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ORIGINAL RESEARCH

The effect of municipal solid waste compost, peat, perlite and vermicompost on tomato (*Lycopersicum esculentum* L.) growth and yield in a hydroponic system

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Abstract

Purpose An experiment was conducted to assess the ability of municipal solid waste compost (MSWC), peat, perlite and vermicompost (VC) to improve the growth of tomato (*Lycopersicon esculentum* L.), an important horticultural commodity, in hydroponic culture.

Methods Organic matter, when used as a substrate, can affect tomato cultivar 'Grandella' plant growth. In this study, we studied the effect of MSWC, either composted by earthworms (VC), or in an uncomposted form, as well as conventional substrates peat and perlite, on tomato growth when incorporated into hydroponic culture. Growth and physiological attributes were assessed at the fruiting stage.

Results Among several ratios of MSWC, peat, perlite and VC, VC with 25 % compost increased the number of red fruits in the harvest period significantly more than the control. The use of VC, peat and perlite increased root fresh and dry weight, root volume, mean photosynthesis, and the number of fruits at all physiological stages compared to the control.

Conclusion Vermicompost can improve tomato growth physiology when used as one part of the substrate in hydroponic culture.

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Keywords Municipal solid waste compost · Organic substrates · Peat · Perlite · Vermicompost

Introduction

The use of municipal solid waste compost (MSWC), an "organic amendment", is one way of converting waste into agriculturally useful compost whose primary purpose is to fulfill the nitrogen (N) requirements of crops (Hargreaves et al. 2008). MSWC is particularly useful in soils that contain low levels of soil organic matter (SOM), or in nutrient-depleted soils since it can influence nutrient mineralization and subsequent plant growth (Hargreaves et al. 2008). It achieves this by reducing the level of toxic heavy metals in soil (Yuksel 2015). Organic fertilizers such as MSWC can also restore nutrient deficiencies and SOM content (Francou et al. 2008), as was observed with faba bean (*Vicia faba* L.) (Abdelhamid et al. 2004) and maize (*Zea mays* L.) (Carbonell et al. 2011) cultures in which nutrients and SOM were depleted. MSWC increases soil pH, which is advantageous to plant growth (Mkhabela and Warman 2005; Alam and Chong 2006). The use of MSWC also increases microbial activity and soil respiration (Margesin et al. 2006) as a result of a dynamic change in soil microbial community structure (Saison et al. 2006) and the activity of soil enzymes used to transform nutrients (Crecchio et al. 2004), which increase microbial biomass associated with symbiotic root associations (Bouzaiane et al. 2014). Organic amendments can suppress diseases in the rhizosphere although compost feedstocks (i.e., the starting organic material) can alter plant growth (Rodda et al. 2006) and microbial communities in substrates containing those composts (Lores et al. 2006). MSWC applied at 40–120 kg/ha increased the electrical conductivity (EC) of soils, organic carbon (OC), total soil N at the highest rate, soil Zn, Pb, and Cu and increased plant uptake of Zn (Walter et al. 2006). One of the risks of using MSWC is the possible increase in heavy metals which could have negative environmental implications (McBride 1995), although the number of reports on persistent organic pollutants introduced into crop cultures using MSWC remains low (Hargreaves et al. 2008) or underreported.

When soil and organic materials are degraded by earthworms, it is collectively termed vermicompost (VC). This does not usually involve a thermophilic stage, and temperature is strictly regulated to avoid death of the earthworms (Karmegam 2012). In contrast, thermophilic or thermogenic composts have lower concentrations of plant-available nutrients (NO_3^-, exchangeable Ca, P, and soluble K) and significantly smaller and less diverse microbial populations (Edwards et al. 2006). Transplant media amended with 20 % (v/v) VC increased tomato (*Lycopersicum esculentum* L.) biomass but did not impact the growth or yield of field-grown plants (Paul and Metzger 2005). In contrast, the use of composted sewage sludge improved the growth parameters of tomato, cucumber (*Cucumis sativus* L.) and pepper (*Capsicum frutescens* L.) seedlings (Cai et al. 2010). Danaher et al. (2016) found that tomato growth was not negatively affected when dewatered aquaculture effluent was used to partially replace a substrate. The positive contribution of VC to tomato growth (yield, morphological and chemical fruit parameters) is strongly influenced by genotype (Zaller 2007). Compost derived from grape pomace wastes and extracted olive press cake induced systemic resistance to *Septoria lycopersici*, a foliar pathogen, when the roots of tomato plants were inoculated with a transgenic strain of the root-infecting fungal pathogen *Fusarium oxysporum* f.sp. *radicis-lycopersici* (Kavroulakis et al. 2005).

Purpose of the experiment

This study aimed to assess the effect of MSWC and VC as organic substrates in tomato hydroponic culture and compared them with two conventionally used substrates, peat and perlite. An additional objective of this study was to find environmentally friendly alternatives to conventional substrates that would allow for the production of high-quality tomato plants with comparable vegetative and reproductive parameters.

Materials and methods

Study area, raw materials and treatments

A greenhouse experiment was conducted at the Department of horticulture, College of Agriculture, Isfahan University of Technology, Iran, between June 2012 and January 2013 (32°43′36″N, 51°31′33″E) with an average temperature of 35.33 °C and 20–70 % humidity (6-month range). Tomato seeds of cultivar 'Grandella' were sown in plugs containing peat moss of pH ($CaCl_2$) 5.2–6.0, salt content (H_2O) <1.5 g/l, 110–250 mg/l nitrogen (N), 60–140 mg/l phosphate (P_2O_5), and 140–280 mg/l potassium (K_2O). After sowing, pots were placed in a greenhouse until the seeds germinated. After germination, tomato seedlings with 2–3 true leaves were transplanted into cylindrical gray tubes (200 cm in length, 11 cm in diameter; Persian cube, Tehran, Iran) filled with different substrate mixtures. Each cylindrical tube contained seven plants at an equal distance of 30 cm. Treatments were different substrate ratios (Table 1) using MSWC, VC, peat and perlite whose properties are described in Table 2. The experiment, conducted once, was based on a completely randomized design (CRD) with seven replicates.

Plants in hydroponic culture were irrigated with nutrient solution (freshly prepared each time) whose composition was (in mg/l): 270 potassium phosphate (KH_2PO_4), 200 nitrate potassium (KNO_3), 500 sulfate magnesium ($MgSO_4{\cdot}7H_2O$), 100 potassium sulfate (K_2SO_4), 500–680 calcium nitrate ($Ca(NO_3)_2$), 79 chelated iron (EDTA), 6.76 manganese chloride ($MnCl_2{\cdot}4H_2O$), 7.50 boric acid (H_3BO_3), 0.39 copper sulfate ($CuSO_4{\cdot}2H_2O$), 0.15 molybdenum trioxide (MnO_3), and 1.18 zinc sulfate ($ZnSO_4$. $7H_2O$). Irrigation, which was uniform for all treatments, took place every 3 h for 15 min at the same time each morning. The pH of the culture solution was adjusted, when required, to 6.5 ± 0.5 by adding diluted HNO_3.

Tomatoes were allowed to grow freely on a wire trellis, and plants were not thinned. Plants were harvested 171 days after transplanting, which corresponds to ideal ripe red fruit stage suitable for harvesting. Fruits from a single harvest were assessed.

Table 1 The ratio (v/v) of different substrates used in treatments in this study

Substrate	Peat	Perlite	MSWC	VC
P50:PR50 (control)	50	50	0	0
P75:PR25	75	25	0	0
C25:P25:PR50	25	50	25	0
C25:V25:PR50	0	50	25	25
C50:PR50	0	50	50	0
C75:PR25	0	25	75	0
V50:P50	50	0	0	50
V75:P25	25	0	0	75
V25:P25:PR50	25	50	0	25

C compost = municipal solid waste compost (MSWC), *P* peat, *PR* perlite, *VC* vermicompost

Table 2 Characteristics of municipal solid waste compost, vermicompost and perlite used in this study

Substrate	Value/amount
Municipal solid waste compost	
OC (%)	35–75
SOM (%)	28–77
pH	5.4–6.9
EC (ds/m)	13–36
N (%)	1.3–1.9
P (mg/Kg)	120–2400
K (mg/Kg)	90–718
Na (mg/Kg)	200–590
Ca (mg/Kg)	166–1300
Mn (mg/Kg)	19–120
Cd (mg/Kg)	0.0–5.5
Fe (mg/Kg)	6000–21,000
Mg (mg/Kg)	120–370
Zn (mg/Kg)	124–490
Pb (mg/Kg)	49–250
Cu (mg/Kg)	40–300
Vermicompost[a]	
P (%)	1
N (%)	2.3
K (%)	1.12
EC (ds/m)	2.56
pH	7.25
OC (%)	29
C/N	12.6
Perlite	
Size (mm)	1–2
N (%)	0.3
K (mg/Kg)	0.01
Ca (mg/Kg)	0.5
Mn (mg/Kg)	10
Fe (mg/Kg)	250
Mg (mg/Kg)	0.3
Zn (mg/Kg)	5.3
pH	5.6
EC (ds/m)	0.04

Compost was prepared from MSWC provided by the Compost Plant of Isfahan Municipality Building Co

Purchased from Goldasht Co. (Isfahan, Iran) which was made from the composting activity of *Eisenia fetida* earthworms on MSWC

Plantaflor Humus, Verkaufs-GmbH, Niedersachsen, Germany

[a] Details about micronutrients not available

Growth parameters assessed

Plant fresh weight (FW) (shoot, root and fruit) was measured by an analytical balance (0.001 decimal places). Individual plant parts were dried in an oven at 70 °C for 48 h, after which dry weight (DW) was determined.

Total soluble solids (TSS) (°Brix) were assessed with a hand refractometer (Carl Zeiss, Jena, Germany) from the juice (2–3 drops) of ripe fruits. Juice was prepared by cutting fruits, blending them in a mixer and, then, using several drops of the juice in the assay (Haghighi 2013).

After 20 weeks, physiological parameters were measured, as described next.

Relative water content (RWC) was measured according to Mohsenzadeh et al. (2006) using the following equation:

$$\mathrm{RWC} = \frac{W_i - W_d}{W_f - W_d} \times 100,$$

where W_i = FW of harvested leaves, which were cut to 1-cm segments; W_f = the weight of leaf segments soaked in water at 4 °C in dark for 24 h; and W_d = DW of the segments oven-dried at 80 °C for 24 h.

The leaves were weighed at three stages, immediately after sampling, then dried in an incubator at 28 °C at 50 % RH for 6 h, and, then, dried again in an oven for 24 h at 70 °C as proposed by Clarke (1987). Excised leaf weight loss (ELWL) was calculated by the following formula:

$$\mathrm{ELWL} = [(\mathrm{FW} \times \mathrm{DW\ after\ 6\ h}) = (\mathrm{FW} \times \mathrm{DW})] \times 100$$

Measurement of plant chlorophyll and photosynthetic attributes

Leaf chlorophyll (chl) content was measured using three fully expanded leaves in each replicate with a non-destructive dual-wavelength chl meter (SPAD-502, Minolta Corp., Ramsey, NJ, USA). Five measurements were made per replicate at the time of harvest.

Photosynthetic rate (μmol m^{-2} s^{-1}), stomatal conductance (g_s) (mol m^{-2} s^{-1}), sub-stomatal CO_2 (μmol) and transpiration rate (mol m^{-2} s^{-1}) were determined using a portable area meter (Li-Cor, Li-3000, USA). Mesophyll conductance (mmol CO_2 m^{-2} s^{-1}) was calculated by dividing the photosynthetic rate by the sub-stomatal CO_2 concentration (Ahmadi and Siosemardeh 2005). Photosynthetic water-use efficiency (PWUE) (μmol CO_2 m^{-2} s^{-1}) was calculated by dividing photosynthesis rate by transpiration (Haghighi et al. 2012).

Statistical analysis

The study was arranged in a complete randomized block design with seven replicates. Data were analyzed with Statistix 8 (Tallahassee FL, USA). All data were subjected to one-way analysis of variance (ANOVA), and the means were compared for significance by the least significant difference (LSD) test at $P < 0.05$.

Results

Root FW and DW and root volume increased in all treatments relative to the control except for V25:P25:PR50. The highest root FW, root DW and root volume were observed in C50:Pr50, although there were no significant differences between C25:V25:PR50 and C75:PR25 in terms of root FW and DW. These treatments were statistically similar to V50:P50 and V75:P25. Mean shoot FW did not increase significantly in any treatment compared to the control. Highest values were observed for C25:V25:PR50 and lowest values in P50:PR50. Fruit was largest in V50:P50 but statistically similar to P75:PR25, C75:PR25 and V20:P25:PR50. Highest fruit weight and yield/plant were obtained in C25:V25:PR50 and the highest TSS in C25:V25:PR50 (Table 3).

The treatments containing VC and 25 % MSWC increased the number of red fruits at harvest time more than the control. Most red fruits were harvested from C25:V25:PR50, V50:P50, V75:P25, and V20:P25:PR50 treatments. Similarly, most green and orange fruits were harvested from C25:V25:PR50 (Fig. 1a). The highest growth rate of fruits was observed in V75:P25 and the lowest in C75:PR25 (Fig. 1b). The growth rate of fruit was higher than the control in V75:P25, V50:P50, and C25:V25:PR50 (Fig. 1b).

The number of fruits of all physiological stages increased when VC and MSWC were both added to the substrate. Red and orange fruits increased in the substrate containing a mixture of MSWC with VC and peat, each at 25 % (Fig. 2c). ELWR was statistically the same in all treatments but decreased in C50:PR50 (Fig. 2a). Mean photosynthesis increased in all treatments except for C25:V25:PR50 (lowest mean), while highest photosynthesis was observed in C75:PR25 (Fig. 2b). Average stomatal conductance increased in all treatments except for V25:P25:PR50 relative to the control, and highest stomatal conductance was in V75:P25 but lowest in V20:P25:PR50 (Fig. 2c). CO_2 assimilation increased in all mixed substrates compared to the control. These treatments were not statistically different, except for V50:P50 and V25:P25:PR50. CO_2 assimilation peaked in V75:P25 and was lowest in V50:P50 (Fig. 2d). Compared to the standard substrate (P50:PR50) used for tomato hydroponic culture, when VC and MSWC were used at a low concentration (25 %), transpiration increased (Fig. 2e). Compared to the control substrate (P50:PR50), when 25 % MSWC was added to the basal substrate, highest chl content was observed in C25:P25:PR50 (Fig. 2f). Relative to the control, PWUE increased when high levels of VC and MSWC (75 %) were applied in C75:PR25 and V75:P25 (Fig. 2g). Mesophyll conductance increased significantly in V50:P50 (Fig. 2h).

Discussion

This study provides a viable way of increasing plant growth as well as physiological and nutritional parameters of tomato fruits by altering the ratio of MSWC, VC, peat and perlite in hydroponic culture.

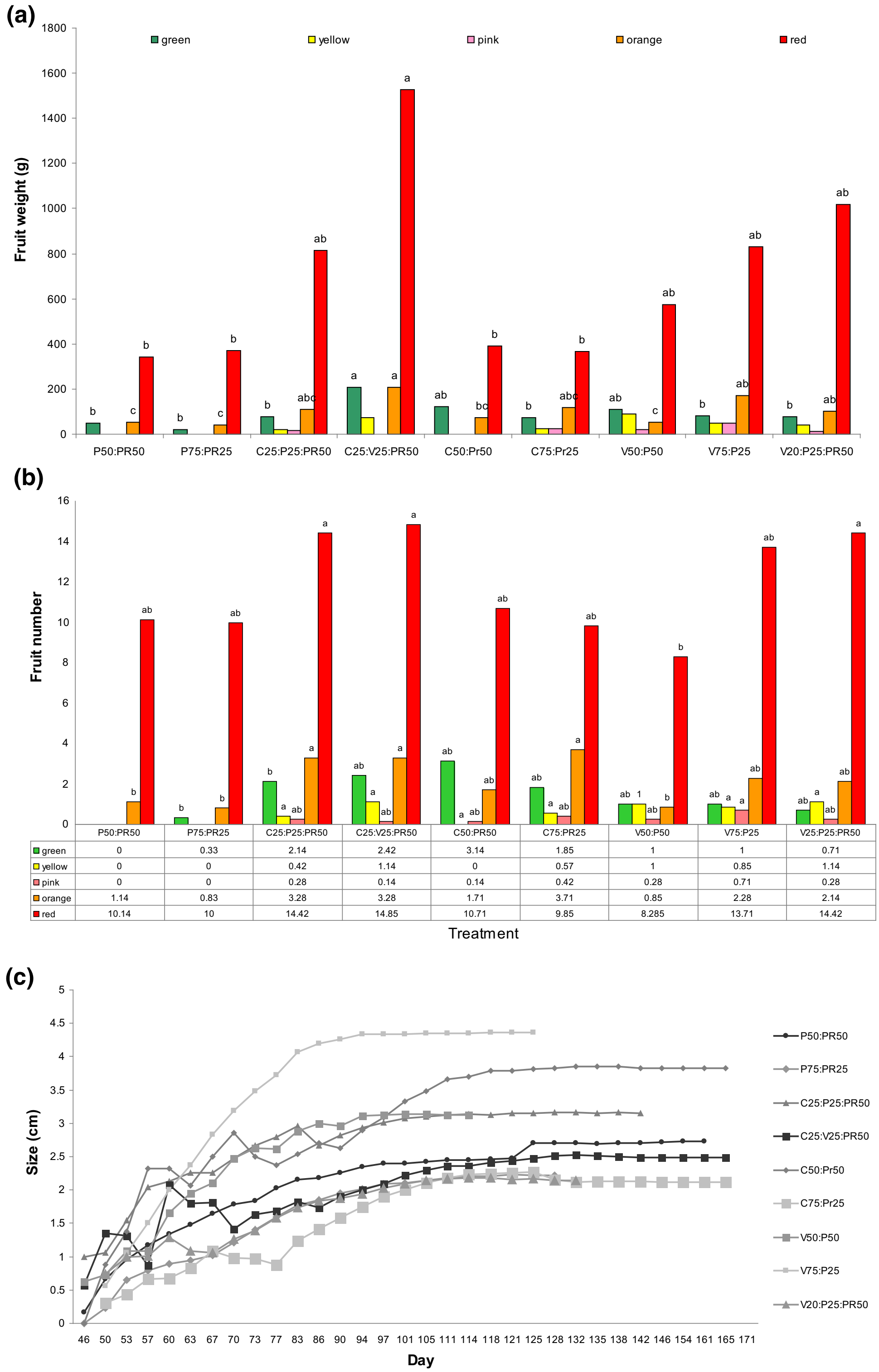
Table 3 The effect of different substrates on growth characteristics of tomato

Substrate	Root FW (g)	Root DW (g)	Root volume (mL)	Shoot FW (g)	Shoot DW (g)	Fruit size (mm)	Fruit weight (g)	Yield/plant (g)	TSS (°Brix)
P50:PR50	53.09 d	4.20 d	108.57 d	230.58 e	26.42 de	2.16 c	37.16 b	449.05 b	6.37 bc
P75:PR25	62.63 cd	5.56 cd	160.0 cd	302.20 de	33.97 cde	3.12 abc	39.57 ab	437.12 b	6.10 c
C25:P25:PR50	81.28 bcd	8.38 bcd	182.86 bcd	446.36 bcd	53.69 a	2.43 c	33.71 b	1050.9 ab	8.81 a
C25:V25:PR50	115.42 ab	11.22 abc	288.57 ab	726.55 a	35.69 bcd	3.17 bc	80.36 a	2037.5 a	5.78 c
C50:PR50	147.93 a	17.20 a	347.14 a	434.43 cd	35.89 bcd	2.52 bc	35.46 b	617.35 b	8.01 ab
C75:PR25	104.08 abc	13.74 ab	250 abc	381.82 de	19.91 e	3.88 ab	61.55 ab	626.84 b	5.90 c
V50:P50	87.49 bcd	8.63 bcd	257.14 abc	611.69 ab	21.566 de	4.37 a	61.2 ab	849.08 b	4.77 c
V75:P25	83.21 bcd	9.370 bcd	258.57 abc	562.79 abc	48.90 ab	2.43 c	57.34 ab	1189.0 ab	6.48 bc
V25:P25:PR50	46.09 d	3.7 d	127.14 d	365.48 de	44.26 abc	3.05 abc	34.27 b	1185.0 ab	6.38 bc

Within a column, the means followed by the same letter are not significantly different at $P < 0.05$ according to the LSD test. $N = 63$

DW dry weight, *FW* fresh weight, *MSWC* municipal solid waste compost, *TSS* total soluble solids, *VC* vermicompost

Treatments: peat:perlite (50:50; P50:PR50) = control; peat:perlite (75:25; P75:PR25); MSWC:peat:perlite (25:25:50; C25:P25:PR50); MSWC:VC:perlite (25:25:50; C25:V25:PR50); MSWC:perlite (50:50; C50:PR50); MSWC:perlite (50:25; C50:PR25); VC:peat (50:50; V50:P50); VC:peat (75:25; V75:P25); VC:peat:perlite (25:25:50; V25:P25:PR50)



	P50:PR50	P75:PR25	C25:P25:PR50	C25:V25:PR50	C50:PR50	C75:PR25	V50:P50	V75:P25	V25:P25:PR50
green	0	0.33	2.14	2.42	3.14	1.85	1	1	0.71
yellow	0	0	0.42	1.14	0	0.57	1	0.85	1.14
pink	0	0	0.28	0.14	0.14	0.42	0.28	0.71	0.28
orange	1.14	0.83	3.28	3.28	1.71	3.71	0.85	2.28	2.14
red	10.14	10	14.42	14.85	10.71	9.85	8.285	13.71	14.42

Fig. 1 The effect of different substrates on the total season fruit weight (**a**), number of fruits (**b**), and fruit size (**c**) in different physiological stages (*green*, *yellow*, *pink*, *orange* and *red*). $N = 7$ replicates in each treatment. *Different letters* indicate significant differences at $P < 0.05$ according to the LSD test

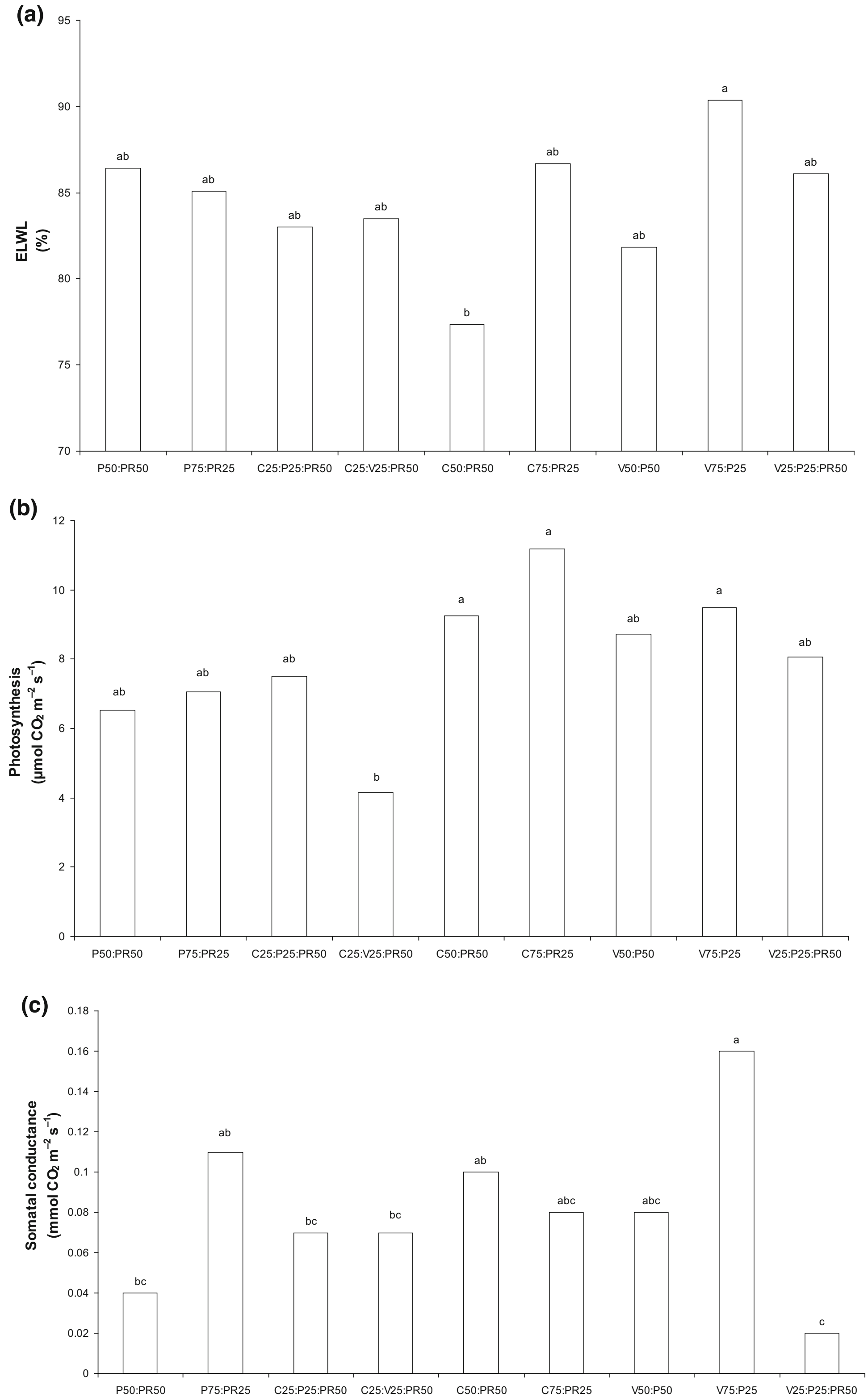


Fig. 2 The effect of different substrates on the excised leaf weight loss (ELWL) (**a**), photosynthesis (**b**), stomatal conductance (**c**), CO_2 assimilation (**d**), transpiration (**e**), chl content (**f**), photosynthetic water-use efficiency (PWUE) (**g**), and mesophyll conductance (**h**). $N = 3$ in each treatment. *Different letters* indicate significant differences at $P < 0.05$ according to the LSD test

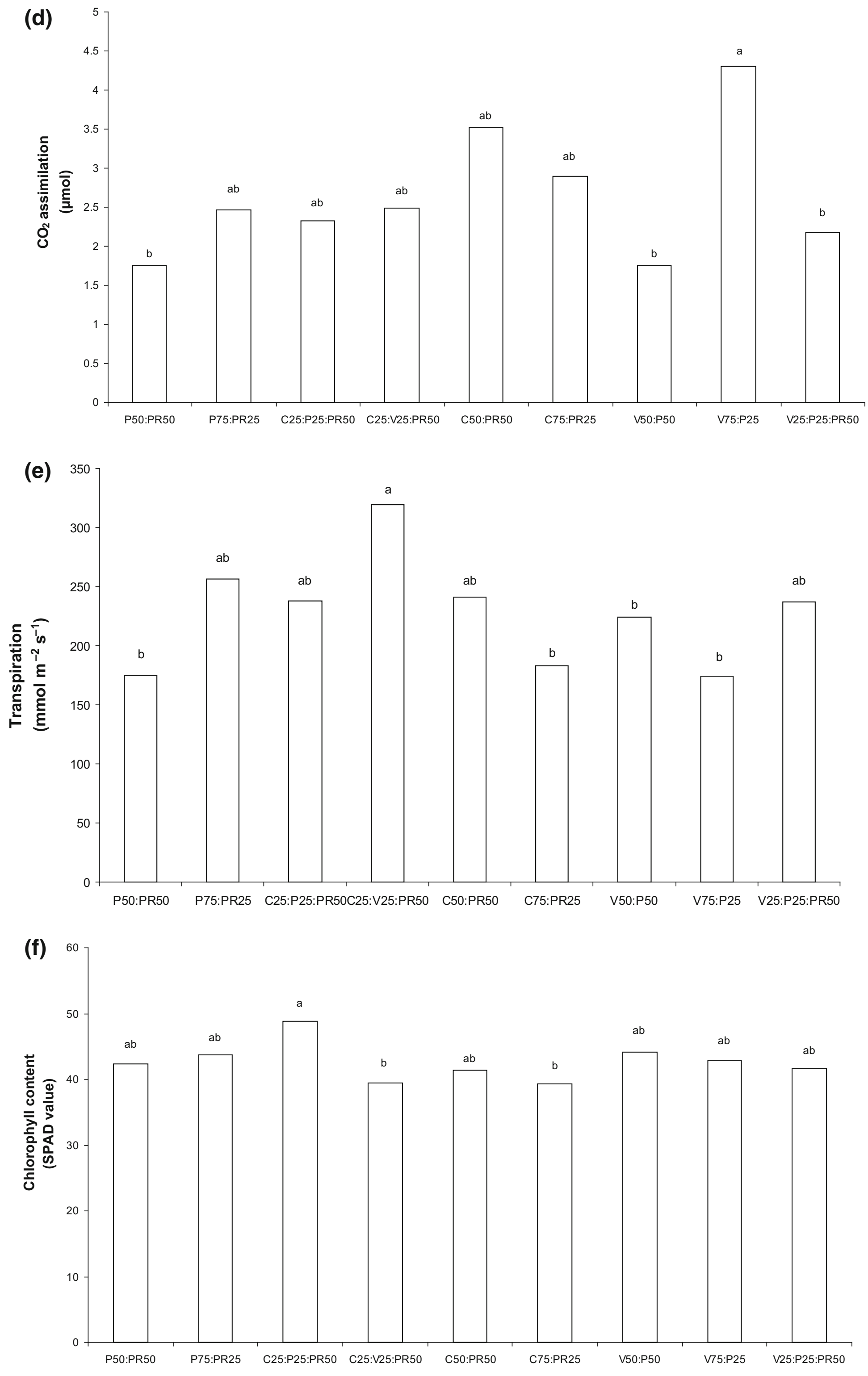


Fig. 2 continued

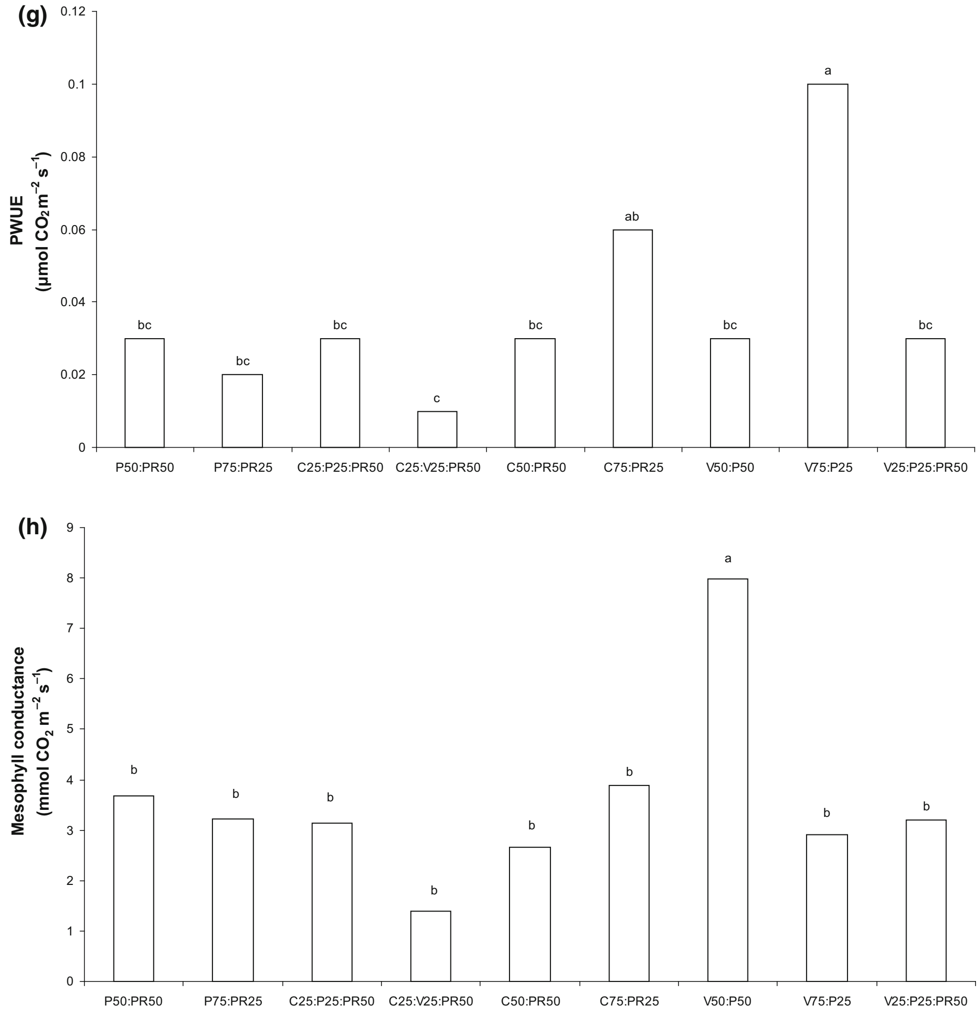


Fig. 2 continued

Plant growth

The leaf area, numbers of suckers, number of flowers, shoot weight and total marketable yield increased significantly in strawberry (*Fragaria X ananassa* L.) plots treated with VC compared to those that received inorganic fertilizers only (Arancon et al. 2003). VC increased the biomass, plant height, number of buds and flowers of French marigold (*Tagetes patula*) (Gupta et al. 2014). VC also improved tomato fruit-related parameters in our study, but even more so when combined with peat and perlite (Fig. 1).

MSWC improved the stem and leaf growth of tomato 'Atletico' seedlings, but only when added at a 3:7 ratio with peat (Herrera et al. 2008), as observed in this study (Table 3). When Gutiérrez-Miceli et al. (2007) used VC-processed sheep manure to amend tomato (cv. 'Rio Grande') cultures, VC decreased soil pH and titratable acidity, increased soluble and insoluble solids of fruits, and resulted in significantly larger plants and yield relative to the control (unamended soil). The VC used in this study was very basic (Table 2), but likely when combined with peat or perlite, resulted in a neutral pH suitable for plant growth. Low doses of compost (10 and 20 %) and high doses of *Eisenia fetida*-derived VC increased the aerial and root biomass of 'Marlglobe' tomato plants significantly (Lazcano et al. 2009). Composts from distillery wastes showed physical, physicochemical and chemical properties comparable to peat, which was the control substrate, when used to grow lettuce (*Lactuca sativa* L.), chard (*Beta vulgaris* L.), broccoli (*Brassica oleracea* L.) and coriander (*Coriandrum sativum* L.) (Bustamante et al. 2008). The physicochemical properties of the three substrates used in this study, however, varied considerably (Table 2).

Jack et al. (2011) compared three groups of organic amendments, plant-based amendments (sesame meal, alfalfa meal), composted manure amendments (VC, thermogenic compost, industry standard) and a non-amended peat as well as a vermiculite-based mix to assess organic tomato production in the field. Depending on the organic amendment used, germination rates, transplant growth in the greenhouse, crop growth in the field and final yields were affected. For example, total yield was highest when soil was amended with 20 % alfalfa and sesame meal in the first season, but this mix of amendments negatively impacted germination and had no impact on the second season's growth (Jack et al. 2011). In this study, tomato yield was significantly affected by the use of VC in combination with peat and perlite (Table 3).

Photosynthetic traits

The EC of growth medium and plant growth increased when geranium (*Pelargonium x hortorum* Bailey cv. 'Meridonna') greenhouse pot cultures were fertilized with MSWC, but leaf N and P levels decreased (Ribeiro et al. 2000). Pant et al. (2012) examined how compost teas derived from several composts and VC affected pakchoi (*Brassica rapa* L.) performance in a peat–perlite substrate base. All compost teas increased the growth and mineral content of pakchoi, although the extent differed and was associated with the presence of mineral N and gibberellin (GA_4) in the teas. Cow manure VC improved the growth and metabolite content of Chinese cabbage (*Brassica campestris* ssp. *chinensis*) (Wang et al. 2010). The EC and mineral properties of all substrates used in this study differed considerably (Table 1).

Limited studies have examined the impact of any compost, VCs or other organic amendments on the photosynthetic attributes of tomato. In a study examining the photosynthetic response of tomato 'Capello' on peat, rockwool and a nutrient film technique under three levels of EC, peat at an EC of 1–4 showed the highest FW and fruit index, and highest maximum gross photosynthetic and respiration rates (Xu et al. 1995). Increasing sulfate concentration in substrate to 10.4 mmol/l increased chl *a* and *b* and total chl content of tomato fruit (Lopez et al. 1996). Food-, leaf- or biosolid-based wastes that had been vermicomposted by *Eisenia* sp. improved the growth (i.e., total chl content, shoot DW, microbial activity) of tomato 'Rutgers' and marigold (*Calendula officinalis* L.) (Atiyeh et al. 2000).

Yield and fruit properties

The marketable yield of tomato (var. BHN 543 F1) treated with VC was higher than that of plants that were treated with inorganic fertilizers only (Arancon et al. 2003). VC also increased yield and flowering-related parameters of rice (*Oryza sativa* L.) (Bejbaruah et al. 2013). Tomato yield in this study also increased in response to the application of VC, but even more so when mixed with peat and MSWC (Fig. 1).

MSWC has been shown to benefit the growth and yield of several crops, including some horticultural plants, in most cases, but this depends on several factors such as application load (Hargreaves et al. 2008). For example, MSWC applied at 37.5 kg/ha in the first year and half that amount in the second year significantly increased soil Na in strawberry plots (Shanmugam and Warman 2004). Although application of MSWC to cocksfoot (*Dactylis glomerata* L.) increased yield relative to the control (mineral fertilizer), alfalfa (*Medicago sativa* L.) yield was equivalent to that of the control (Montemurro et al. 2006). When potatoes (*Solanum tuberosum* L.) were grown in sandy soil (but not in other soil types) supplemented with 15 kg/ha MSWC, yield increased, but the increase in soil Pb, Cu, and Zn was small (Sebastião et al. 2000). MSWC-amended soil improved plant development and yield of common bean (*Phaseolus vulgaris* L.), but yield was even greater when soil was amended with VC created by the action of *Eisenia fetida* on this MSWC (Fernández-Luqueño et al. 2010). In spinach (*Spinacia oleracea* L.), MSWC increased yield as well as P, Mn, Pb, Na, and Cl uptake (Maftoun et al. 2004). For potatoes and sweet corn (*Zea mays* L.), MSWC increased pH and provided as much P as the control, mineral fertilizer (Mkhabela and Warman 2005). In the latter study, for potatoes, 21.7, 43.4, and 65.1 kg/ha MSWC or, for sweet corn, 7.5, 15, and 22.5 kg/ha were sufficient for good growth, while only half these amounts were required for the second year of growth. Two applications of MSWC at 35, 70, or 140 kg/ha increased soil Mn and leaf Ni in blueberries (*Vaccinium corymbosum* L.) (Warman et al. 2004). When MSWC was applied at 24 and 48 kg/ha to tomato and squash (*Cucurbita moschata* L.) cultures, the concentration of Cd, Cu, Pb, Ni, and Zn in the soil increased (Ozores-Hampton and Hanlon 1997). When MSWC was applied at 54 kg/ha over 6 years, the concentration of Ni, Pb, Cd, and Cr in soils and grapevine (*Vitis vinifera* L.) leaves increased (Pinamonti et al. 1999). In a pot experiment using Swiss chard (*Beta vulgaris* subsp. *cicla* L.) and basil (*Ocimum basilicum* L.), Zhelzaskov and Warman (2004) found that MSWC applied at 200, 400, or 600 kg/l increased the concentration of Cu and Zn in soil, but uptake by plants was not observed. Marketable yield of potato was as high as regular NPK fertilizer, only in the second and third years after the application of MSWC (Warman et al. 2011). In this study, the effect of choice of substrate on changes in the physicochemical properties of the hydroponic medium was not assessed.

Organic amendments and composts have benefited the growth and performance of other horticultural crops. Mn increased in lettuce and broccoli, while Zn increased in lettuce, broccoli, and coriander when compost was used, but all other amendments showed a lower level of micronutrients (Fe, Cu, Mn, Zn) relative to peat, which was explained by a decrease in the availability of these micronutrients as the pH of the media increased after adding compost (Pérez-Murcia et al. 2006). The use of non-composted olive water waste sludge together with poultry manure increased N content in tomato cultured in the field, but plant nutrient content and yield varied widely, depending on the organic amendment used (Rigane and Medhioub 2011). Olive water waste sludge, when suitably treated, can benefit agriculture (Musculo 2010). In this study, the effect of choice of substrate on changes in nutrient content of the hydroponic medium or of different plant parts was not assessed.

The use of composts based on clover grass hay, deep litter and peat did not affect the fruit nutrients or physicochemical and sensory properties of tomato ('Aromata' grafted onto 'Beaufort' roots) grown organically in a greenhouse (Thybo et al. 2006). This has an impact on organic tomatoes, which are mainly grown in soil. 'Rutgers' tomato plants grown in commercial potting substrate amended with VC improved shoot DW, root DW, leaf area, and the shoot:root ratio (Bachman and Metzger 2008). In that study, similar positive effects were also observed for 'Queen Sophia' French marigold (*Tagetes patula* L.), 'California Wonder' bell pepper (*Capsicum annuum* L.), and 'Imperial' cornflower (*Centaurea cyanus* L.). Commercially produced VCs made from the action of *Eisenia fetida* on cattle manure, food wastes and paper wastes improved the germination of petunia (*Petunia* sp. var. Dreams Neon Rose F_1) seed (Arancon et al. 2008). Composted spent mushroom substrate, when added to peat in a 3:1 ratio, improved 'Muchamiel' tomato, pepper and courgette (*Cucurbita pepo* L.) seed germination (Medina et al. 2009). Secondary metabolites (tannin and iridoids) of three bulbous ornamental plants (*Eucomis autumnalis*, *Tulbaghia ludwigiana* and *Tulbaghia violacea*) were enhanced when VC leachate was added to the stressed plants (Aremu et al. 2014). The use of vermicasts decreased the amount of potentially toxic heavy metals (Cr, Zn, Ni) in lettuce but did not affect chl content when mixed in a 2:8 ratio with green waste feedstock (Ali et al. 2007). In this study, the effect of choice of substrate on changes in seed germination, secondary metabolite production and the levels of heavy metals in the hydroponic medium or in plant tissues were not assessed.

Conclusions

The growth of tomato in hydroponic culture was enhanced when MSWVC and MSWC were used. The use of MSWVC has already been shown to improve the growth of a wide range of horticultural crops, including tomato (Ievinsh 2011), while the use of MSWC does not result in the accumulation of heavy metals (Giannakis et al. 2014). The most likely reason may be the presence of plant growth-promoting substances in MSWVC (Zhang et al. 2014). Parameters related to fruit quality, plant physiology and yield can be improved, making this nutrient amendment a useful and practical way to increase tomato productivity. This has tremendous ramifications since tomato is a popular horticultural crop grown and consumed in most countries around the world. The recommended ratio of organic amendments for tomato hydroponic growth is MSWC:peat:perlite (25:25:50).

Compliance with ethical standards

Conflict of interest The authors have no conflicts of interest to declare.

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