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Effects of Vermicompost Tea (Aqueous Extract) on Pak Choi Yield, Quality, and on Soil Biological Properties

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This study investigated the effects of vermicompost tea (aqueous extract) on yield and chemical quality of pak choi (*Brassica rapa* cv Bonsai, Chinensis group) grown in three media (two soils and a peat-perlite medium) under two fertilizer regimes (compost and synthetic fertilizer). The impacts of tea application on the chemical and biological properties of the growth media were also investigated. Vermicompost teas were prepared using various extraction methods (non-aerated, aerated, aerated with additives) with 1:10 (v:v) chicken manure-based vermicompost to water dilution and applied weekly at the rate of 200 mL plant^{-1} for 4 weeks. Application of vermicompost tea increased plant production, total carotenoids and total glucosinolates in plant tissue. This effect was most prominent under compost fertilization. Total phenolic was lower in vermicompost tea treated plants compared to those treated with only mineral nutrient solution and the water control. Vermicompost tea improved mineral nutrient status of plants and media, and enhanced the biological activity of the media. Variability in yield and chemical quality of plants across treatments was explained largely by variability in tissue N uptake and dry matter accumulation. Dehydrogenase activity and soil respiration of vermicompost tea-treated growth media were approximately 50% higher than untreated media. This study confirmed that vermicompost tea can positively influence plant yield and quality and increase soil biological activity in multiple soil types.

Introduction

Application of aqueous extract of vermicompost (vermicompost tea) has been shown to improve plant health, crop yield, and nutritive quality (Gamaley *et al.* 2001; Pant *et al.* 2009). The primary mechanism of this response is not clearly understood. It is believed that soluble mineral nutrients, organic acids and water-soluble plant-growth regulators extracted in the tea have positive effects on initial root development and plant growth with both foliar and soil application (Keeling *et al.* 2003; Edwards *et al.* 2006; Arancon *et al.* 2007). Living microorganisms present in compost tea may also induce disease resistance as well as stimulate nutrient uptake and plant growth (Scheuerell and Mahaffee 2002; Ingham 2005; Hargreaves *et al.* 2008).

Compost tea can be prepared employing non-aerated or aerated methods. Non-aerated methods result in generally low-oxygen conditions during tea extraction whereas aerated methods maximize oxygen during the extraction of compost. Sugars, grain, fish emulsion, kelp tea, humic acid and other products are often added during extraction of aerated teas to enhance microbial activity of the finished product (Ingham 2005), but a limited work regarding the impact of these additives on tea quality or plant response has been reported. Non-aerated compost tea reportedly has greater positive effects on disease control and plant growth than aerated compost tea (Weltzien 1991; Cronin *et al.* 1996; Scheuerell and Mahaffee 2006). However, Welke (2005) showed that both aerated and non-aerated compost tea extracted from composted animal manure have similar positive effects on strawberry yield and suppression of *Botrytis cinerea*.

Soil chemical and biological properties are indicators of soil quality and health as influenced by management practices. Previous studies have shown that vermicompost improved soil mineral nutrient status and biological properties (Arancon *et al.* 2006; González *et al.* 2010). However, studies on effects of vermicompost tea on soil chemical and biological properties are limited. The objectives of this study were to determine: (i) the effects of vermicompost tea types (based on different extraction methods) applied to different growth media on yield of pak choi, root growth, mineral nutrient concentration and phytonutrient content, and (ii) the effect of vermicompost tea on chemical and biological properties of growth media.

Materials and Methods

Media

Two soils used in this study were an Oxisol (Wahiawa series and Family: clayey, kaolinitic, isohyperthermic, Tropeptic Eutrustox) and a Mollisol (Waialua series and Family: very-fine, kaolinitic, isohyperthermic, Vertic Haplustolls). Both soils were air-dried and passed through a 3-mm mesh sieve. A third medium used was a peat-perlite mix (Sunshine mix # 4, Sun Gro Horticulture, Canada Ltd.).

Fertilizer

Two greenhouse experiments were simultaneously conducted on Feb- April 2009. A leafy green, pakchoi (*Brassica rapa* 'Bonsai' Chinensis group) was selected as the test crop for the experiments. This fast-growing vegetable has tender green leaves and crispy green petioles and is considered a good source of vitamins A, C and folic acid (USDA 2008). Plants were grown with compost (green waste thermophilic compost) as the sole fertilizer in one experiment and with solely chemical (Osmocote 14-14-14: N-P-K) fertilization in other experiment. Fertilizer rate was calculated to provide 150 mg N kg^{-1} soil for both experiments. Since the Oxisol contains very low Ca, gypsum was added to provide 1g Ca kg^{-1} soil. Micronutrients (mg kg^{-1} soil) were added as follows: 50 Mg as $MgSO_4.7H_2O$, 10 Zn as $ZnSO_4.7H_2O$, 10 Fe as $Fe_2SO_4.7H_2O$, 5 Cu as $CuSO_4.5H_2O$ and 2 B as H_3BO_3 in all growth media.

Compost Tea Treatments

Five treatments at the rate of 200 mL pot^{-1} were applied weekly for four weeks starting 3 days after transplanting to the root zone and foliage of plants. Half of the tea was applied to the root zone and remaining half was applied to the foliage, however, the tea applied to the foliage moved to the root zone once the foliage was saturated. The treatments consisted of: three types of vermicompost tea based on extraction method (non-aerated, NCT; aerated, ACT, and aerated augmented, ACTME); a mineral nutrient solution (MNS) prepared by mixing di-ammonium phosphate and potassium nitrate resembling the N content of vermicompost teas; and aerated water (control). The greenhouse experiments had a randomized complete block design with 3*5 factorial treatments (media x treatment) and 4 blocks of each treatment combination.

Chicken manure-based vermicompost used in this study was obtained from Waikiki Worm Company, HI. The teas were prepared in separate events every week before application using the same batch of vermicompost (cured for 3 months) in a shade closed to the greenhouse, where the experiments were conducted. The tea extraction ratio was 1:10 (by volume) vermicompost to water using three different methods: (i) non-aerated vermicompost tea (NCT); (ii) aerated vermicompost tea (ACT); and (iii) aerated vermicompost tea augmented with microbial enhancer (ACTME). Dry humic acid and powder kelp (Peaceful Valley, CA) were used at the rate of 1 and 3 g L^{-1} respectively, before extraction in ACTME to enhance the microbial growth.

Analysis of Chemical Properties of Vermicompost and Vermicompost Tea

The pH and electrical conductivity (EC) of the vermicompost and extracts were measured in a 1:1 (v:v) mixture of deionized water: vermicompost, using a conductivity/pH Meter (SB80PC, sympHony, VWR Scientific Products, MN). Dissolved oxygen (DO) was recorded at 21-22°C with a dissolved oxygen meter (thermo sympHony SP70D, VWR Scientific Products, MN). Total C and N of vermicompost samples were analyzed by dry combustion (LECO CN-2000 analyzer, Leco Corp., St. Joseph, MI). Mineral N (NH_4-N, NO_3-N and NO_2-N) of the vermicompost tea were analyzed colorimetrically using a discrete analyzer (Easy Chem Plus, Systea Scientific, IL). Other nutrients of the vermicompost tea were measured with an inductively coupled plasma (ICP) spectrophotometer (Jarrel-Ash Division/Fisher Scientific Co., Waltham, MA).

Analysis of Microbial Activity in Vermicompost Tea

Microbial activity of each vermicompost tea was analyzed on 3 samples from 3 separate events for each extraction methods. Tea samples were taken after 12 h of a brewing cycle for ACT and ACTME and 7 days of steeping for NCT. A 10-fold serial dilution of each sample was prepared. Active bacteria and active fungi were assessed using a 1:10 dilution under Epifluorescence Microscopy at 40x and 20x objective, respectively (Vieira *et al.* 2008). Microbial activity of the mineral nutrient solution and water (control) was also analyzed.

Plant Growth, Harvest and Measurements

Seedlings were grown in peat-perlite media and one seedling pot^{-1} (containing 2 L of growth media) was transplanted 10 days after emergence. Plants were grown in the greenhouse on a bench fitted with overhead sprinklers, which were opened for 3 minutes every 4 hours.

All pak-choi plants were harvested four weeks after transplanting. Plant height and above ground plant fresh weight were measured. Plants were immediately frozen in liquid N and stored at - 20°C, and then freeze dried using a lyophilizer (D4A, Leybold-Heraeus Vacuum Products, Inc. PA). Above ground dry weight of each plant was recorded, ground using mortar and pestle, and stored in air-tight containers prior to further analysis.

Root Growth

Total root length and surface area of the roots experiments were calculated using WinRHIZO Pro V. 2003b system (Regent Instruments Inc., QC, Canada). The system consists of a scanner and WinRHIZO software. After taking the root fresh weight, roots were oven dried at 70°C for 72 h and dry weight was recorded.

Measurement of Phytonutrients

Total carotenoids and total phenolics were analyzed on lyophilized samples o by extracting 100 mg in 20 mL of ethanol: acetone (1:1, v:v) in glass vials for 24 hr. All data were reported based on dry weight. Extracts were evaluated for total carotenoids at 470 nm using a Genesys 20 spectrophotometer (Thermo Scientific - Model 4001-000, MA). Total carotenoids were calculated using the equation: mg kg^{-1} total carotenoids = $(A*V \times 10^6)/(A\% \times 100G)$, where A is the absorbance, V is the total volume of the extract (mL) A% is the extinction coefficient of 2500, and G is the sample weight in grams (Gross 1991). Total soluble phenolics were measured using the Prussian Blue assay as described by Stern *et al.* (1996) and the data were reported in mg kg^{-1} equivalents of gallic acid. Total glucosinolates were extracted and analyzed from lyophilized samples as described by Radovich *et al* (2005).

Measurement of Mineral Nutrients in the Plant Tissue

Total C and N of dried tissue samples were analyzed by dry combustion as described earlier. Other nutrients in the tissue samples were measured after wet acid digestion using an inductively coupled plasma spectrophotometer (ICP).

Measurement of pH, EC and Mineral Nutrients in Soil

Total soil N and C were analyzed by the dry combustion method as described earlier. Other nutrients were extracted from the soil with the Mechlich-3 solution and measured with ICP.

Soil Respiration and Dehydrogenase Activity

Soil respiration rate was measured with a portable soil respiration rate measuring system (LI-6400, LI-COR, Lincoln, NB, USA) fitted with a soil respiration chamber (6400-09, LI-COR, NB, USA). The respiration rate was expressed as μmol CO_2 fluxes m^{-2} sec^{-1}. Dehydrogenase activity expressed in μg g^{-1} (dwt) of soil was calculated based on the amount of 1,3,5-triphenyltetrazolium formazan (TPF) formed when 2,3,5-triphenyltetrazolium chloride (TTC) was reduced by microbes in the soil (Alef 1995).

Statistical Analysis

Two-way analysis of variance (ANOVA) of plant growth parameters, mineral nutrients and phytonutrients in plant tissues, as well as soil properties was performed on main treatment effects and their interactions. Means were separated using Tukey's pair wise comparison in SAS 9.1 statistical software (SAS Institute Inc.). Statistical significance was obtained at 95% confidence level (· = 0.05).

Results

Chemical Properties of Vermicompost and Vermicompost Teas

The pH of the vermicompost was 7.1 and EC was 3.4 dS m^{-1}, with a C:N ratio of 12.5:1. The extraction method significantly affected pH, EC, DO, and extractable nutrient concentrations in vermicompost tea (Table 1). The average pH levels of ACTME, MNS and control treatment were significantly higher ($p<0.01$) than those of ACT and NCT. The pH level of ACT was not significantly different from that of NCT. Dissolved oxygen in vermicompost tea measured at the end of the extraction period was reduced by the use of microbial enhancer during production. Dissolved oxygen level increased in the order ACTME<NCT=ACT<MNS=Control. Electrical conductivity level was highest in ACTME, with a reverse order as DO.

Levels of total N (NO_3-N + NH_4-N) in ACTME were not significantly different from those in ACT, NCT and MNS, however, chemical analysis of humic acid and kelp showed that use of these additives added about 48 19 and 15 mg L^{-1} of total N, NO_3-N and NH_4-N, respectively, to ACTME (data not shown). Phosphorus content in the vermicompost tea was not influenced by the extraction methods. Potassium content was significantly higher ($p<0.05$) in ACTME than the other tea treatments. Calcium was significantly higher in ACT and ACTME compared to MNS and the control

TABLE 1.
Chemical properties of vermicompost tea.

Extraction Method	pH	DO ($mg\ L^{-1}$)	EC ($dS\ m^{-1}$)	N	NO3-N	NH4-N	P ($mg\ L^{-1}$)	K	Ca	Mg
ACT	7.5b	7.9b	1.4b	166.3a	162.3 a	2.2b	5.1b	35.3b	185.9a	80.1a
ACTME	8.2a	6.1c	3.0a	192.8a	158.7 a	31.9ab	6.7b	401.4a	149.6a	61.4ab
NCT	7.4b	7.6b	1.5b	99.5ab	96.7ab	1.9b	3.5b	34.5b	114.6ab	50.2ab
MNS	8.1a	8.4a	1.1c	76.6ab	25.2b	51.2a	48.0a	57.7b	9.7b	14.4b
Control	8.1a	8.7a	0.4d	3.4b	1.2 b	1.9b	0.3b	4.1b	9.8b	14.3b

Means (N=3) followed by the same letter are not significantly different ($p<0.05$). DO=Dissolved oxygen, EC=Electrical conductivity.NCT=Non-aerated vermicompost tea, ACTME=Aerated vermicompost tea with microbial enhancer, ACT=Aerated vermicompost tea, MNS=Mineral Nutrient Solution, Control=water.

treatment. Magnesium was significantly higher in ACT compared to MNS and the control treatment.

Microbial Population in Vermicompost Tea

The active bacterial and fungal populations were significantly higher ($p<0.01$) in all teas compared to MNS and the control (Table 2). The active bacteria (cell numbers) and active fungi (hyphal length and mass) were not affected by the extraction methods. However, the cell mass of the active bacteria was significantly greater in ACTME than the other teas.

TABLE 2.
Microbial population in vermicompost tea.

Extraction Method	Active Bacteria ($\log_{10}$ cells mL^{-1})	Active Bacteria ($\mu g\ mL^{-1}$)	Length of Active fungi ($cm\ mL^{-1}$)	Active Fungi ($\mu g\ mL^{-1}$)
ACT	7.5 a	6.0 b	31.9 a	0.7 a
ACT ME	7.8 a	21.8 a	29.2 a	0.6 a
NCT	7.6 a	5.7 b	29.5 a	0.6 a
MNS	0.0 b	0.0 c	0.0 b	0 b
Control	0.0 b	0.0 c	0.0 b	0 b

Means (N=3) followed by the same letter are not significantly different ($p<0.05$). NCT=Non-aerated vermicompost tea, ACTME=Aerated vermicompost tea with microbial enhancer, ACT=Aerated vermicompost tea, MNS=Mineral Nutrient Solution, Control=water.

Effect on Plant Growth

Compost

Vermicompost tea significantly ($p<0.0001$) increased above ground plant fresh weight, however, there was a significant ($p<0.0001$) interaction effect of vermicompost tea and growth media (Table 3a). Except for ACTME in the Mollisol, all types of vermicompost tea significantly increased ($p<0.01$) above ground plant fresh weight compared to MNS and the control treatment across the growth media (Figure 1a). The effect of vermicompost tea extraction method on above ground plant fresh weight was not significant in the peat-perlite medium. However, the effect of ACT and NCT on above ground plant fresh weight was significantly higher ($p<0.01$) than that of ACTME in the Oxisol. The effect of tea type, growth media type and their interaction on above ground plant dry weight was similar to that of fresh weight (Figure 1b). Root biomass and total root length increased significantly ($p<0.01$) in vermicompost tea treated plants compared to the MNS and control across growth media (Figure 1c&d). The effect of vermicompost tea extraction methods on measured root growth parameters was not significant in the peat-perlite medium.

TABLE 3.
Analysis of variance of the effect of vermicompost tea on growth and phytonutrient content of pak choi; and biological properties of growth media

Source	df	Above Ground Fresh Weight	Above Ground Dry Weight	Root Dry Weight	Total Root Length	Total Carotenoids	Total Gluco-sinolates	Total Phenolics	DHA (Growth Media)	Respiration (Growth Media)
Compost										
Growth media (M)	2	****	****	****	****	****	****	****	****	****
Vermicompost tea (T)	4	****	****	****	****	****	****	****	****	****
M*T	8	****	****	****	****	****	*	NS	NS	**
Osmocote										
Growth media (M)	2	****	****	****	****	****	****	****	****	**
Vermicompost tea (T)	4	****	****	**	****	****	NS	*	****	****
M*T	8	**	NS	*	****	NS	NS	*	****	***

DHA=Dehydrogenase activity, NS, *, **, ***, ****=Not significant or significant at $P<0.05$, 0.01, 0.001 or 0.0001, respectively.

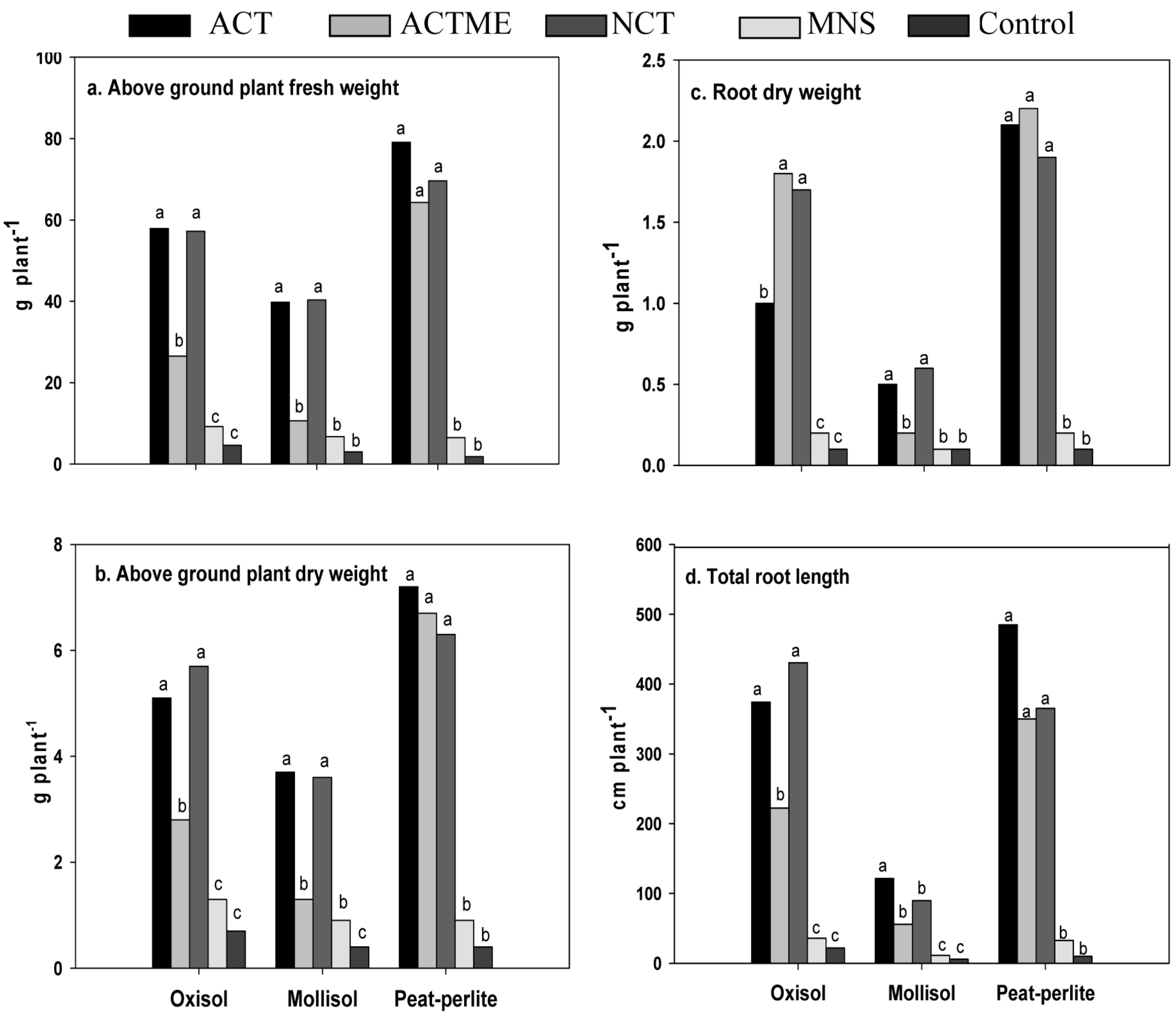

FIGURE 1. Extract effect on a. above ground plant fresh weight, b. above ground plant dry weight, c. root dry weight and d. total root length under compost fertilization (n=4). Means followed by the same letter are not significantly different (p<0.05) within each growth medium. ACT=Aerated vermicompost tea, ACTME=Aerated vermicompost tea with microbial enhancer, NCT=Non-aerated vermicompost tea, MNS=Mineral nutrient solution, Control=water.

The effect of extraction methods on the root growth parameters varied in the two soils.

Osmocote

Vermicompost tea significantly ($p<0.0001$) increased above ground plant fresh and dry weight, However, there was a significant ($p<0.01$) interaction effect of vermicompost tea and growth media on plant fresh weight (Table 3b). Above ground plant fresh and dry weights were not affected by vermicompost tea application in the Mollisol (Figure 2a&b). Vermicompost tea significantly increased ($p<0.05$) root biomass in the peat-perlite medium but not in the soils (Figure 2c). Vermicompost teas significantly increased ($p<0.05$) total root length in the Oxisol and the peat-perlite medium compared to control treatment (Figure 2d). Only ACT had a significantly positive effect on total root length and root surface area compared to other treatments in the Mollisol.

Effect on Mineral Nutrient Content of Plant Tissue

Compost

Vermicompost tea significantly ($p<0.0001$) increased tissue N, P, K, Ca and Mg content however, there was a significant ($p<0.0001$) interaction effect of vermicompost tea and growth media. Except for ACTME in the Mollisol, all teas significantly increased ($p<0.0001$) total N content plant^{-1} compared to MNS and the control treatment across the growth media (Table 4a). The effect of ACT and NCT on total N content was significantly higher ($p<0.0001$) than that of ACTME in the Oxisol and in the Mollisol, however, the effect of ACT and ACTME on total N content was significantly higher ($p<0.0001$) than that of NCT in the peat-perlite medium. The effect of vermicompost tea on P content plant^{-1} followed a trend similar to that of total N across the growth media. Ex-

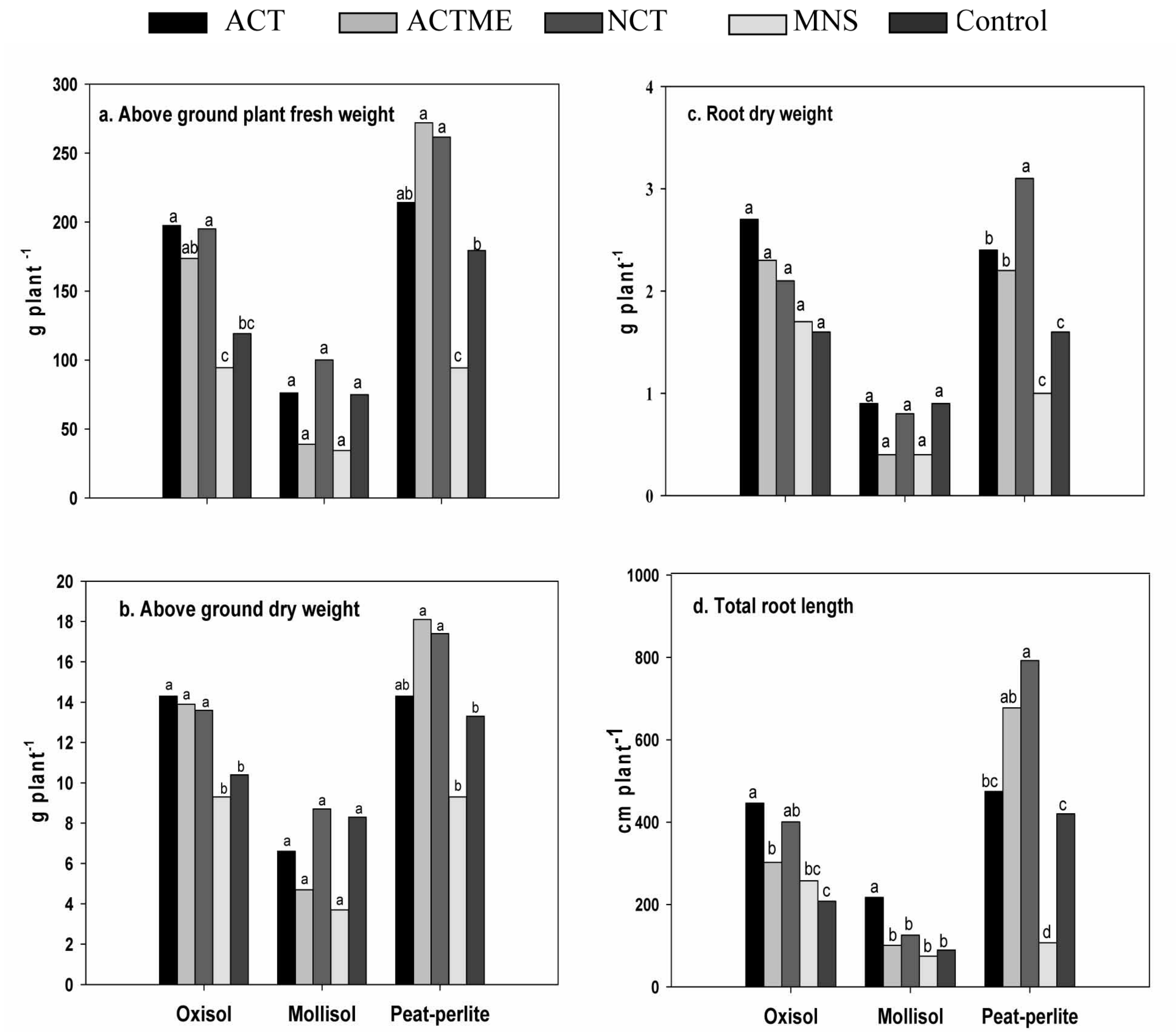

FIGURE 2. Extract effect on a. above ground plant fresh weight, b. above ground plant dry weight, c. root dry weight and d. total root length under Osmocote fertilization (n=4). Means followed by the same letter are not significantly different ($p<0.05$) within each growth medium. ACT=Aerated vermicompost tea, ACTME=Aerated vermicompost tea with microbial enhancer, NCT=Non-aerated vermicompost tea, MNS=Mineral nutrient solution, Control=water.

cept for ACTME under the Mollisol, all vermicompost teas significantly increased K content plant^{-1} compared to MNS and the control across the growth media. The effect of ACT and NCT on K content plant^{-1} was significantly higher ($p<0.05$) than that of ACTME in the soils but the effect of ACTME on K content plant^{-1} was significantly higher ($p<0.05$) than that of ACT and NCT in the peat-perlite medium. With the exception of ACTME in the Mollisol, all vermicompost teas significantly increased ($p<0.0001$) Ca plant^{-1} across the growth media. Also, the effect of ACT and NCT on Ca was greater ($p<0.01$) than that of ACTME in the Oxisol and the peat-perlite medium. The effect of vermicompost tea on Mg content plant^{-1} followed a trend similar to that of Ca across the growth media.

Osmocote

Vermicompost tea significantly ($p<0.0001$) increased tissue N content. However, there was a significant ($p<0.001$) interaction effect of vermicompost tea and growth media. All teas significantly increased ($p<0.05$) total N content of plants compared to the MNS treatment in the Oxisol and the peat-perlite medium; however the treatment effect was not significant in the Mollisol (Table 4b). The effect of vermicompost tea on P content was similar to that of N across the growth media. None of the vermicompost tea increased K content of plants in the Oxisol compared to MNS and the control. Application of ACTME increased ($p<0.05$) K content of plants in the peat-perlite medium but decreased ($p<0.05$) K content of plants compared to the MNS and control in the Mollisol. Only

TABLE 4.
Effect of vermicompost tea on mineral nutrient content in plant tissue grown in growth media fertilized with a. compost b. Osmocote

Extraction Method	N	P	K	Ca	Mg
	mg plant^{-1}				
a. Fertilizer: Compost					
Oxisol					
ACT	82.4 a	21.9 a	173.1 a	98.4 a	15.9 a
ACTME	33.5 b	8.6 b	54.7 b	44.8 b	8.4 b
NCT	92.2 a	22.8 a	184.9 a	113.3 a	18.9 a
MNS	15.5 bc	4.7 bc	32.4 c	21.9 bc	4.2 bc
Control	5.9 c	2.4 c	13.5 c	13.5 c	2.6 c
Mollisol					
ACT	61.6 a	18.6 b	120.4 a	60.2 b	18.7 a
ACTME	11.9 b	3.4 c	10.8 b	16.0 c	6.8 b
NCT	63.1 a	23.7 a	133.3 a	80.1 a	20.3 a
MNS	11.0 b	4.3 c	17.9 b	12.8 c	4.3 b
Control	5.2 b	2.5 c	8.8 b	8.5 c	2.9 b
Peat perlite medium					
ACT	115.3 a	40.8 a	225.2 b	168.4 a	35.5 a
ACTME	101.2 a	31.4 b	257.6 a	127.8 b	27.5 b
NCT	90.3 b	32.9 b	189.5 c	146.8 ab	30.6 ab
MNS	9.9 c	4.6 c	21.7 d	19.2 c	4.7 c
Control	2.7 c	1.8 c	7.9 d	6.6 c	1.6 c
b. Fertilizer: Osmocote					
Oxisol					
ACT	256.8 a	54.5 a	416.0 ab	250.8 a	48.2 a
ACTME	217.1 a	45.5 ab	458.3 ab	218.7 ab	41.3 ab
NCT	261.2 a	57.8 a	469.9 a	225.6 ab	44.8 ab
MNS	139.2 b	30.0 b	284.1 b	148.6 b	27.5 b
Control	174.2 ab	46.1 ab	382.6 ab	172.2 b	36.8 ab
Mollisol					
ACT	97.5 a	25.7 a	132.5 ab	78.8 a	30.3 a
ACTME	53.8 a	15.2 a	65.0 b	50.6 a	21.7 a
NCT	116.2 a	30.6 a	231.4 a	109.4 a	33.6 a
MNS	48.6 a	16.5 a	75.2 b	58.1 a	24.5 a
Control	103.2 a	32.2 a	209.0 a	115.1 a	46.3 a
Peat perlite medium					
ACT	263.6 b	76.2 ab	222.3 bc	307.1 a	93.8 a
ACTME	367.3 a	98.9 a	770.5 a	318.0 a	91.5 a
NCT	357.1 a	95.5 a	360.7 b	326.7 a	97.6 a
MNS	116.1 c	40.9 c	207.7 c	196.4 b	60.5 b
Control	198.8 bc	61.3 bc	283.9 bc	278.7 ab	88.9 ab

Means (N=3) followed by the same letter are not significantly different ($p<0.05$) within each growth medium. NCT=Non-aerated vermicompost tea, ACTME=Aerated vermicompost tea with microbial enhancer, ACT=Aerated vermicompost tea, MNS=Mineral Nutrient Solution, Control=water.

ACT increased Ca content significantly ($p<0.05$) in plant tissue in the Oxisol, whereas, none of the tea affected Ca content in plant tissue in the Mollisol. All vermicompost teas, irrespective of extraction methods significantly ($p<0.05$) increased tissue Ca compared to MNS in the peat-perlite medium. The effect of vermicompost teas on Mg content was the same as that of Ca.

Effect on Phytonutrients

Compost

Vermicompost teas significantly increased ($p<0.0001$) total carotenoids compared to MNS and the control across the growth media. This was most notable in the peat-perlite medium, where tea treated plants had about 4 times more carotenoids than the control (Figure 3a). Tea treated plants grown on the soils had about twice as much total carotenoids as the control. Plants receiving ACTME had lower carotenoids compared to ACT and NCT in the Mollisol and the peat-perlite medium, however all vermicompost tea had similar effects on total carotenoids in the Oxisol. The effect of vermicompost tea types, growth media and their interaction on total glucosinolates was similar to that of total carotenoids (Figure 3b). Total phenolics content was significantly lower ($p<0.0001$) in tea treated plants compared to the control and MNS across the growth media (Figure 3c).

Osmocote

Tea applications increased total carotenoids significantly ($p<0.0001$) compared to MNS and the control across the growth media (Figure 3d). The level of total carotenoids was not affected by tea extraction methods. The effect of vermicompost tea on total glucosinolates was not significant across the growth media; however total glucosinolates was significantly higher ($p<0.0001$) in the peat-perlite medium and the Oxisol than in the Mollisol (Figure 3e). Tea applications significantly decreased ($p<0.05$) total phenolics. However, there was a significant ($p<0.05$) interaction effect of vermicompost tea and growth media. Plants receiving NCT had significantly lower ($p<0.01$) total phenolics compared to the other treatments in the Mollisol, whereas, only ACTME treated plants had significantly lower ($p<0.01$) phenolics compared to the other treatments in the peat-perlite medium (Figure 3f). Total phenolics content was not affected by vermicompost tea treatment in the Oxisol.

Effect on Microbial Respiration and Dehydrogenase Activities

Compost

Tea applications significantly ($p<0.0001$) increased soil respiration. However, there was a significant ($p<0.01$) interaction effect of vermicompost tea and growth media. All vermicompost teas significantly increased ($p<0.001$) microbial respiration compared to MNS and the control treatment in the peat-perlite medium (Figure 4). Application of ACTME and NCT increased microbial respiration in the Oxisol compared to the other treatments. Microbial respiration was inferior with MNS treatment compared to tea and the control treatments. Dehydrogenase activity was positively ($p<0.0001$) influenced by the use of vermicompost tea across growth media (Figure 2b). Dehydrogenase activity was not affected by the tea extrac-

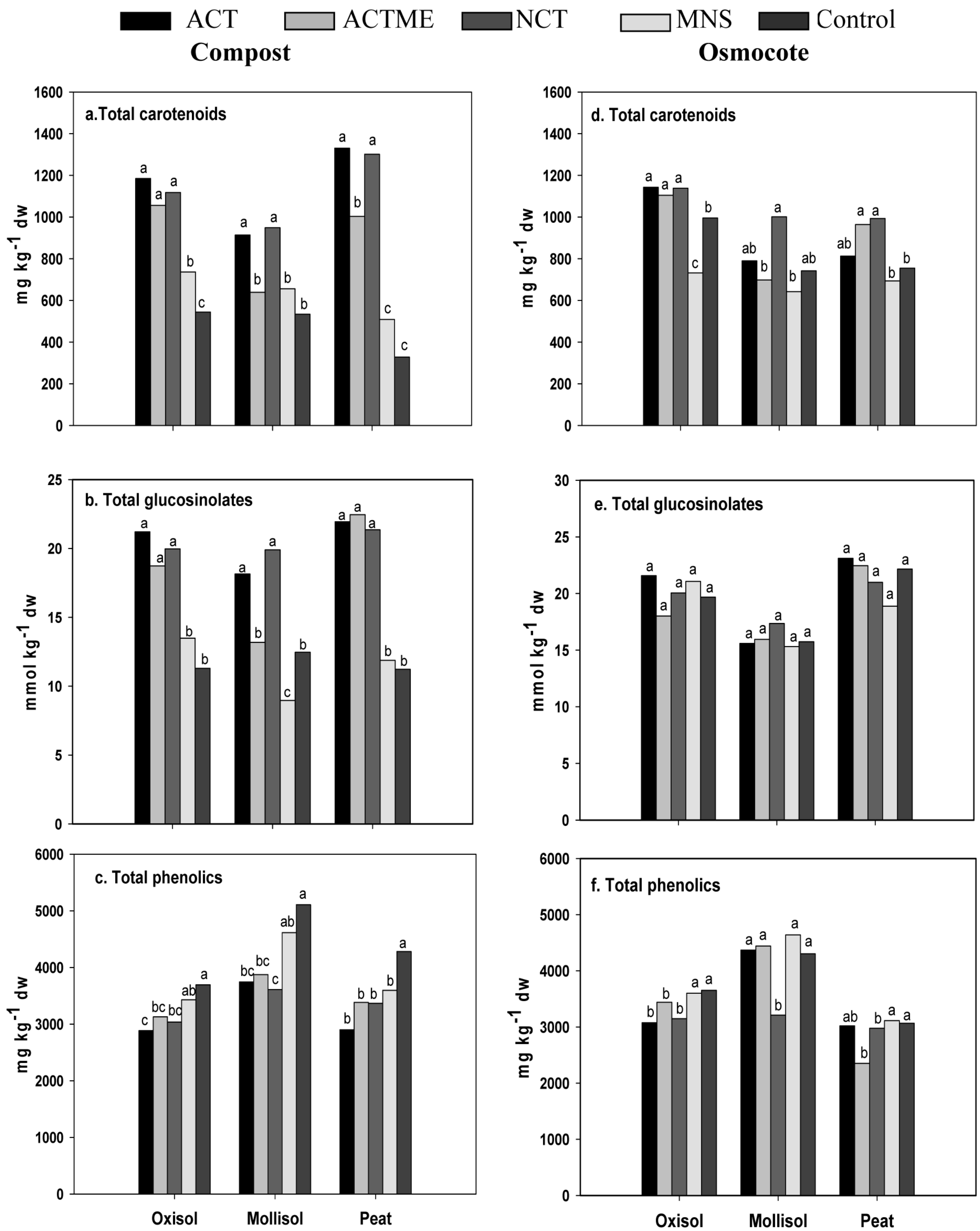

FIGURE 3. Extract effect on total carotenoids, total glucosinolates and total phenolics across the treatments (n=3). Means followed by the same letter are not significantly different ($p<0.05$) within each growth medium. ACT=Aerated vermicompost tea, ACTME=Aerated vermicompost tea with microbial enhancer, NCT=Non-aerated vermicompost tea, MNS=Mineral nutrient solution, Control=water.

tion methods in the soils but ACT had greater effect ($p<0.05$) compared to NCT and ACTME in the peat-perlite medium.

Osmocote

Vermicompost tea significantly ($p<0.01$) increased soil respiration and dehydrogenase activity

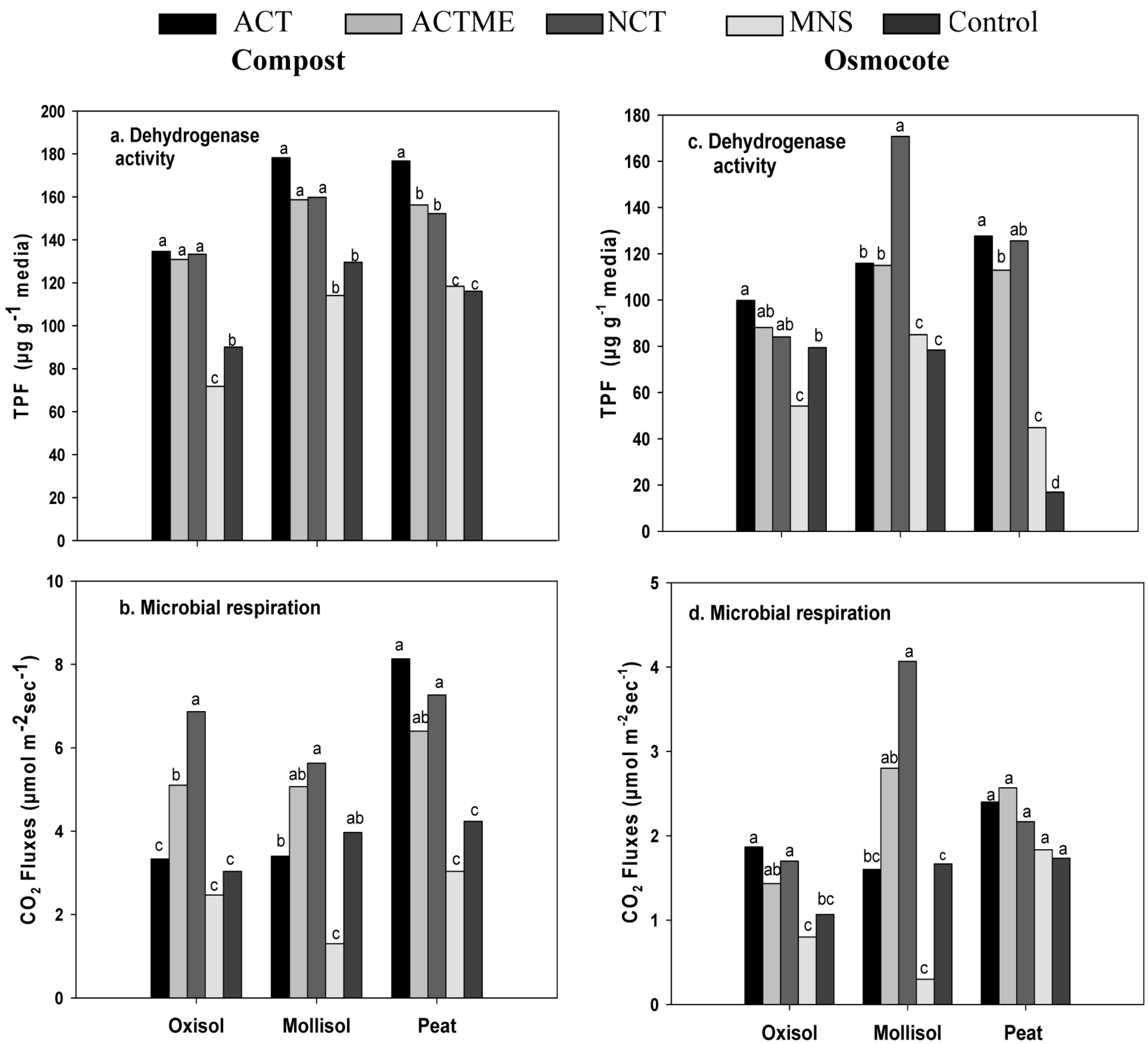

FIGURE 4. Soil respiration (CO_2 fluxes µmol m^{-2} s^{-1}) and dehydrogenase activity (TPF µg g^{-1} of media) across the treatments (n=3). Means followed by the same letter are not significantly different (p<0.05) within each growth medium. ACT=Aerated vermicompost tea, ACTME=Aerated vermicompost tea with microbial enhancer, NCT=Non-aerated vermicompost tea, MNS=Mineral nutrient solution, Control=water.

(Figure 4). However, there was a significant ($p<0.0001$) interaction effect of teas and growth media. Microbial respiration was not affected by the application of teas in the peat-perlite medium, whereas, all teas significantly increased ($p<0.05$) the microbial respiration compared to MNS; and ACT and NCT increased microbial respiration compared to the control in the Oxisol. Only ACTME and NCT increased microbial respiration compared to MNS and the control in the Mollisol. All teas significantly increased ($p<0.05$) dehydrogenase activities compared to the control and MNS in the Mollisol and the peat-perlite medium. However, dehydrogenase activity was not affected by vermicompost tea treatments in the Oxisol.

Effect on Soil Chemical Properties

Compost

Application of vermicompost teas did not affect pH of growth media (Table 5a). Application of vermicompost tea increased ($p<0.0001$) EC, N and K content of the growth media and there was a significant ($p<0.0001$) interaction of vermicompost tea and growth media. All teas significantly increased ($p<0.05$) EC of the soils. However, only ACTME and NCT increased EC of the peat-perlite medium. Both ACT and ACTME significantly increased ($p<0.05$) total N of the growth media compared to the control. NCT had no significant effect on total N of the growth media. Total carbon was not affected by the application of teas in the

TABLE 5.
Effect vermicompost tea on chemical properties of growth media fertilized with a. compost b. Osmocote

Extraction Method	pH	EC (μS cm^{-1})	Total N (g kg^{-1})	Total C (g kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})
a. Fertilizer: Compost						
Oxisol						
ACT	7.6 a	590.3 a	2.5 a	25.0 a	39.3 a	335.6 b
ACTME	7.6 a	594.7 a	2.4 a	23.2 a	40.7 a	655.2 a
NCT	7.6 a	588.0 a	2.2 b	26.6 a	40.7 a	333.7 b
MNS	7.5 a	544.3 b	2.2 b	26.1 a	40.3 a	374.2 b
Control	7.6 a	542.0 b	2.1 b	24.9 a	42.0 a	416.4 b
Mollisol						
ACT	7.6 a	789.7 b	2.9 a	31.1 a	115.0 a	961.6 b
ACTME	7.5 a	990.0 a	2.8 a	32.2 a	106.7 ab	1471.7 a
NCT	7.6 a	789.0 b	2.6 a	30.8 a	114.3 a	1043.9 b
MNS	7.5 a	773.3 b	2.5 ab	29.3 a	100.7 bc	939.9 b
Control	7.6 a	757.3 c	2.3 b	26.5 a	97.3 c	997.0 b
Peat perlite medium						
ACT	7.4 a	437.67 b	10.7 b	418.0 a	3.2 a	10.9 b
ACTME	7.5 a	594.33 a	12.9 a	426.6 a	4.1 a	92.5 a
NCT	7.3 a	480.00 b	10.3 bc	441.4 a	2.8 a	12.4 b
MNS	7.3 a	432.67 b	9.5 bc	422.6 a	3.6 a	11.7 b
Control	7.4 a	433.67 b	8.9 c	376.3 b	2.9 a	16.1 b
b. Fertilizer: Osmocote						
Oxisol						
ACT	5.6 ab	518.3 b	1.5 b	10.6 b	45.7 b	84.9 b
ACTME	5. 7 ab	576.7 a	1.9 a	11.6 ab	39.0 b	278.5 a
NCT	5.9 a	520.0 b	1.4 b	12.4 a	54.0 a	105.4 b
MNS	5.4 b	517.7 b	0.7 b	11.0 b	45.3 b	142.6 b
Control	5.4 b	506.0 b	0.8 b	11.1 b	42.3 b	124.3 b
Mollisol						
ACT	6.2 b	883.0 b	1.6 a	13.4 a	102.3 a	714.89 b
ACTME	6.6 a	1007.0 a	1.5 a	13.4 a	111.0 a	1138.38 a
NCT	6.2 b	990. 7 a	1.0 ab	11.9 b	106.7 a	672.82 b
MNS	6.1 bc	891.3 b	0.6 b	11.1 b	106.0 a	743.56 b
Control	6.0 c	715.0 c	0.5 b	11.2 b	84.5 b	646.99 b
Peat perlite medium						
ACT	4.6 bc	497.0 b	12.9 b	335.8 a	11.4 a	16.2 a
ACTME	4.9 a	673.3 a	13.8 a	313.8 a	9.4 a	16.2 a
NCT	4.7 ab	494.0 b	9.6 c	332.9 a	10.2 a	9.4 a
MNS	4.8 a	444.7 b	12.6 c	349.4 a	7.1 a	10.6 a
Control	4.4 c	421.0 b	8.6 d	309.9 a	11.8 a	15.7 a

Means (N=3) followed by the same letter are not significantly different ($p<0.05$) within each growth medium. NCT=Non-aerated vermicompost tea, ACTME=Aerated vermicompost tea with microbial enhancer, ACT=Aerated vermicompost tea, MNS=Mineral Nutrient Solution, Control=water.

soils but increased ($p<0.05$) in the peat-perlite medium compared to the control. Phosphorus content was not affected by tea applications in the Oxisol and the peat-perlite medium but increased ($p<0.05$) in the Mollisol compared to the control. Application of ACTME significantly increased ($p<0.0001$) K content across the growth media compared to the other treatments.

Osmocote

Application of teas significantly increased ($p<0.0001$) pH, EC and total N. However, there was a significant ($p<0.01$) interaction of teas and growth media. Application of NCT significantly increased ($p<0.05$) pH of the Oxisol, whereas, ACTME increased pH of the Mollisol and the peat-perlite medium compared to the control (Table 5b). All teas significantly increased ($p<0.01$) EC of the Mollisol, but only ACTME increased EC of the Oxisol and the peat-perlite medium. Application of ACTME increased ($p<0.05$) total N in the Oxisol, whereas, both ACT and ACTME increased N content in the Mollisol. All vermicompost teas irrespective of extraction method significantly increased ($p<0.0001$) total N compared to the control in the peat-perlite medium. NCT increased total carbon significantly ($p<0.05$) in the Oxisol but ACT and ACTME increased total carbon in the Mollisol compared to the other treatments. Total carbon was not affected by the application of vermicompost tea in the peat-perlite medium. Only NCT significantly increased ($p<0.05$) P content in the Oxisol but all the teas significantly increased ($p<0.05$) P content compared to the control in the Mollisol. None of the teas had significant effect on P and K content of the peat-perlite medium. Application of ACTME significantly increased ($p<0.01$) K content of the soils compared to the control.

Discussion

Chemical properties of ACTME differed from those of ACT and NCT. The addition of kelp extract and humic acid resulted in higher EC, some mineral nutrients and lower DO in ACTME. The higher K in ACTME relative to the other extracts can be accounted for by the additives. Greater amount of active bacteria (cell mass) in ACTME compared to the other teas attributed to the reduced DO level in ACTME compared to the other teas. However, active fungi and active bacterial population (cell number) in ACTME were not significantly different from that of ACT and NCT. It is possible that the additives increased microbial populations in ACTME and that microbes remained bound to vermicompost particles that were removed during screening. This could be the likely cause for the reduced DO in ACTME.

Vermicompost tea generally enhanced plant growth and mineral nutrient content in plant tissue in the Oxisol and the peat-perlite medium under both fertilizer regimes, consistent with previous studies (Gamaley *et al.* 2001; Hargreaves *et al.* 2009; Pant *et al.* 2009). A lack of plant growth response with ACTME in the Mollisol is possibly due to poor drainage combined with addition of extra salts as suggested by higher EC of the Mollisol after tea applications (Table 5a&b). Although the above ground fresh and dry plant weights were high under Osmocote fertilization compared to compost, the effect of vermicompost tea was most pronounced under compost fertilization. Enhanced plant growth with tea application in the peat-perlite medium compared to the Oxisol and the Mollisol observed in this study was associated with differences in physical and chemical properties of the peat-perlite medium and the soils. Although all growth media received the same level of nutrients through fertilizers and teas, plants grown in the peat-perlite medium were benefited from good drainage and aeration which improved root development and nutrient uptake, and thereby enhancing plant growth.

Soluble mineral nutrients and microbial byproducts in compost teas can enhance nutrient uptake from the soil and increase foliar uptake of nutrients by plants (Ingham 2005; Hargreaves *et al.* 2008). Strong correlation between plant fresh weight and nitrogen uptake explains yield response to tea applications (Figure 5). Siddiqui *et al.* (2008) reported that compost tea applications enhanced plant growth and increased tap

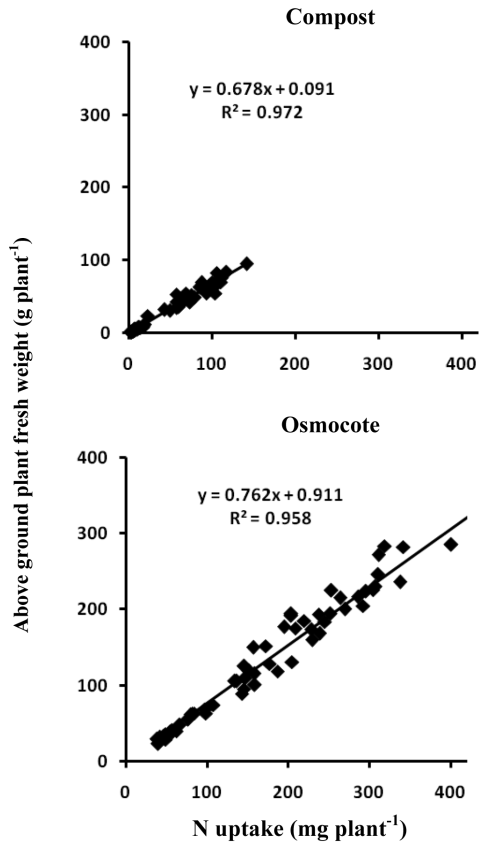

FIGURE 5. Above ground plant fresh weight of pak-choi relative to N uptake in plants fertilized with compost and Osmocote (n=60).

root length of okra (*Abelmoschus esculentus)* plant. Keeling *et al.* (2003) observed that application of compost tea on oil seed rape plants at an early stage of growth increased both root development and plant growth. Increased root biomass, total root length and root surface area with the application of vermicompost tea observed in this study agrees with the findings of these previous studies. Enhanced overall root development accompanied with better nutrient uptake by tea treated plants compared to MNS treated and the control plants suggests that improved root growth or nutrient uptake per unit root is one of the mechanisms involved in plant growth stimulation. Garcia Martinez *et al.* (2002) showed that methanolic extract of different commercial composts contained a compound with molecular structure and biological activity analogous to auxins. Leachate from a well decomposed compost has been shown to contain cytokinin-like substances, derived from hydrolysis of glucosides by the enzyme ,-glucosidase produced by microbes (Arthur *et al.* 2001). These studies suggest phytohormones (plant growth regulators) may be present in compost extract. However, phytohormones or growth regulators in vermicompost tea were not measured in this study.

Plant growth was not influenced by the extraction methods in the peat-perlite medium which is consistent with previous work (Pant *et al.* 2009). Ingham (1999) noted that aerated compost tea augmented with a microbial enhancer imparted a better plant response by increasing microbial population densities in the compost tea. However, the effect of ACTME on plant growth was not more pronounced compared to ACT and NCT in this study. While active bacterial biomass was higher in ACTME compared to ACT and NCT, the same level of the active bacterial cell count and fungal population was observed in all types of vermicompost tea. Thus, the contribution of microbial activities to nutrient uptake and plant growth is similar. Inferior plant growth with ACTME compared to ACT and NCT in the Mollisol is associated with the heavy soil texture and poor drainage in the Mollisol accompanied with added salts in ACTME. There is a debate regarding the efficacy of aeration during compost tea production. Ingham (1999) suggested that ACT would provide better results than NCT. However, several other investigators have reported that NCT prepared using Weltzien's method has a more consistent and significantly positive effect than that of ACT on disease control and plant growth (Weltzien 1991; Cronin *et al.* 1996; Scheuerell and Mahaffee 2006). Welke (2005) has shown that both ACT and NCT (extracted for a week) have similar effect on plant growth and disease suppression. Our results also suggested that aeration is not essential for plant growth promotion provided the extraction period is sufficient.

Increased total carotenoids level in plant in response to vermicompost tea treatments was associated with improved plant growth (Figure 6a). This agrees with previous findings (Pant *et al.* 2009). Various studies have shown the positive relationship between N availability and total glucosinolates concentration of Brassica crops. Krumbein et al. (2002) reported that the levels of total glucosinolates were low with low N fertilizer in broccoli plants, whereas, total glucosinolates levels were high at sufficient N supply. In another study, the levels of several glucosinolates decreased in leaves under nitrogen deficiency but accumulated in roots of Arabidopsis thaliana (Hirai et al. 2004). However, Chen et al. (2006) observed lower levels of total glucosinolates in pak choi at high levels of foliar nitrogen application. Applications of vermicompost tea contributed to increased N availability to plants grown under compost fertilization in this study likely explain the positive relationship between total glucosinolates and plant growth (Figure 6b). In the case of Osmocote fertilization, vermicompost tea did not have any influence on total glucosinolates, presumably because of greater N availability.

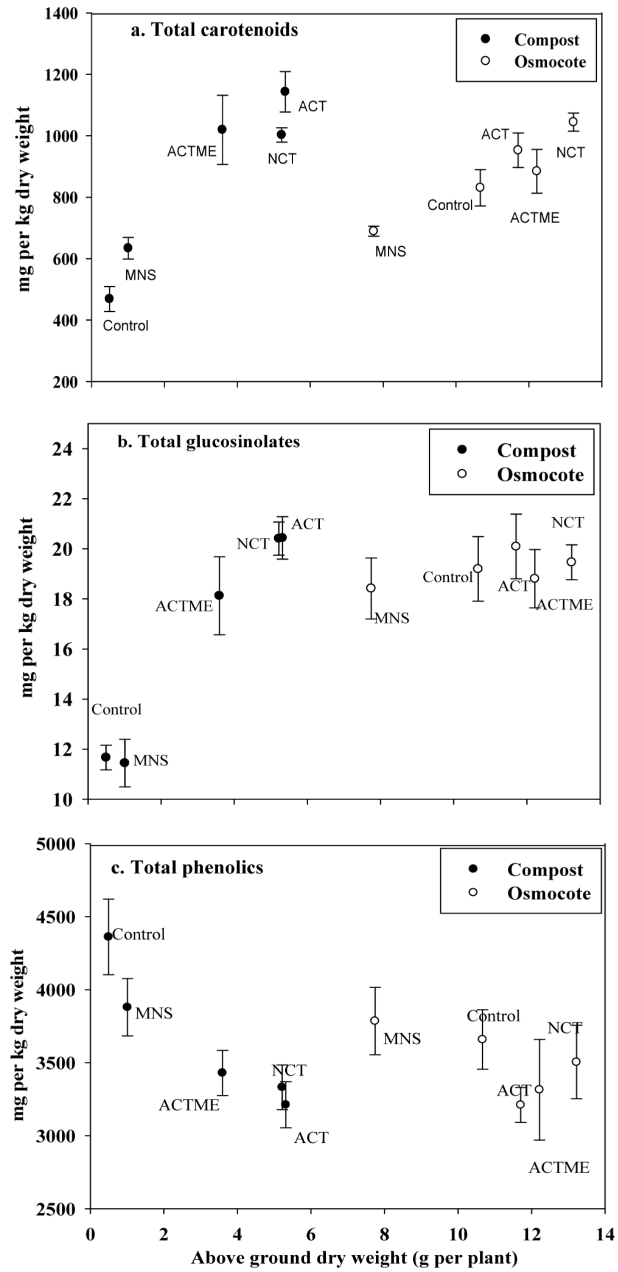

FIGURE 6. Total a. carotenoids, b. glucosinolates and c. total phenolics relative to above ground plant dry weights in all of the growth media. Plotted points are means of 9 samples, and error bars represent standard errors of the mean. ACT=Aerated vermicompost tea, ACTME=Aerated vermicompost tea with microbial enhancer, NCT=Non-aerated vermicompost tea, MNS=Mineral nutrient solution, Control=water.

Stress either due to unfavorable environmental conditions or due to low nutrient status, can induce greater concentrations of phenolics in plant tissues (Brown *et al.* 1984; Estiarte *et al.* 1994). Nutrient stresses can reduce growth more than photosynthesis; the excess carbon relative to nutrients will be allocated to carbon-based defensive compounds including phenolics. Increased concentrations of total phenolics were associated with lower plant growth and low mineral N concentration in tissue of control plants compared to tea treated plants grown under compost fertilization in this study (Figure 6c). Between the two fertilizer regimes, a higher level of total phenolics content was observed in plants grown under compost fertilization compared to Osmocote fertilization. This could be due to a relatively rapid release of plant available nutrient from Osmocote compared to compost. Asami *et al.(2003)* also observed consistently greater levels of total phenolics in organically grown crops than those produced by conventional agricultural practices. Also, greater concentrations of total phenolics in the plants grown in the Mollisol compared to that of the Oxisol and the peat-perlite medium were linked with lower plant growth and low tissue N concentration in the Mollisol grown plants.

Applications of vermicompost tea added a significant amount of mineral nutrients as well as active microbial populations to growth media and this addition affected some of the chemical and biological properties of the media. Higher EC in vermicompost tea treated media was associated with an increase in mineral nutrient concentrations, primarily total N and K content. Soil respiration and dehydrogenase activity were higher in the growth media that had received compost than that of Osmocote. The increase in soil respiration with the application of compost may be explained by improved microbial decomposition of soil organic matter. This is be due to the availability of active organic carbon or enrichment of nutrients for the microbes through the addition of high organic carbon content of compost (Sikora and Yakovchenko 1996; Bernal *et al.* 1998). Vermicompost tea applications contributed to increased soil respiration and dehydrogenase activity, particularly under compost fertilization, implying a more efficient of organic matter decomposition and mineralization of nutrients in growth media, and therefore producing better plant growth.

Summary

Application of vermicompost tea enhanced plant yield, mineral nutrient content and total carotenoids in plant tissue under both compost and Osmocote fertilizations. The effect was more pronounced under compost fertilization. Vermicompost tea enhanced total glucosinolates under compost fertilization but had no effect under Osmocote fertilization. Vermicompost tea applications reduced total phenolics compared to MNS and the control. In general, all vermicompost teas, regardless of extraction methods, provided similar effect on plant growth and nutrient concentration in the Oxisol and the peat-perlite medium. Aeration and additives during extraction are not essential for growth promotion and nutrient quality if tea extraction period is sufficiently long. Vermicompost tea improved mineral nutrient concentration and microbial activities in the growth media. Better root and shoot growth and increased N uptake by vermicompost tea treated plants over MNS treated plants suggest the possibility of microbial and hormonal contributions along with the nutrient effects of the teas.

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