serve as inoculants dominating the diversity of complex microbial systems such as soil. Reeve et al. [61] contented that at a rate of 5 g per preparation per 11 mg material, it is unlikely that the teas are effective microbial inoculants. They suggested that a more plausible mode of action may be through hormonal action.

Whether compost teas provide sufficient microorganisms to inoculate soil or other growing media may not be as critical as their stimulatory effects on indigenous microbes. Natarajan [83] suggested that microbes present in compost tea compliment activities of native microbes favouring decomposition of organic matter at a faster rate, resulting in better transformation of nutrients and their availability to crops. This position is supported by greater respiration rates and dehydrogenase activity for compost tea-treated soils arising from greater availability of active organic carbon or enrichment of nutrients for the microbes through addition of high organic carbon content compost [84]. It is notable that this response is similar for soil amended with either mineral fertilisers or compost [66]. Sanwal et al. [41] investigated broccoli performance under different nutrient management systems and found lower yield for inorganic fertiliser than compost tea plus fertiliser. They concluded that organics would increase the retention and slow release of nutrients at critical periods of crop growth and improve microbial properties.

Current knowledge suggests that compost teas work through a combination of chemical and biological mechanisms, which have not been fully unravelled. A ready supply of macro- and chelated micronutrients becomes more available to plants through hormonal action of humic acids and other phytohormones that act both on the roots and leaves. The variability that exists across compost teas' chemical and biological constituents compounded by edaphic and crop factors challenges precise determination of mechanistic effects.

5. Conclusion

There are several organic fertilisers and nutrient sources available but with few liquid options. Compost tea presents the best alternative liquid organic nutrient source for horticultural and agricultural use. Its origin in compost ensures that the product is sanitary and contains soluble constituents of the compost. By definition, being associated with mature compost also minimises the potential for phytotoxic compounds and effects on crop health and soil quality. The term compost tea must be differentiated from other extracts and from other organic sources as these may have potential negative or non-stimulatory effects. Regardless of the nature of the composting system, composting feedstock and brewing conditions, compost tea has been reported to enhance soil quality through increased microbial diversity and nutrient availability and increase crop growth and importantly yield. The latter is especially so when compost tea is combined with mineral or organic fertilisers. Several mechanisms have been posited for the altered effects associated with compost tea use including increased availability and uptake of nutrients especially when applied as a foliar treatment. Secondary mechanisms include increased soil organic matter and nutrients turnover through microbial activity. Stimulatory effects occur on plants through PGRs, humic and other biostimulatory compounds present in compost teas. Further benefit is derived through the suppression of plant pathogens which provides the best opportunity for maximum growth. As an amendment its versatility betters even its source material. Compost tea has shown potential for being an ideal beneficial product in any cropping system.

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References

[1] Lazcano C, Domínguez J. The Use of Vermicompost in Sustainable Agriculture: Impact on Plant Growth. New York, USA: Nova Science Publishers, Inc; 2011. pp. 1-23

[2] Doan TT, Rumpel C, Janeau J-L, Jouquet P, Henry-Des-Tureaux T. Impact of compost, vermicompost and biochar on soil fertility, maize yield and soil erosion in Northern Vietnam: A three year mesocosm experiment. Science of the Total Environment. 2015;**514**:147-154. Available from: https://www.researchgate.net/publication/271837945

[3] Goswami L, Nath A, Sutradhar S, Bhattacharya SS, Kalamdhad A, Vellingiri K, et al. Application of drum compost and vermicompost to improve soil health, growth, and yield parameters for tomato and cabbage plants. Journal of Environmental Management. 2017;**200**:243-252. DOI: 10.1016/j.jenvman.2017.05.073

[4] Martínez-Blanco J, Lazcano C, Christensen TH, Muñoz P, Rieradevall J, Møller J, et al. Compost benefits for agriculture evaluated by life cycle assessment. A review. Agronomy for Sustainable Development. 2013;**33**(4):721-732

[5] Hubbe MA, Nazhad M, Sánchez C. Composting of lignocellulosics. BioResources [Internet]. 2010;**5**(4):2808-2854. Available from: https://bioresources.cnr.ncsu.edu/BioRes_05/BioRes_05_4_2808_Hubbe_NS_Composting_Review_1298.pdf

[6] Erhart E, Hartl W. Genetic engineering, biofertilisation, soil quality and organic farming. In: Lichtfouse E, editor. Genetic Engineering, Biofertilisation, Soil Quality and Organic Farming [Internet]. Sustainable Agriculture Reviews. Vol. 4. Dordrecht: Springer Netherlands; 2010. pp. 311-345. Available from: http://link.springer.com/10.1007/978-90-481-8741-6

[7] Zaccardelli M, Pane C, Villecco D, Maria Palese A, Celano G. Compost tea spraying increases yield performance of pepper (*Capsicum annuum* L.) grown in greenhouse under organic farming system. Italian Journal of Agronomy. 2018;**13**(3):229-234

[8] Islam MK, Yaseen T, Traversa A, Ben Kheder M, Brunetti G, Cocozza C. Effects of the main extraction parameters on chemical and microbial characteristics of compost tea. Waste Management [Internet]. 2016;**52**:62-68. DOI: 10.1016/j.wasman.2016.03.042

[9] Xu D, Zhao S, Xiong Y, Peng C, Xu X, Si G, et al. Biological, physicochemical, and spectral properties of aerated compost extracts: Influence of aeration quantity. Communications in Soil Science and Plant Analysis [Internet]. 2015;**46**(18):2295-2310. DOI: 10.1080/00103624.2015.1081693

[10] Hegazy MI, Hussein E, Salama A, Salama A. Improving physico-chemical and microbiological quality of compost tea using different treatments during extraction. African Journal of Microbiology Research. 2015;**13**(50):763-770

[11] Remedios Morales-Corts M, Pérez-Sánchez R, Ángeles Gómez-Sánchez M. Marcelo Gonçalves de Oliveira C. Efficiency of garden waste compost teas on tomato growth and its. Scientia Agricola [Internet]. 2017;**75**(5):400-409. DOI: 10.1590/1678-992X-2016-0439

[12] Palmer AK, Evans KJ, Brown J, Ross T, Metcalf DA, Palmer AK. Potential for growth of *E. coli* in aerobic compost extract. Compost Science & Utilization. 2010;**18**(3):152-161

[13] Taha SS, Seoudi OA, Abdelaliem YF, Tolba MS, El Sayed SSF. Influence of bio-spent mushroom compost tea and potassium humate as a sustainable partial alternate source to mineral-N influence of bio-spent mushroom compost tea and potassium humate as a sustainable partial alternate source to mineral-N fertigation on. Egyptian Journal of Basic and Applied Sciences. 2018;**33**(1):103-122

[14] Mohd Din ARJ, Cheng KK, Sarmidi MR. Assessment of compost extract on yield and phytochemical contents of Pak Choi (*Brassica rapa* cv. *chinensis*) grown under different fertilizer strategies. Communications in Soil Science and Plant Analysis. 2017;**48**(3):274-284. DOI: 10.1080/00103624.2016.1269793

[15] Omar AEDK, Belal EB, El-Abd AENA. Effects of foliar application with compost tea and filtrate biogas slurry liquid on yield and fruit quality of Washington navel orange (*Citrus sinenesis* Osbeck) trees. Journal of the Air & Waste Management Association. 2012;**62**(7):767-772

[16] Pane C, Palese AM, Spaccini R, Piccolo A, Celano G, Zaccardelli M. Enhancing sustainability of a processing tomato cultivation system by using bioactive compost teas. Scientia Horticulturae [Internet]. 2016;**202**:117-124. DOI: 10.1016/j.scienta.2016.02.034

[17] Santiago-López G, Preciado-Rangel P, Sánchez-Chavez E, Esparza-Rivera JR, Fortis-Hernández M, Moreno-Reséndez A. Organic nutrient solutions in production and antioxidant capacity of cucumber fruits. Emirates Journal of Food and Agriculture. 2016;**28**(7):518-521

[18] St. Martin CCG. Potential of compost tea for suppressing plant diseases. CAB Reviews Perspectives in Agriculture Veterinary Science Nutrition and Natural Resources. 2014;**9**(032):1-38. Available from: http://www.cabi.org/cabreviews/review/20153038604

[19] Scheuerell S, Mahaffee W. Compost tea: Principles and prospects for plant disease control. Compost Science & Utilization. 2002;**10**:313-338. Available from: http://apps.webofknowledge.com.proxy.library.cornell.edu/full_record.do?product=UA&search_mode=GeneralSearch&qid=120&SID=2DeKI57IjfNd2a7JkIB&page=1&doc=1

[20] Litterick AM, Harrier L, Wallace P, Watson CA, Wood M. The role of uncomposted materials, composts, manures, and compost extracts in reducing pest and disease incidence and severity in sustainable temperate agricultural and horticultural crop production—A review. Critical Reviews in Plant Sciences. 2004;**23**:453-479

[21] Zhou C, Wang R, Zhang Y. Fertilizer efficiency and environmental risk of irrigating impatiens with composting leachate in decentralized solid waste management. Waste Management. 2010;**30**(6):1000-1005. DOI: 10.1016/j.wasman.2010.02.010

[22] Tejada M, Gonzalez JL, Hernandez MT, Garcia C. Agricultural use of leachates obtained from two different vermicomposting processes. Bioresource Technology. 2008;**99**(14):6228-6232

[23] Edwards CA, Arancon NQ, Greytak S. Effects of vermicompost teas on plant growth and disease. Biocycle. 2006;**47**(5):28

[24] Ingham ER. The Compost Tea Brewing Manual. 5th ed. Soil Food Web Incorporated: Oregon; 2005. p. 79

[25] Hegde NK, Siddappa R, Hanamashetti SI. Response of curry leaf (*Murraya koenigii* Spreng) “suvasini” for foliar spray of vermiwash and nutritional treatments. Acta Horticulturae. 2012;**933**:279-284

[26] Zarei M. Jahandideh Mahjen Abadi VA, Moridi A. Comparison of vermiwash and vermicompost tea properties produced from different organic beds under greenhouse conditions. International Journal of Recycling of Organic Waste in Agriculture. 2018;**7**(1):25-32. DOI: 10.1007/s40093-017-0186-2

[27] Azeez JO, Ibijola TO, Adetunji MT, Adebisi MA, Oyekanmi AA. Chemical characterization and stability of poultry manure tea and its influence on phosphorus sorption indices of tropical soils. Communications in Soil Science and Plant Analysis. 2014;**45**(20):2680-2696

[28] Knewtson SJB, Griffin JJ, Carey EE. Application of two microbial teas did not affect collard or spinach yield. HortScience. 2009;**44**(1):73-78

[29] Brinton W, Storms P, Evans E, Hill J. Compost teas: microbial hygiene and quality. Biodynamics. Jan 2004;**2**:36-45

[30] Naidu Y, Meon S, Kadir J, Siddiqui Y. Microbial starter for the enhancement of biological activity of compost tea. International Journal of Agriculture and Biology. 2010;**12**(1):51-56

[31] Kannangara T, Forge T, Dang B. Effects of aeration, molasses, kelp, compost type, and carrot juice on the growth of escherichia coli in compost teas. Compost Science & Utilization. 2006;**14**(1):40-47

[32] Pant AP, Radovich TJK, Hue NV, Paull RE. Biochemical properties of compost tea associated with compost quality and effects on pak choi growth. Scientia Horticulturae. 2012;**148**:138-146. DOI: 10.1016/j.scienta.2012.09.019

[33] Wichuk KM, McCartney D. Compost stability and maturity evaluation—A literature review. Journal of Environmental Engineering and Science. 2013;**8**(5):601-620. Available from: http://www.icevirtuallibrary.com/doi/10.1680/jees.2013.0063

[34] Griffin TS, Hutchinson M. Compost maturity effects on nitrogen and carbon mineralization and plant growth. Compost Science & Utilization. 2007;**15**(4):228-236

[35] Weltzien HC. Biocontrol of foliar fungal diseases with compost extracts. In: Microbial Ecology of Leaves. New York, NY: Springer; 1991. pp. 430-450

[36] O'Rell K. NOSB Recommendation for Guidance: Use of Compost, Vermicompost, Processed Manure and Compost Tea. National Organic Standards Board Crops Committee Recommendation for Guidance Use of Compost, Vermicompost, Processed Manure, and Compost teas [Internet]. 2006. Available from: https://www.ams.usda.gov/sites/default/files/media/NOP Final Rec Guidance use of Compost.pdf

[37] Radin AM, Warman PR. Assessment of productivity and plant nutrition of Brussels sprouts using municipal solid waste compost and compost tea as fertility amendments. International Journal of Vegetable Science. 2010;**16**(4):374-391

[38] Hargreaves JC, Adl MS, Warman PR. Are compost teas an effective nutrient amendment in the cultivation of strawberries? Soil and plant tissue effects. Journal of the Science of Food and Agriculture. 2009;**89**(3):390-397

[39] Hargreaves J, Adl MS, Warman PR, Rupasinghe HPV. The effects of organic amendments on mineral element uptake and fruit quality of raspberries. Plant and Soil. 2008;**308**(1-2):213-226

[40] Smith RF, Cameron SI, Letourneau J, Livingstone T, Livingstone K, Sanderson K. Assessing the Effects of Mulch, Compost Tea, and Chemical Fertilizer on Soil Microorganisms, Early Growth, Biomass Partitioning,

and Taxane Levels in Field-grown Rooted Cuttings of Canada Yew (*Taxus canadensis*). [Internet]. 2006. Available from: https://cfs.nrcan.gc.ca/publications?id=32892

[41] Sanwal SK, Laxminarayana K, Yadav DS, Rai N, Yadav RK. Growth, yield, and dietary antioxidants of broccoli as affected by fertilizer type. Journal of Vegetation Science. 2006;**12**(2):13-26

[42] Hargreaves JC, Adl MS, Warman PR, Rupasinghe HPV. The effects of organic and conventional nutrient amendments on strawberry cultivation: Fruit yield and quality. Journal of the Science of Food and Agriculture. 2008;**88**(15):2669-2675

[43] Hargreaves JC, Adl MS, Warman PR, Warman PR. The effects of municipal solid waste compost and compost tea on mineral element uptake and fruit quality of strawberries. Compost Science & Utilization. 2009;**17**(2):85-94

[44] Ezz El-Din AA, Hendawy SF. Effect of dry yeast and compost tea on growth and oil content of borago officinalis plant. Research Journal of Agriculture and Biological Sciences. 2010;**6**(4):424-430

[45] Bethe LA, Salam MA, Fatema UK, Rana KS. Effects of molasses and compost tea as foliar spray on water spinach (*Ipomoea aquatica*) in aquaponics system. International Journal of Fisheries and Aquatic Studies. 2017;**5**(3):203-207

[46] Khalid KA, Hendawy SF, El-Gezawy E. *Ocimum basilicum* L. production under organic farming. Research Journal of Agricultural and Biological Sciences. 2006;**2**(1):25-32

[47] El-Gizawy E, Shalaby G, Mahmoud E. Effects of tea plant compost and mineral nitrogen levels on yield and quality of sugar beet crop. Communications in Soil Science and Plant Analysis. 2014;**45**(9):1181-1194

[48] Fayed TA. Effect of compost tea and some antioxidant applications on leaf chemical constituents, yield and fruit quality of pomegranate. World Journal of Agricultural Sciences. 2010;**6**:402-411. Available from: http://www.idosi.org/wjas/wjas6(4)/9.pdf

[49] Gutiérrez-Miceli FA, García-Gómez RC, Rincón Rosales R, Abud-Archila M, María Angela OL, Cruz MJG, et al. Formulation of a liquid fertilizer for sorghum (*Sorghum bicolor* (L.) Moench) using vermicompost leachate. Bioresource Technology. 2008;**99**(14):6174-6180

[50] Mahmoud E, El-Gizawy E, Geries L. Effect of compost extract, N2-fixing bacteria and nitrogen levels applications on soil properties and onion crop. Archives of Agronomy and Soil Science. 2014;**61**(2):185-201

[51] Russo VM, Fish WW. Efficacy of microbial amendments on vegetables in greenhouse and field trials. HortScience. 2012;**47**(3):349-355

[52] Ansar Shourije F, Sadeghi H, Pessarakli M. Effects of different types of composts on soil characteristics and morphological traits of two dry rangeland species. Journal of Plantnutrition. 2014;**37**(12):1965-1980

[53] Singh R, Gupta RK, Patil RT, Sharma RR, Asrey R, Kumar A, et al. Sequential foliar application of vermicompost leachates improves marketable fruit yield and quality of strawberry (Fragaria × ananassa Duch.). Scientia Horticulturae. 2010;**124**(1):34-39

[54] Pant A, Radovich TJ, Hue NV, Arancon NQ. Effects of vermicompost tea (aqueous extract) on pak choi

yield, quality, and on soil biological properties. Compost Science & Utilization. 2011;**19**(4):279-292

[55] Atiyeh RM, Lee S, Edwards CA, Arancon NQ, Metzger JD. The influence of humic acids derived from earthworm-processed organic wastes on plant growth. Bioresource Technology. 2002;**84**(1):7-14. Available from: http://www.ncbi.nlm.nih.gov/pubmed/12137272

[56] Keeling AA, McCallum KR, Beckwith CP. Mature green waste compost enhances growth and nitrogen uptake in wheat (*Triticum aestivum* L.) and oilseed rape (*Brassica napus* L.) through the action of water-extractable factors. Bioresource Technology. 2003;**90**(2):127-132

[57] Khan MH, Meghvansi MK, Gupta R, Veer V, Singh L, Kalita MC. Foliar spray with vermiwash modifies the arbuscular mycorrhizal dependency and nutrient stoichiometry of bhut jolokia (*Capsicum assamicum*). PLoS One. 2014;**9**(3):e92318

[58] Gouveia GA, Eudoxie GD. Distribution of fertiliser N among fixed ammonium fractions as affected by moisture and fertiliser source and rate. Biology and Fertility of Soils. 2007;**44**(1):9-18

[59] Atiyeh RM, Subler S, Edwards CA, Bachman G, Metzger JD, Shuster W. Effects of vermicomposts and composts on plant growth in horticultural container media and soil. Pedobiologia (Jena) [Internet]. 2000;**44**(5):579-590. Available from: http://www.sciencedirect.com/science/article/pii/S0031405604700736

[60] Sifola MI, Barbieri G. Growth, yield and essential oil content of three cultivars of basil grown under different levels of nitrogen in the field. Scientia Horticulturae. 2006;**108**(4):408-413

[61] Reeve JR, Carpenter-Boggs L, Reganold JP, York AL, Brinton WF. Influence of biodynamic preparations on compost development and resultant compost extracts on wheat seedling growth. Bioresource Technology. 2010;**101**(14):5658-5666. DOI: 10.1016/j.biortech.2010.01.144

[62] Schönherr J. Calcium chloride penetrates plant cuticles via aqueous pores. Planta. 2000;**212**(1):112-118

[63] Kaya M, Atak M, Khawar KM. Çiftçi, Cemalettin Y, Özcan S. Effect of pre-sowing seed treatment with zinc and foliar spray of humic acids on yield of common bean (*Phaseolus vulgaris* L.). International Journal of Agriculture Biology. 2005;**7**(6):875-878. Available from: http://www.ijab.org

[64] De Swart EAM, Groenwold R, Kanne HJ, Stam P, Marcelis LFM, Voorrips RE. Non-destructive estimation of leaf area for different plant ages and accessions of *Capsicum annuum* L. Journal of Horticultural Science and Biotechnology. 2004;**79**(5):764-770

[65] Pant AP, Radovich TJ, Hue NV, Paull RE. Biochemical properties of compost tea associated with compost quality and effects on pak choi growth. Scientia Horticulturae. 2012;**148**:138-146

[66] Siddiqui Y, Islam TM, Naidu Y, Meon S. The conjunctive use of compost tea and inorganic fertiliser on the growth, yield and terpenoid content of *Centella asiatica* (L.) urban. Scientia Horticulturae. 2011;**130**(1):289-295. DOI: 10.1016/j.scienta.2011.05.043

[67] Tollefson SJ, Curlango-Rivera G, Huskey DA, Pew T, Giacomelli G, Hawes MC. Altered carbon delivery from roots: Rapid, sustained inhibition of border cell dispersal in response to compost water extracts. Plant and Soil. 2015;**389**(1-2):145-156

[68] Kim MJ, Shim CK, Kim YK, Hong SJ, Park JH, Han EJ, et al. Effect of aerated compost tea on the growth promotion of lettuce, soybean, and sweet corn in organic cultivation. The Plant Pathology Journal. 2015;**31**(3):259

[69] de Sanfilippo EC, Argüello JA, Abdala G, Orioli GA. Content of auxin-inhibitor-and gibberellin-like substances in humic acids. Biologia Plantarum. 1990;**32**(5):346-351

[70] Chen Y, Aviad T. Effects of humic substances on plant growth. In: MacCarthy P, Clapp C, Malcolm R, Bloom PR, editors. Humic Substances in Soil and Crop Sciences [Internet]. WI: SSSA; 1990. pp. 161-186. Available from: https://dl.sciencesocieties.org/publications/books/abstracts/acsesspublicati/humicsubstances/161

[71] Muscolo A, Bovalo F, Gionfriddo F, Nardi S. Earthworm humic matter produces auxin-like effects on Daucus carota cell growth and nitrate metabolism. Soil Biology & Biochemistry. 1999;**31**(9):1303-1311

[72] Valdrighi MM, Pera A, Agnolucci M, Frassinetti S, Lunardi D, Vallini G. Effects of compost-derived humic acids on vegetable biomass production and microbial growth within a plant (*Cichorium intybus*)-soil system: A comparative study. Agriculture, Ecosystems and Environment. 1996;**58**(2-3):133-144. Available from: https://www.sciencedirect.com/science/article/pii/0167880996010316

[73] Cacco G, Attinà E, Gelsomino A, Sidari M. Effect of nitrate and humic substances of different molecular size on kinetic parameters of nitrate uptake in wheat seedlings. Journal of Plant Nutrition and Soil Science. 2000;**163**(3):313-320. Available from: http://doi.wiley.com/10.1002/1522-2624%28200006%29163%3A3%3C313%3A%3AAID-JPLN313%3E3.0.CO%3B2-U

[74] Panuccio MR, Muscolo A, Nardi S. Effect of humic substances on nitrogen uptake and assimilation in two species of pinus. Journal of Plant Nutrition. 2001;**24**(4-5):693-704

[75] Auer CA, Motyka V, Březinová A, Kamínek M. Endogenous cytokinin accumulation and cytokinin oxidase activity during shoot organogenesis of Petunia hybrida. Physiologia Plantarum. 1999

[76] Spaccini R, Baiano S, Gigliotti G, Piccolo A. Molecular characterization of a compost and its water-soluble fractions. Journal of Agricultural and Food Chemistry. 2008

[77] Arancon NQ, Pant A, Radovich T, Hue NV, Potter JK, Converse CE. Seed germination and seedling growth of tomato and lettuce as affected by vermicompost water extracts (teas). HortScience. 2012;**47**(12):1722-1728

[78] Garcia Martinez I, Cruz Sosa F, LarqueSaavedra A, Soto HM. Extraction of auxin-like substances from compost. Crop Research Hisar. 2002;**24**(2):323-327. Available from: https://eurekamag.com/research/003/766/003766310.php

[79] Arancon QN, Edwards CA, Dick R, Dick L. Vermicompost tea production and plant growth impacts. Biocycle. 2001:51-52. Available from: www.biocycle.net

[80] Arancon NQ, Edwards CA, Bierman P. Influences of vermicomposts on field strawberries: Part 2. Effects on soil microbiological and chemical properties. Bioresource Technology. 2006;**97**(6):831-840. Available from: http://www.ncbi.nlm.nih.gov/pubmed/15979873

[81] Kale RD, Mallesh BC, Kubra B, Bagyaraj DJ. Influence of vermicompost application on the available macronutrients and selected microbial populations in a paddy

field. Soil Biology & Biochemistry. 1992;**24**(12):1317-1320. Available from: https://www.sciencedirect.com/science/article/abs/pii/003807179290111A

[82] Carpenter-Boggs L. Understanding the science. Diving into compost tea. Biocycle. 2005

[83] Panchakavya NK. A Manual. Goa, India: Mother India Press; 2003

[84] Bernal MP, Sánchez-Monedero MA, Paredes C, Roig A. Carbon mineralization from organic wastes at different composting stages during their incubation with soil. Ecosystems and Environment: Agriculture; 1998