Treated wastewater and/or Municipal Solid Waste Compost applied for greenhouse pepper cultivation

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Abstract
The performance and suitability of municipal solid waste compost (MSWC) in different content and/or irrigation with treated wastewater (TW) in pepper (*Capsicum annuum* L. cv. Oregon) plants were studied over a 4-month period in greenhouse conditions. Five different substrates with soil (S) and/or MSWC mixtures (v:v %) [S (100%) as control: S:MSWC 95:5; S:MSWC 90:10; S:MSWC 80:20 and S:MSWC 60:40] were used with or without irrigation with TW, resulting in ten treatments. Substrate affected some characteristics of plant growth and yield. Plants grown in 5-20% MSWC were taller and produced higher leaf number compared with the control while irrigation with TW slightly delayed plant growth. Increased MSWC content (> 10%) into the substrate resulted in thicker plant stems. The number of flowers, and as a consequence, the number of fruits fluctuated among treatments with increased numbers in 5-20% MSWC irrigated with TW, revealing earliness of 15 days on fruit production. Plant biomass increased in 10-20% MSWC applications, and this was evidenced even at 5% MSWC irrigated with TW. Plant yield decreased in 40% MSWC, whereas TW irrigation alleviated that reduction. There were no differences regarding leaf fluorescence, leaf photosynthetic rate and stomatal conductance in different MSWC content and/or TW. The addition of MSWC into the soil increased nutritive value (N, K, P, organic matter) and/or altered physicochemical properties of the substrate resulting in increased EC and Na accumulation. Fruit fresh weight decreased (up to 19% and 34%) as plants grown in higher MSWC content or TW, respectively. Fruit size fluctuated when different MSWC content was used in the soil and the effects were mainly in fruit length rather than in fruit diameter. Fruit firmness was maintained in plants grown in <10% MSWC (and in <5% MSWC +TW). Interestingly, the scale of marketable fruits was reduced as MSWC content was increased in the substrate but TW irrigation reversed this trend and maintained the fruit marketability. Peppers were less acid in plants grown in 10% MSWC content as the pH fruit juice increased but no differences were observed in the pepper juice EC. Additionally, the total soluble solids and/or acidity variation affected pepper sweetness. Total phenols content decreased with the addition of >20% MSWC in the substrate. Fruit lightness (L) increased as MSWC content increased in the substrate. Fruit green colour (Chroma a and b) fluctuated in different MSWC content with/without TW. Bacteria (Total Coliform and *E. coli*) units on the fruits did not differ among the treatments. The results indicate that the low content of MSWC added into substrate improved plant growth and maintained fruit fresh weight for greenhouse pepper without affecting plant yield, while TW could be an alternative means for irrigation in vegetables following strictly applied safety aspects.

Keywords: compost; municipal solid waste; growth; quality; fertigation; pepper; wastewater

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Introduction

Over 500 kg of municipal solid waste (MSW) per inhabitant are generated yearly in the European Union [1]. Worldwide residue generation has increased considerably over the last 30 years, entailing not only the loss of materials and energy, but also negative environmental impacts. Many studies have shown that the application of immature composts to soil causes severe damage to plant growth [2]. Composting could turn large volumes of MSW into material to be used as fertilizer, organic soil additive and crop substrate. There are, however, certain limitations on some compost used with marked variation in physical/chemical properties (i.e. porosity, salt content). The use of municipal solid waste (MSWC) or sewage sludge composts in agriculture has been increasingly promoted by environmental agencies, preventing landfill disposal and contributing soil organic matter restoration [3]. Benefits of soil application of compost have been attributed to improvement of physical properties; that is, increased water infiltration, water-holding capacity, aeration and permeability, reduction of disease incidence, weed control, or improvement of soil fertility [4]. Therefore, MSWC as an organic soil additive when applied in field trials suggested that it can be used in agricultural production, improving soil physicochemical properties, increasing water retention as well as supply with considerable amounts of essential nutrients [5-6]. Maynard [7] reported 58% higher yield in tomato crop amended with 11.2 t/ha MSW compost but noticed symptoms of damping off diseases and dying in squash. Additionally, Ozores-Hampton [8] reported improved tomato growth and yield after applying MSW compost but questioned the high cost compared to commercial fertilizer. However, little information is available regarding the use of MSWC as an additive in the soil in horticultural crops as well as in impacts of fruit quality.

Another important issue is the use of marginal-quality water for crop irrigation which has gained importance in water-scarce regions [9] as the demand for water is continuously increasing in arid and semi-arid countries. One of the major types of marginal-quality water is wastewater, which has been reused in agriculture for centuries; however, the amount of wastewater recycled has greatly increased in the last decade [10]. Types of wastewater used for recycling include primary-PTW [11], secondary-STW [12] and tertiary-treated wastewater-TTW [13]. Nowadays, several scientific studies take place to this direction, in order to determine the re-use of processed wastewater for the irrigation needs of crops following primary, secondary and tertiary (chlorotic, UV, O_3 etc) treatment aiming at the maximization of crop yields, not only quantitative, but also qualitative, without environmental risks [13-14]. Disinfection of wastewater is vital in addressing the potential health risks of urban water reuse and the appropriate methods for disinfection as an essential purification step for safe urban reuse have been studied [15]. The above ways of wastewater application will be accompanied with restrictions that ensure the protection of public health and the protection of air, aqueous and soil sources. The use of wastewater affected the chemical properties of soil in the first 30 cm below ground as well as the constitution of plants [16]. Several advantages are related with the use of TW, which include: a) a crop productivity improvement in water-constrained systems [17]; b) a reduced amounts of fresh water used for irrigation; c) a reduced discharge of nutrients in surface waters; and d) a decrease in the cost of wastewater treatment by eliminating the need for nutrient removal [18].

Fruit quality encompasses many aspects, and includes not only flavour, colour, nutritional aspects and firmness, but also shelf life, processing attributes, resistance to pathogens and safety [19]. At the market interface, only produce that corresponds to the consumers' expectations can survive. The firmness of a fruit is an important quality attribute and is directly related to enhancing the storability potential and inducing greater resistance to decay and mechanical damage [20]. Moreover, an increased interest in vegetables has been created by the fact that their consumption has been correlated to human health and the reduced risk of some types of cancer [21].

The present study sought to evaluate the impacts of different content of MSWC mixed with soil in conjunction with different kinds of water quality irrigation management (tap water and tertiary-treated wastewater), in plant growth and fruit quality related parameters in greenhouse pepper production.

Material and Methods

Plant material and municipal solid waste compost source

Pepper (*Capsicum annuum* L. cv. Oregon) plants were grown under natural light during the autumn-winter period (September to January) in 2010-2011. Municipal solid waste compost (MSWC) was taken by the Inter-Municipal Enterprise for the Management of Solid Wastes (IMEMSW), based in Chania, Greece. The compost used was made from the organic fraction of selectively-collected urban waste. The composting procedure lasted for 5-6 months. 60% of the compost consisted of particles with < 4 mm size. The elemental analysis of the pure MSWC revealed the following: pH: 7.52; EC: 16.54 mS/cm; organic C: 26.62%; Total N: 0.57%; P: 164 mg/L; K: 727 mg/L; Na: 403 mg/L [22].

Tertiary-treated wastewater source

Primary treated wastewater was obtained from the sewage treatment unit of Heraklion (180,000 p.e.), Crete, Greece. Tertiary wastewater (TW) was obtained by treating the effluent of packed bed filters (Advantex-AX20, Orenco; used for secondary-treated wastewater) using a sand filter and a chlorination process (obtained by the lab of solid waste and wastewater management at the Technological Educational Institute of Crete, Greece), while the physicochemical characteristics of the tertiary-treated wastewater used in the experiment were measured and presented in previous studies [14]. In detail, the physicochemical characteristics of tertiary-treated wastewater and tap water (in parenthesis) sources used in the experiment were: pH 7.5 (7.8); electrical conductivity-EC (mS/cm) 1.1 (0.7); chemical oxygen demand-COD (mg/L) 24 (16); total soluble solids-TSS (mg/L) 9.1 (2.6); Total Nitrogen-TN (mg/L) 20.0 (4.7); Total Phosphorus-TP (mg/L) 8.0 (2.0); boron-B (mg/L) 251.2 (16.4); magnesium-Mg (mg/L) 51.2 (19.1); calcium-Ca (mg/L) 123.0 (60.5); potassium-K (mg/L) 28.5 (not detected); zinc-Zn (μg/L) 7.0 (not detected).

Experimental design

The experiment was carried out in an unheated plastic greenhouse with a North-South orientation in Crete, Greece. Seedlings were produced in plastic seedling trays filled with expanded clay and were acquired from a local agricultural nursery. Two media, soil (S) and municipal solid waste compost (MSWC), and mixtures of these, were used to create five substrates, which were: 1) S:MSWC (100:0) as control, 2) S:MSWC (95:5), 3) S:MSWC (90:10), 4) S:MSWC (80:20) and 5) S:MSWC (60:40). Plants grown in the above substrates were irrigated with tap water or tertiary-treated wastewater, which resulted in 10 treatments [following from the above: 6) S:MSWC (100:0)+TW, 7) S:MSWC (95:5)+TW, 8) S:MSWC (90:10)+TW, 9) S:MSWC (80:20)+TW and 10) S:MSWC (60:40)+TW] with 3 replications/treatment and 4 plants/replication.

Seedlings were transplanted in single pots (9 L capacity pots filled with substrate) and arranged in a single row with a completed randomized design for the replicates/treatment. Rows were 1.0 m apart and plants were separated by 0.4 m. Drip irrigation emitters (1 emitter/pot) were placed and irrigation took place twice (1 min/time) daily, with the use of a timer, by means of pressure pumps. Fertigation (EC: 2.5-3.0 mS/cm; 200 mL/plant twice a week) with commercial fertilizers took place manually. The drainage solution was collected in trays in each pot and was available for plant water needs through capillary suction. Plants were treated according to the twin lateral pruning system (two lateral stems growing vertically) on string.

Measurements

The soil used in the present study was a fertile one, as indicated from several physicochemical properties that were measured. Organic matter content was determined by lost in ignition method. The electrical conductivity (EC) and pH were determined according to 1:1 soil to solution ratio, employing a portable pH/EC-meter (HI 98130 HR, Hanna Instruments, USA). Nutrient analyses for K and Na (photometric; JENWAY, PEP-7 Jenway, Dunmow, UK), and P (spectrophotometric; Pye Unicam Hitachi U-1100, Tokyo, Japan) were determined while total N was determined by means of Kjeldahl. The soil was mixed with sand at a ratio of 2:1 v/v. Soil mixture had: 0.82% organic matter (0.48% organic C); C/N of 8; pH 6.9; EC 0.71 dS/m; Total N: 140 mg/kg; P: 21.7 mg/kg; K 5.5 mg/kg; and Na 0.32 mg/kg.

Two weeks after transplanting, the impact of MSWC as well as irrigation water quality on plant growth/development and yield in pepper were studied. Plant height, main stem diameter, leaf number produced, flower and fruit number, as well as leaf fluorescence (Chlorophyll fluorometer - opti-sciences OS-30p, UK) were measured. Leaf photosynthetic rate (*p*n), stomatal conductance (*g*s) and internal leaf concentration of CO_2 (*C*i) were measured using a portable infra-red gas analyser (model Li-6200, Li-Cor, Inc., Lincoln, Nebr.). Measurements were carried out between 9:00–11:30AM with conditions as leaf temperature within the chamber 28 ± 2°C, and photosynthetic photon flux density of 1300 μmol/m^2/s at the ambient CO_2 concentration. The Li 6200 was equipped with a leaf chamber with constant area inserts (6.0 cm^2). All gas exchange measurements started 3 h after the onset of the photoperiod and were replicated in nine plants of each treatment and on two fully expanded, healthy, sun-exposed leaves per plant. Plant yield was measured throughout the experiment as plant biomass (fresh weight and the % of dry matter) determined at the end of the experiment. Leaf elemental analysis took place on four replications/treatment (each replication was a homogenized mixture of two leaves per sample). After a hydrochloric digestion of the sample ash, nutrient analysis for K and Na (photometric; JENWAY, PEP-7 Jenway, Dunmow, UK), and P (spectrophotometric; Pye Unicam Hitachi U-1100, Tokyo, Japan) were determined while total N was determined by means of Kjeldahl. Data were expressed in mg per kg of dry weight.

Several fruit quality-related parameters were observed. Fruit fresh weight (in g), dry matter content (%) and fruit size (length and diameter in cm) were measured in each harvested fruit. Fruit marketability was observed by employing a 1-4 scale (1: extra quality; 2: good quality; 3: medium quality (i.e. small size, decolourization); 4: not marketable quality (i.e. malformation, wounds, infection)). Fruit colour measurements were taken around the fruit equator (2 measurements per fruit) with a Minolta Chroma Meter CR300. Data were expressed in *L*, *a* and *b* units. Fruit firmness was measured at 1 point on the shoulder of the fruit, for each treatment, using a penetrometer FT 011 (TR Scientific Instruments, Forli, Italy). The amount of force (in Newtons; N) required to break the radial pericarp (i.e. surface) of each pepper was recorded at ambient (22-24 ^{o}C) temperature.

Total soluble solids (TSS) were determined for the fruit juice for each treatment with a digital refractometer 300017 (Sper Scientific Ltd, Arizona, USA) at 20 ^{o}C and data were expressed as the mean (%) of ^{o}Brix. Sub-samples of homogenised fruit tissue were used to determine the pH and EC of fruit juice using a standard pH/EC meter (Orion 920A, Scientific Support, Hayward, CA, USA). The titratable acidity (TA) was measured *via* potentiometric titration (Mettler Toledo DL22, Columbus, Ohio, USA) of 5 mL supernatant diluted to 50 mL with distilled water using 0.1 N NaOH up to pH 8.1. Results were expressed as a percentage of citric acid. Eighteen measurements for each treatment took place. Total phenolics were determined on blended fruit tissue (5 g) extracts following repeated (4-fold) addition of 2.5 mL of 50% (v/v) methanol as reported previously [21]. Results were expressed in terms of gallic acid equivalents (GAE; Sigma Aldrich, Athens, Greece) per 100 g fresh weight of tissue.

Fruits (n=23) were assessed for bacteria (Total Coliform and *Escherichia coli*) units on the fruits as well as in the fruit, by employing ChromoCult® Coliform Agar (Merck KGaA) which is a selective and differential chromogenic culture medium. Harvested fruits were placed in sterile plastic bags (one fruit per bag), which were then filled with 225 mL sterile Butterfield phosphate buffered water (42.5 g/L KH_2PO_4, pH 7.2, Merck), and were gently shaken to rinse off most of the present bacteria. For isolation of coliform cultures, 1 mL of the solution was added to 0.45μm membrane in vacuum under sterile conditions. Inoculated membrane was transferred to a Petri dish containing ChromoCult® Coliform Agar, and incubated at 35 ^{o}C for 24-48 h. Pink colonies resulting from salmon-galactoside cleavage by β-d-galactosidase were classified as Total Coliform counts, whereas dark blue colonies resulting from salmon-galactoside and X-glucuronide cleavage by β-d-galactosidase and β-d-glucuronidase were classified as presumptive *E. coli* colonies [23]. Similarly, soil samples (n=5 per treatment) were assessed for bacteria (Total Coliform and *Escherichia coli*) units.

Statistical analysis

Data were tested for normality, and then subjected to analysis of variance (ANOVA). Significant differences between mean values were determined using Duncan's Multiple Range test (P<0.05) following one-way ANOVA. Significant differences on percentage values (% dry matter) were logarithmically transformed prior to analysis. Statistical analyses were performed using SPSS (SPSS Inc., Chicago, Ill.).

Results and discussion

Substrate properties

Municipal solid waste is approximately 60-90% biodegradable and might be used as a bulking material to absorb excess water, and supply a useful raw product for the horticulture industry [24]. The addition of MSWC, as organic medium, into the soil increased organic matter content (as a consequence of organic carbon content) and the pH and EC of the medium (Table 1), and the values are in agreement with previous studies [25]. Increasing the amount of MSWC into the soil resulted in increased N, P, and K content which alter the nutritive value of the medium. Waste application caused an increase of soil EC, a phenomenon that has also been reported in other studies (as reviewed by Asgharipour and Armin, [26]). Increased nutrient concentration in soil after immerging compost reduces the activity of soil micro-organisms and promotes the micronutrient absorption by plants [27].

Table 1. Physicochemical properties of substrate medium consisting of soil (S) and municipal solid waste compost (MSWC) resulting in five media.

	Organic matter (%)	Organic C (%)	pH	EC (mS/cm)	Total N (%)	C/N	P (mg/L)	K (mg/L)	Na (mg/L)
MSWC (100:0)	0.825	0.48	6.94	0.71	0.014	21.7	21.73	5.55	0.32
MSWC (95:5)	1.513	0.88	7.17	1.38	0.024	31.9	31.97	11.38	10.24
MSWC (90:10)	2.098	1.22	7.33	2.03	0.056	53.8	53.79	25.93	26.11
MSWC (80:20)	2.304	1.34	7.51	3.39	0.081	58.4	58.45	43.40	40.99
MSWC (60:40)	4.506	2.61	7.58	7.35	0.168	79.8	79.88	124.37	117.02

Effect on plant growth

Plants grown in mixtures with MSWC ≥ 5-20% were taller (up to 29%) and produced higher numbers of leaves (up to 24%) compared with the control (S) after 105 growth days (Fig. 1a and Fig. 2a). Similar effects were observed in potted geranium plants in various MSWC contents [28]. Irrigation with TW caused a higher plant height, being in agreement with previous studies in tomato and cucumber [13]. The application of TW in MSWC-based substrates delayed plant growth and alleviated the improved plant growth caused by MSWC (Fig. 1b and Fig. 2b), as plants had almost the same height and leaf number. Increased MSWC content (> 10%) resulted in significantly thicker (stem diameter) plant stems after 60 days of plant growth (Fig. 3a). This might have happened due to the better nutrient balance with MSWC application, while no differences could be found for stem thickness in pepper plants irrigated with TW (Fig. 3b).

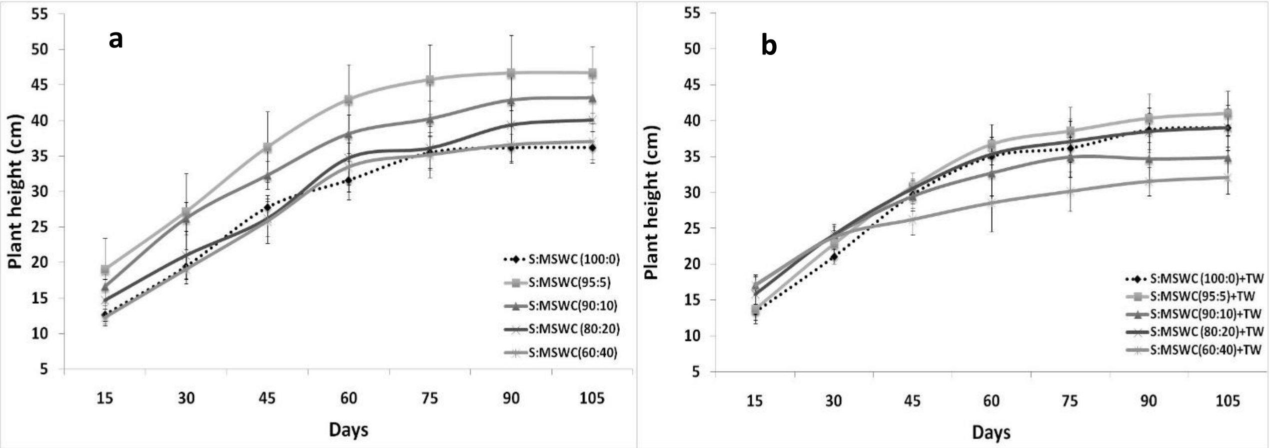

Figure 1. Effects of municipal solid waste compost (MSWC) in soil (S) irrigated with tap water (a) or with treated waste-water (b) on plant height of greenhouse pepper crop. Values represent mean (±SE) of measurements made on six plants per treatment.

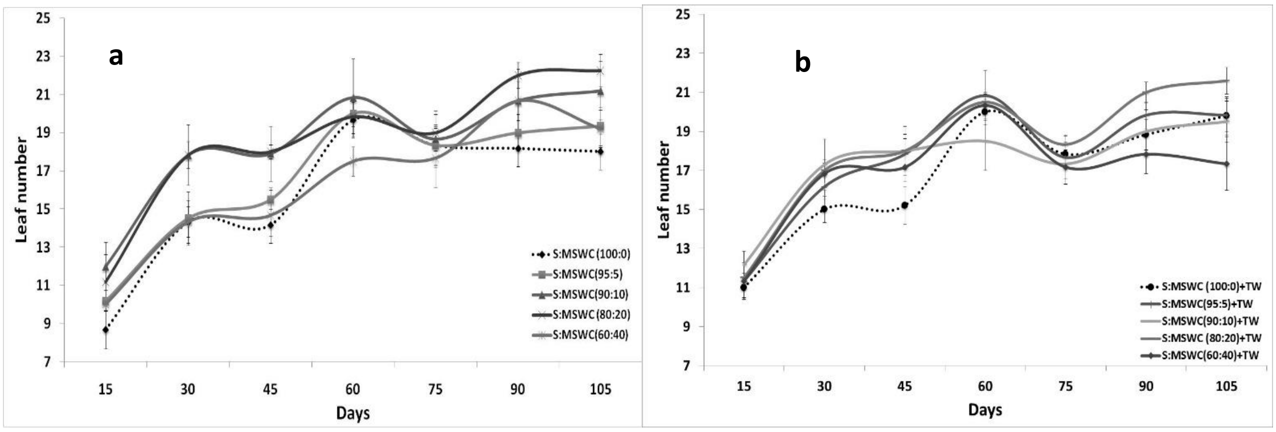

Figure 2. Effects of municipal solid waste compost (MSWC) in soil (S) irrigated with tap water (a) or with treated waste-water (b) on leaf number produced in greenhouse pepper crop. Values represent mean (±SE) of measurements made on six plants per treatment.

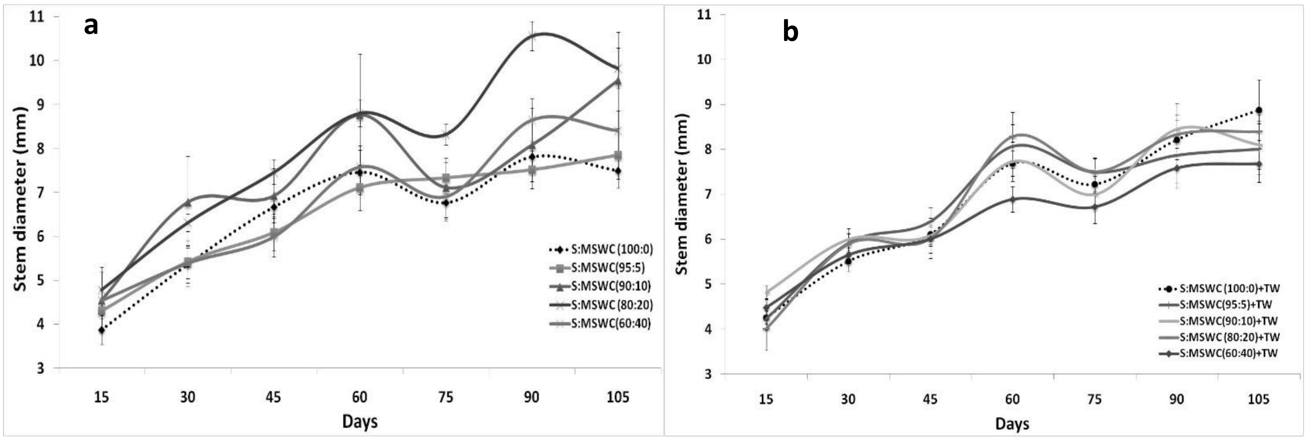

Figure 3. Effects of municipal solid waste compost (MSWC) in soil (S) irrigated with tap water (a) or with treated waste-water (b) on stem diameter of greenhouse pepper crop. Values represent mean (±SE) of measurements made on six plants per treatment.

The number of flowers and as a consequence the number of fruits fluctuated among treatments with higher values in 5-20% MSWC irrigated with TW, revealing earliness of 15 days on fruit production (Fig. 4a, b). Plant biomass increased in 10-20% MSWC applications, and this was evidenced even at 5% MSWC irrigated with TW and the control treatment (TW without MSWC) (Table 2).

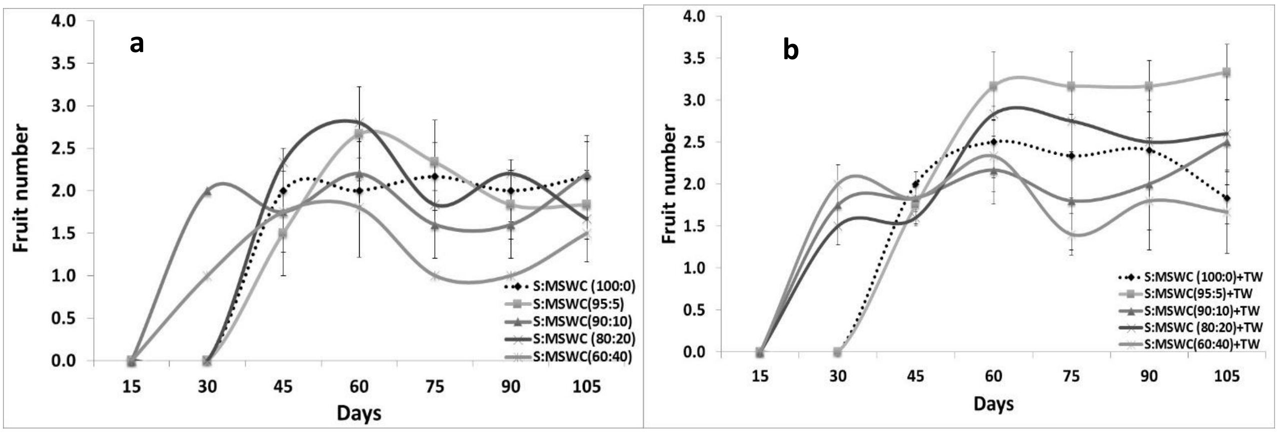

Figure 4. Effects of municipal solid waste compost (MSWC) in soil (S) irrigated with tap water (a) or with treated waste-water (b) on fruit number produced in greenhouse pepper crop. Values represent mean (±SE) of measurements made on six plants per treatment.

Table 2. Effects of municipal solid waste compost (MSWC) in soil (S) irrigated with water or treated waste-water on yield (g/plant), upper biomass fresh fruit (g/plant) and upper biomass dry matter (%) in greenhouse pepper crop.

	Water			Treated-waste water		
	Yield (g/plant)	Biomass (g/plant)	Biomass dry content (%)	Yield (g/plant)	Biomass (g/plant)	Biomass dry content (%)
MSWC (100:0)	338.6 a[Y]	68.6 c	41.7 a	258.8 a	79.3 a	37.7 a
MSWC (95:5)	301.7 a	75.1 b	38.5 ab	327.5 a	82.1 a	35.3 a
MSWC (90:10)	281.2 a	95.5 a	37.3 ab	355.5 a	82.5 a	37.8 a
MSWC (80:20)	318.7 a	100.7 a	34.1 b	298.1 a	84.3 a	38.1 a
MSWC (60:40)	154.1 b	86.1 ab	36.6 b	256.8 a	66.7 b	38.9 a

[Y] values (n=6) in columns followed by the same letter are not significantly different. $P \leq 0.05$.

There were no differences regarding leaf fluorescence, leaf photosynthetic rate and stomatal conductance in different MSWC contents and/or TW (data not presented). Therefore, leaf fluorescence averaged at 0.773 of Fv/Fm values, while leaf photosynthetic rate averaged at 13.78±0.84 μmol/m^2/s, leaf stomatal conductance averaged at 0.38±0.03 μmol/m^2/s, and leaf internal CO_2 concentration averaged at 306.36±4.54 μmol/mol for plants grown in different MSWC contents. The relevant values in plants irrigated with TW were 0.781 for the Fv/Fm; 16.11±0.87 μmol/m^2/s; 0.52±0.06 μmol/m^2/s; and 311.09±5.39 μmol/mol, respectively. This indicates the similar behavior of the crops during cultivation with no changes in physiological aspects such as photosynthetic metabolism.

Nitrogen content in plants grown in > 20% MSWC increased, and this was evidenced for Na content too, compared with plants grown in soil (control), whereas plants grown in 40% MSWC revealed the lowest P content (Table 3). Plants grown on 5-10% MSWC had higher K content compared with the control. In addition it was observed that plants grown in >20% MSWC had higher N (up to 35%) compared to the relevant control (soil irrigated with TW), whereas no differences could be found in K, P and Na content. This is probably due to the extra nutrients that TW contains, and were bioavailable.

Table 3. Effects of municipal solid waste compost (MSWC) in soil (S) irrigated with water or treated waste-water on leaf elemental (N, K, Na and P in mg/kg) content in greenhouse pepper crop.

	Water				Treated-waste water			
	N (mg/kg)	K (mg/kg)	P (mg/kg)	Na (mg/kg)	N (mg/kg)	K (mg/kg)	P (mg/kg)	Na (mg/kg)
MSWC (100:0)	11400 b[Y]	111.30 b	3.11 a	9.93 b	11520 b	108.00 a	2.44 a	14.30 a
MSWC (95:5)	10300 b	138.33 a	2.68 ab	14.97 ab	12601 ab	103.40 a	2.26 a	13.97 a
MSWC (90:10)	12450 ab	136.37 a	2.05 ab	11.97 ab	13428 ab	115.23 a	2.28 a	18.30 a
MSWC (80:20)	14566 a	127.17 ab	2.92 ab	16.63 a	15572 a	117.23 a	2.42 a	13.97 a
MSWC (60:40)	14686 a	125.80 ab	1.47 b	16.97 a	15552 a	125.20 a	2.26 a	17.30 a

[Y] values (n=4) in columns followed by the same letter are not significantly different. $P \leq 0.05$.

Effect on plant yield

Plant yield was decreased by 40% MSWC due to the reduced fruit fresh weight as well as fruit number produced (Table 2; Fig. 4). On the other hand TW irrigation alleviated such a reduction (Table 2). It can be concluded that similar plant yield in plants irrigated with TW is due to the increased fruit number (i.e. more fruits) (see Fig. 4). A decreased yield on 40% MSWC was mentioned, due to the salt stress as it would promote the maximum EC tolerable by this plant. In previous studies, when geranium plant was grown in 20% of MSWC, the maximum EC tolerable by this plant was achieved [29], which differs with the present results, as pepper is probably a more competitive crop in nutrients and/or salt resistance than geranium crop. Therefore the MSWC rates must be adjusted according to the conductivity of the applied compost and to the salt tolerance characteristic of the plant species to avoid salt stress and detrimental effects on plant growth. The application of MSWC increased (up to 58%) tomato yield whereas symptoms of dampening off disease and dying in squash were noticed [7]. Roe [29] reported that application of MSWC might affect physiological processes and/or elemental accumulation as higher zinc concentration in soil and a low germination rate of squash after application of MSW compost took place.

Several studies examined the effects of wastewater used in agriculture for irrigation needs as well as the impact of fertilizers in the crop-soil system, such as alfalfa, radish and tomato [13-14, 30-32], cucumber [12-13], eggplant [31, 33], ornamentals [34], cauliflower and red cabbage [16]. When municipal-treated wastewater was used in ornamental plants in nurseries, the nutrient content of the tertiary effluent was able to maintain good plant growth as well as fertigated water for most of the tested species [34] which is in accordance with the present study. However, the reuse of wastewater for irrigation may potentially create environmental problems if not properly treated and managed [35], such as nutrient accumulation. Consequently, management of irrigation with wastewater should consider the nutrient content in relation to the specific crop requirements and the concentrations of plant nutrients in the soil, and other soil fertility parameters. Thus, wastewater irrigation in lettuce had a high influence in soil parameters: organic matter, N, P, Ca, Al, Fe, Pb and Zn, as well as pathogenic microorganisms [36]. Wastewater irrigation treatments also increased the yield as well as N, P, K, Ca, Mg, Na, Fe, Mn, Zn, Cu, Pb, Ni and Cd contents of cauliflower and red cabbage plants [16]. Additionally, a part of the increased yield in tomato and eggplant irrigated with TW can be related to better soil moisture and increased available nitrogen in the root zone [31, 33] which is in line with the present study with the increased nutrient concentration i.e. N, of TW compared with tap water.

Effect on fruit quality

Regarding fruit quality-related parameters, fruit fresh weight was significantly reduced (up to 32%) in plants grown in substrates with media of higher than 10% MSWC compared with the control and/or 5% MSWC medium (Fig. 5). Fruit fresh weight was lower (up to 34%) when TW was applied compared to the tap water application in every examined MSWC ratio, averaging at 81.2 g per harvested pepper. This indicates that the increased nutrition that was obtained either by high rates of MSWC or by TW negatively affected the fruit fresh weight. Fruit dry matter content did not change among treatments. Fruit size fluctuated when different MSWC contents were used in the soil. Such differences were mainly focused on fruit length rather than in fruit diameter (i.e. thicker fruits) (Fig. 6). Therefore, fruit length was increased in the case of plants grown in S:MSWC 80:20 and S:MSWC 60:40 substrates compared with the control, the lower MSWC ratio and irrigation with or without TW. Fruit diameter did not differ among different MSWC contents in the soil or TW applications.

Interestingly, taking into account the scale (out of 4 units) of marketable fruits reduced from 2.55 for the control treatments to 1.52 as MSWC content was increased in the substrate (Fig. 7), the TW irrigation reversed this trend and maintained the fruit's marketability, achieving the maximum values (3.11 out of 4 values) in the greater MSWC content (40%) applied with TW. This was possible due to the lower yield and better nutrition that the plants achieved.

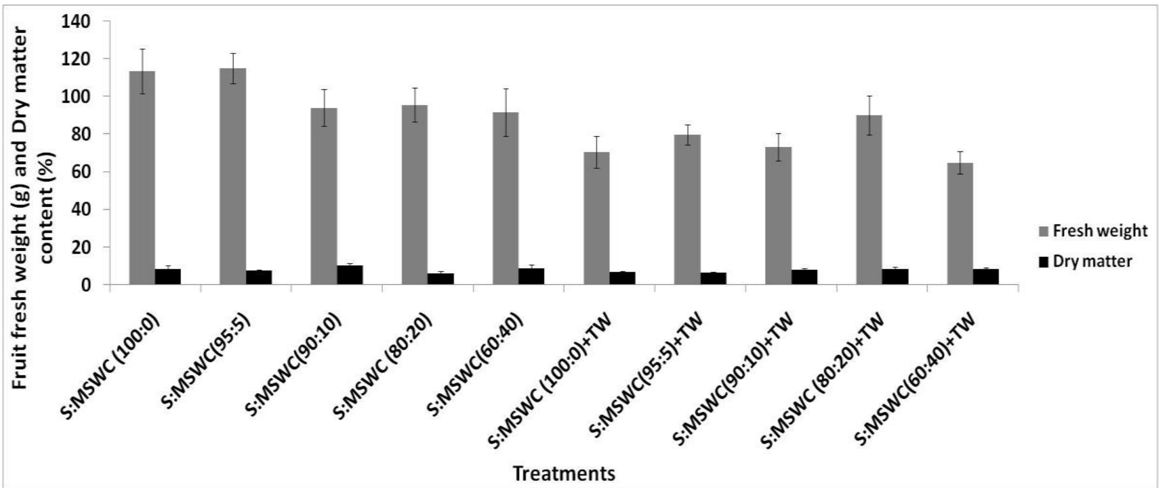

Figure 5. Effects of municipal solid waste compost (MSWC) in soil (S) irrigated with tap water or with treated waste-water on fruit fresh weight (g) and dry matter content (%) of greenhouse pepper crop. Values represent mean (±SE) of measurements made on average of 23 fruits per treatment.

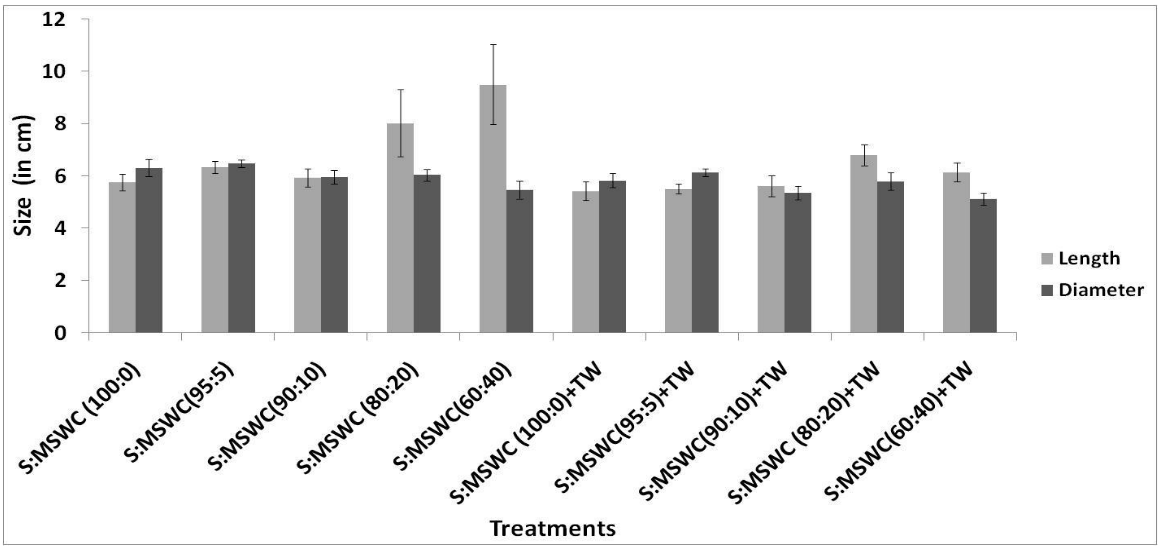

Figure 6. Effects of municipal solid waste compost (MSWC) in soil (S) irrigated with tap water or with treated waste-water on fruit size (length and diameter in mm) of greenhouse pepper crop. Values represent mean (±SE) of measurements made on average 23 fruits per treatment.

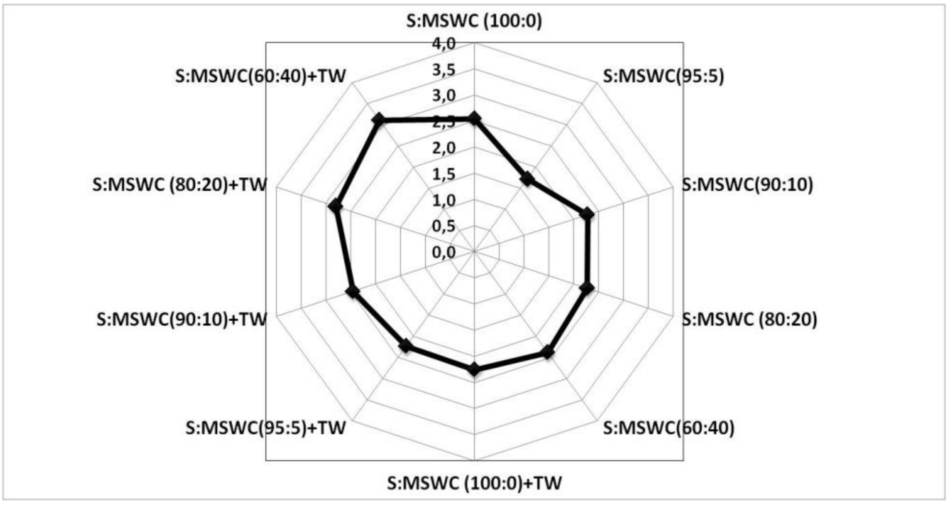

Figure 7. Effects of municipal solid waste compost (MSWC) in soil (S) irrigated with tap water or with treated waste-water on fruit marketability in 1-4 scale ((1: extra quality; 2: good quality; 3: medium quality; 4: not marketable quality) of greenhouse pepper crop. Values represent mean of measurements made on average 23 fruits per treatment.

Fruit lightness (L) was increased as MSWC content increased in the substrate. Fruit green colour (Chroma a and b) fluctuated in different MSWC content with/without TW (Table 4). Fruit firmness was maintained in plants grown in <10% MSWC (and in <5% MSWC +TW) (Table 4). Fruit firmness is an important quality attribute and is directly related to enhancing the storability potential and inducing greater resistance to decay and mechanical damage [20].

Peppers were less acid in plants grown in 10% MSWC content as the fruit juice pH increased but no differences were observed in the EC of the pepper juice. Additionally, the total soluble solids and/or acidity variation were affected as it was reduced in plants grown in 40% MSWC. Total phenols content decreased (up to 41%) with the addition of more than 20% MSWC in the substrate. Such a phenomenon has been reported in strawberry sweetness as it was unaffected by the MSWC application [4]. In previous studies, irrigation with treated wastewater did not affect tomato fruit pH, but it increased their size up to 2 cm in diameter, and weight up to 78.7 g. Additionally, a decrease of 1.5% in the TSS, 5.78 N in firmness, and 5.1% in weight loss of tomato fruit were recorded [37].

Bacteria (Total Coliform and *E. coli*) units on the fruits did not differ among the treatments (data not presented), being in agreement with previous studies in tomato and eggplant [33]. In detail, the average Total Coliform units were 8.5 CFU/100 g fruit fresh weight (fwt). The average number of *E. coli* units was approximately 2.14 CFU/100 g fruit fwt and it was only present in the case of the application of TW in the substrates. Selected fruit examined for bacteria contamination into the tissue, were not infected (data not presented), meaning that bacteria did not move through plant tissue. However, this fact needs to be examined more precisely and in more detail in the future, before any final statements. It's worthwhile to mention, that the bacterial load into the soil was approximately 10^3 times more than that in fruits which is in agreement with previous studies [13], for the equivalent treatments (see Table 5) while the wastewater application in tomato crop resulted in increased microbial contamination (*E. coli* and faecal *Streptococci*) on the soil surface [32]. In previous studies, the washings of tomato fruits grown with wastewater were analyzed for fecal coliforms. It appeared that the fruit skins were free of viable fecal coliforms 24 hours after the wastewater application. Subsurface drainage analyses did not show any alarming levels of constituents irrespective of the source of the water: wastewater or freshwater [30].

Table 4. Effects of municipal solid waste compost (MSWC) in soil (S) irrigated with water or treated waste-water on fruit firmness (N) and fruit color (L, a, b values) in greenhouse pepper crop.

		Fruit firmness	Fruit color		
			L	a	b
Water	S:MSWC (100:0)	4.40 a [Y]	33.68 b	-10.57 b	13.62 ab
	S:MSWC (95:5)	3.61 a	33.55 b	-8.84 a	10.93 c
	S:MSWC (90:10)	3.65 a	35.41 a	-11.76 c	15.61 a
	S:MSWC (80:20)	3.33 b	35.15 a	-9.50 ab	12.10 b
	S:MSWC (60:40)	3.23 b	36.29 a	-12.43 c	16.94 a
Treated- waste water	S:MSWC (100:0)	4.37 a	34.16 b	-9.55 ab	13.21 b
	S:MSWC (95:5)	3.13 a	33.59 b	-10.88 b	14.42 b
	S:MSWC (90:10)	3.00 b	34.98 ab	-10.75 b	15.62 a
	S:MSWC (80:20)	1.80 b	36.24 a	-8.91 a	11.89 c
	S:MSWC (60:40)	2.02 b	36.35 a	-8.47 a	15.92 a

[Y] values (n=9) in columns followed by the same letter are not significantly different. $P \leq 0.05$.

Table 5. Effects of municipal solid waste compost (MSWC) in soil (S) irrigated with water or treated waste-water on total soluble solids (TSS: ^{o}Brix), titratable acidity (TA: (% citric acid), sweetness (TSS/TA), Ph, EC (mS/cm) and total phenols (gallic acid equivalent: GAE/ 100 g fwt) in greenhouse pepper crop.

		TSS	TA	TSS/TA	pH	EC	Total phenols
Water	S:MSWC (100:0)	3.20 a [Y]	3.09 c	1.03 a	5.30 bc	1.48 a	296.91 a
	S:MSWC (95:5)	3.40 a	3.93 b	0.86 ab	5.91 b	1.57 a	276.56 a
	S:MSWC (90:10)	3.43 a	5.41 a	0.63 b	6.30 a	1.88 a	259.03 a
	S:MSWC (80:20)	3.37 a	4.04 b	0.83 ab	5.39 bc	1.29 a	181.73 b
	S:MSWC (60:40)	2.73 b	3.04 c	0.89 ab	5.11 c	1.33 a	176.76 b

Treated-waste water	S:MSWC (100:0)	3.53 ab	3.53 ab	1.00 a	5.38 a	2.03 b	186.61 ab
	S:MSWC (95:5)	3.90 ab	3.35 b	1.16 a	5.35 a	2.24 b	235.08 a
	S:MSWC (90:10)	4.45 a	4.47 a	0.99 a	5.35 a	3.88 a	251.89 a
	S:MSWC (80:20)	4.20 a	3.69 ab	1.13 a	5.39 a	2.07 b	131.47 b
	S:MSWC (60:40)	3.04 b	4.14 a	0.73 b	5.59 a	2.23 b	162.36 b

^{Y} values (n=6) in columns followed by the same letter are not significantly different. $P \leq 0.05$.

The irrigation with municipal wastewater is considered an environmentally friendly wastewater disposal practice that helps to minimize the pollution of the ecosystem subjected to contamination by direct disposal of wastewater into surface or groundwater [38]. In addition, wastewater is a valuable source for plant nutrients (exchangeable Na, K, Ca, Mg, and P) and organic matter needed for maintaining fertility and productivity of arid soils while the microbial load that wastewater may contain may act as a negative parameter for plant growth and fruit production. The use of TW for vegetable production, considered as edible fresh products, needs further exploitation. Indeed, the negligible microbial contamination of pepper fruit and washing solution suggested the putative use of TW in agriculture. However, the treated wastewater can be used as an alternative for irrigation practice in vegetables i.e. tomatoes, eaten after cooking, but not for those taken as raw provided that the effluent quality is continuously monitored to avoid contamination [37].

Conclusions

The production of MSWC is an important recycling opportunity for many communities; however the safety of its use in agriculture has been debated because of concerns over the levels of its salt and heavy metals content. Salinity seems to be the major limiting factor to the use of large amounts of MSWC as a growth-media component. Therefore the MSWC rates must be adjusted according to the conductivity of the applied compost and the salt tolerance characteristic of the plant species to avoid salt stress and detrimental effects on plant growth. Therefore, the results indicate that the low content of MSWC added into substrate improved plant growth and maintained fruit fresh weight for greenhouse pepper without affecting plant yield. Treated wastewater may be used as an additional water resource and act as an alternative means of irrigation for pepper cultivation in water-scarce Mediterranean environments, following strictly applied safety aspects.

Acknowledgement

This work was funded by the Greek National Research program XM EOX: EL0031. The authors are thankful to the solid waste and wastewater management lab (Technological Educational Institute of Crete, Greece) for the TW supply.

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