

## Article

# Treated Wastewater and Fertigation Applied for Greenhouse Tomato Cultivation Grown in Municipal Solid Waste Compost and Soil Mixtures

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**Abstract:** Low-fertility soil and the use of brackish water for irrigation act as obstacles and limit crop production. The utilization of municipal solid waste (MSW), compost (C), and treated wastewater (TWW) is receiving attention nowadays not only to overcome the above limitations but also as an efficient way for waste management and reuse of raw materials. In the present study, MSW compost in different ratios (5%, 10%, 20%, and 40%), fertigation and/or irrigation with TWW were studied in tomato plants (*Solanum lycopersicum* L.). The addition of compost increased organic content, pH, electrical conductivity (EC), and mineral content of the growing media, while fertigation and TWW supported the mineral status of the growing media, and this was reflected in the increase of N, K, and Na in tomato leaves. Plants grown in compost-based media with fertigation produced more leaves, compared to the control, while irrigation with TWW did not increase the number of leaves. Plant biomass increased with the application of  $\geq 20\%$  C, fertigation, and/or TWW applications. Plant yield increased in 40% C, while fertigation increased yield in case of lower (5%–10% C) compost ratios, but TWW application did not change the yield. The combination of high C ratios and fertigation and/or TWW decreased tomato fresh weight. Different levels of C did not affect leaf photosynthesis, stomatal conductance, internal CO<sub>2</sub> concentration, and chlorophyll fluorescence, but, in general, the combination of compost with fertigation and/or TWW affected them negatively. Fruit total soluble solids, acidity, ascorbic acid, firmness, and total phenolics were increased with the high ratios of compost and/or fertigation and TWW applications, but marketability did not. Bacteria (total coliform and *Escherichia coli*) units increased in growing media subjected to TWW, but lower levels were counted on the fruit, mainly due to splashing or fruit contact with the soil. The results indicate that up to 40% C can be added into the substrate, as increased plant growth and maintained plant yield for greenhouse tomato cultivation is observed, while fertigation and TWW could be used in a controlled manner as alternative means for nutrient and irrigation in vegetables following safety aspects.

**Keywords:** compost; municipal solid wastes; growth; quality; fertigation; tomato; wastewater

## 1. Introduction

Waste management in cities is a great challenge with increased environmental concern; there are severe problems caused by waste accumulation in the areas that are related to increased population, urbanization, and industrialization [1]. Over 487 kg of municipal waste per capita were generated yearly in the European Union in 2017 [2]. Inefficient municipal solid waste (MSW) management includes waste-filled land and contamination of underground water sources. This leads to environmental and

health-related issues [3], and to the production of combustible gases ( $\text{CO}_2$  and  $\text{CH}_4$ ) that amplify the greenhouse effect [4]. Typical feedstocks of MSW consist of building materials, consumer goods, packing materials, residential pruning green yard waste and food wastes, to name a few. The applications of MSW should always take into account their impact on the environment, human and other organism health. Strategies for mixing digested sludge with compost are currently applied to reduce the environmental risk posed by each material and to maximize its nutrient levels [5].

The application of composted MSW as an alternative approach to landfill incineration and disposal is promoted by environmental agencies because it contributes to the restoration of the soil's organic matter [6,7] and to a sustainable crop production [8]. Compost (C) is a suitable way of waste management and material recycling, by turning large volumes of MSW into materials that contribute to the soil organic matter and minerals, having an impact on the physicochemical and microbial properties of the soil [9–11], and by bioremediating contaminated soils [12]. However, the use of compost as growing media component can affect plant growth and yield, as it may cause problems of high salt levels and unsuitable media physicochemical characteristics [6]. Compost quality such as stability and maturity should be tested before compost is applied to soil, as immature compost can adversely affect plant growth and soil characteristics by decreasing oxygen and available nitrogen (N) levels or releasing phytotoxic components [13]. Moreover, compost of MSW may have high levels of trace elements and heavy metals; Paradelo et al. [14] reported copper (Cu), lead (Pb), and zinc (Zn) accumulation in plant tissue. Nutrient accumulation in plant is related to mineral availability in soil, soil properties, and changes in the pH, but is also species specific [7]. MSW compost addition has an alkalinized effect on soils while repeated and long term MSW compost applications might have a destructive effect on crop production and nutrient status [15]. Additionally, Ozores-Hampton et al. [16] reported the accumulation of various heavy metals and trace elements in the soil after MSW compost application in tomato crops but not in tomato fruit. Ribeiro et al. [17] exhibited the increased growth of potted geranium when MSW compost was mixed with peat at 10%–20%, while Castillo et al. [18] recommended the use of 30% MSW compost in peat instead of pure peat as growing media for tomato seedling production. Moreover, low MSW compost levels (10%–30%) were recommended for eggplant [19], watermelon [20], and pepper [21] seedling production in peat-based growing media. Interestingly, MSW compost was able to reduce (up to 60%) cadmium (Cd) levels in onion, spinach, and lettuce, indicating the importance of the MSW compost as a low-cost soil conditioner, effective enough to reduce Cd accumulation in plants [22].

For most agricultural areas of the Mediterranean basin, the amount of organic matter is poor due to the arid and semi-arid climates. Bostani [23] emphasized the role of the organic matter of the MSW compost in affecting the availability of nutrients to the plants, as exemplified for iron (Fe) fractionation and availability. The low-fertility status of soils can be improved through the use of organic fertilization by using peat, manure, sewage sludge, or compost [24].

In arid and semi-arid areas, as in the largest part of the Mediterranean basin, water demand for agricultural use is increasing in parallel with the increased population, the demanding living standards, and climate change worldwide. However, water availability is decreased, and alternative water sources are desired [25]. It is possible to treat and reuse urban and industrial wastewater for various purposes, mostly for agricultural uses [26]. Wastewater is one of the main forms of poor quality water, as different technologies have been applied to improve its quality and meet health and environmental issues, with general public constraints [27]. Depending on the technology applied, treated wastewater (TWW) is mainly divided in primary, secondary, and tertiary-treated wastewater [25,28]. A large scientific portfolio on wastewater treatment, reuse, and applications in agriculture supports our knowledge, but ongoing research in this area is investigating a way to maximize the efficacy of wastewater in agriculture, with both qualitative and quantitative outcomes, without environmental and health-related risks [25,28–30]. Applications of wastewater in agriculture do affect the chemical properties of the upper level (<0.3 m) of the soil and plant chemical composition [31]. Several studies have reported

the use of wastewater for vegetables and ornamentals [29,31–34], with applications in high-demand growing systems such as hydroponics [28].

The increased consumer needs and demands for vegetable production throughout the calendar year are a great challenge to the commodities' quality and safety. This requires additional nutrients in the soil that can be added either by increased fertilizer applications or alternative use of other sources, such as compost and treated wastewater, which affect the physicochemical and nutrient composition of the soil, in parallel with the efficient waste management. The present study examined the effects of (i) different ratios of municipal solid waste compost mixed with soil, (ii) fertigation used, and (iii) the quality of irrigation water (tap water and tertiary-treated wastewater), either alone or with fertilizers, in tomato plant growth, physiology, fruit quality, and safety-related attributes in greenhouse crops, replacing part of the fertilizers and/or irrigation water with alternative sources.

## 2. Materials and Methods

### 2.1. Plant Material and Compost

Municipal solid waste compost was obtained from the Inter-Municipal Enterprise for the Management of Solid Wastes at the prefecture of Chania, Greece. Organic fractions of municipal waste were used for the compost preparation. Organic material was composted for a period of 56 months and then sieved with the majority (~60%) of particles sized <4 mm. The chemical properties of the final material were previously presented [35], and are briefly mentioned here: pH of 7.51; electrical conductivity (EC) of 16.54 mS cm<sup>-1</sup>; organic C of 26.62%; total N of 0.57%; P of 164 mg kg<sup>-1</sup>; K: 727 mg kg<sup>-1</sup>; Mg: 386 mg kg<sup>-1</sup>; Ca: 645 mg kg<sup>-1</sup>; and Na: 403 mg kg<sup>-1</sup>.

Tomato (*Solanum lycopersicum* L. cv. 1414) seedlings were purchased from a commercial nursery and plants were grown during the autumn–winter period.

### 2.2. Treated Wastewater

Primary-treated wastewater was collected from the sewage treatment unit of Heraklion (180,000 p.e.), Crete, Greece. Tertiary-treated wastewater (tertiary-TWW) was collected by treating the effluent of packed bed filters (Advantex-AX20, Orenco; used for secondary-treated wastewater) using sand filtration and chlorination process (obtained by the lab of Solid Waste and Wastewater Management at the Technological Educational Institute of Crete, Greece), while the physicochemical properties of the tertiary-TWW used in the experiment were analyzed as documented previously [30]. In brief, the chemical characteristics of tertiary-TWW and tap water (in parenthesis) sources used in the present study were: pH of 7.5 (7.8); EC (mS cm<sup>-1</sup>) of 1.1 (0.7); chemical oxygen demand, COD (mg L<sup>-1</sup>) of 24 (16); total soluble solids, TSS (mg L<sup>-1</sup>) of 9.1 (2.6); total nitrogen, TN (mg L<sup>-1</sup>) of 20.0 (4.7); total phosphorus, TP (mg L<sup>-1</sup>) of 8.0 (2.0); boron, B (mg L<sup>-1</sup>) of 251.2 (16.4); magnesium, Mg (mg L<sup>-1</sup>) of 51.2 (19.1); calcium, Ca (mg L<sup>-1</sup>) of 123.0 (60.5); potassium, K (mg L<sup>-1</sup>) of 28.5 (not detected); zinc, Zn (µg L<sup>-1</sup>) of 7.0 (not detected).

### 2.3. Experimental Set Up

The experiment was implemented in an unheated plastic greenhouse in Crete, Greece. Tomato seedlings were grown in peat-based substrate. Two media, soil (S) and compost (C) derived from municipal solid waste, and mixtures of them, were used to make five substrates, which were: (1) 0% C (soil) as control; (2) 5% C (S:C 95:5); (3) 10% C (S:C 90:10); (4) 20% C (S:C 80:20); and (5) 40% C (S:C 60:40). Plants grown in the above substrates were irrigated with tap water (Treatments 1–5) or fertigated following from the above: (6) 0% C+Fert; (7) 5% C+Fert; (8) 10% C+Fert; (9) 20% C+Fert; and (10) 40% C+Fert (Treatments 6–10). Additionally, plants grown in the above substrates were irrigated with tertiary-treated wastewater without fertigation following from the above: (11) 0% C+TWW; (12) 5% C+TWW; (13) 10% C+TWW; (14) 20% C+TWW; and (15) 40% C+TWW (Treatments 11–15) or with fertigation following from the above: (16) 0% C+TWW+Fert; (17) 5%

C+TWW+Fert; (18) 10% C+TWW+Fert; (19) 20% C+TWW+Fert; and (20) 40% C+TWW+Fert (Treatments 16–20). A total of 20 treatments (combinations of compost ratio, fertigation and/or TWW) were used with 3 replications/treatment and 4 plants/replication. Therefore, each treatment was applied to 12 tomato plants.

Tomato seedlings were transplanted in single pots (9 L capacity pots filled with substrate) and arranged with a completed randomized pattern in single rows. The rows were 1.0 m apart and 0.45 m divided the plants. Drip irrigation emitters (1 emitter/pot) were installed and irrigation occurred two times (1.5 min/time) per day, or according to crop needs, using a timer and pressure pumps. Fertigation (EC: 2.5 mS cm<sup>-1</sup>; 200 mL plant<sup>-1</sup>) with commercial (i.e., 20-20-20; 11-15-15) fertilizers was applied (manually) once a week. The drainage solution from each plant was collected in each pot tray, and was available via capillary suction for plant water needs. Plants were handled on a string according to the single pruning scheme (the main stem grew vertically).

#### 2.4. Measurements

The soil used in the present study was characterized as a fertile one, as this was indicated from the physicochemical properties measured, as previously described [36]. Organic matter content was determined by loss-on-ignition method. The equivalent calcium carbonate was determined using the calcimeter method. The 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. Soil mixture had: 0.82% organic matter (0.48% organic carbon); C/N 8; pH 6.9; EC 0.71 mS cm<sup>-1</sup>; total N 140 mg kg<sup>-1</sup>; P 21.7 mg kg<sup>-1</sup>; K 5.5 mg kg<sup>-1</sup>; and Na 0.32 mg kg<sup>-1</sup>.

Two weeks after transplanting, the effects of compost, fertigation, and irrigation water quality on plant growth and yield in tomato were studied. Height of plant, diameter of main stem, number of leaves, number of flowers and fruits, as well as chlorophyll fluorescence (Chlorophyll fluorometer; Opti-Sciences OS-30p, UK) were measured. Leaf photosynthetic rate (*pn*), stomatal conductance (*gs*), and internal leaf concentration of CO<sub>2</sub> (*Ci*) were measured with a portable infrared gas analyzer (model Li-6200, Li-Cor, Inc., Lincoln, Nebr.). Measurements were taken between 9:00 and 11:15 AM with conditions of leaf temperature within the chamber 28 ± 2 °C, and photosynthetic photon flux density of 1300 μmol m<sup>-2</sup> s<sup>-1</sup> at the ambient CO<sub>2</sub> concentration and leaf chamber area of 6.0 cm<sup>2</sup>, as previously described [19]. Two measurements took place for each of the nine plants (replicates) per treatment. Plant yield was assessed throughout the experiment as a cumulative result of individual fruit harvesting and fresh weight. Plant biomass (fresh weight in grams and dry matter content in percentage) was determined at the end of the experiment. Leaf nutrient accumulation tested in four replicates/treatment (each replicate was a pool of two leaves). Samples were ashed, acid digested (1 N HCl), and 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.

Harvested fruits were examined for fruit quality-related parameters. Fruit fresh weight (in g), and fruit size (length and diameter in cm) were measured in each harvested fruit. Fruit color was measured using the Hunter Lab System and a Minolta colorimeter model CR300 (Konica Minolta, Osaka, Japan). Values were recorded from 2 points around the equator of each fruit for *L\**, *a\**, and *b\** while parameters as chroma value (*C*), hue (*h*), and color index (*CI*) were calculated as described previously [37]. Fruit marketability was assessed by using a 1–4 scale (1: extra quality; 2: good quality; 3: medium quality (i.e., small size, decolorization); 4: not marketable quality (i.e., malformation, wounds, infection)) and results were expressed in percentage. Symptoms of cracking, malformation and blossom end rot (BER) were also recorded.

Fruit firmness was assessed at two points on each tomato's shoulder using a texture-meter FT 011 (TR Scientific Instruments, Forli, Italy) with an 8-mm plunger. The amount of force (in Newtons; N) needed to break through the tomato's radial pericarp (i.e., surface) in eight replicates was measured at room temperature. Total soluble solids (TSS in °Brix) of the fruit juice was measured by a digital refractometer (model Atago PR-101, Atago Co. Ltd., Tokyo, Japan). Titratable acidity (TA) was assayed 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 in citric acid percentage. The fruit sweetness/ripening index was calculated using TSS/TA ratio. The pH and EC of the fruit juice were also measured. Twelve measurements for each treatment took place.

Ascorbic acid (AA; which consists of the main part of vitamin C) was measured using the 2,6-dichloroindophenol titrimetric method as previously described [37]. An aliquot of 5 mL of pooled tomato juice was diluted with 5 mL of water and titrated by the dye solution until the color changed. Data were expressed as mg of AA per gram of fresh weight. Total phenolic content was measured on blended fruit tissue (5 g) extracts following repeated (4-fold) addition of 2.5 mL of 50% (v/v) methanol, as reported previously [38]. Results were expressed as gallic acid equivalents (GAE) per gram of fresh weight.

The microbial load of bacteria (total coliform and *Escherichia coli*) was assessed on the fruit surface (n = 23) and inside the fruit, using ChromoCult® Coliform Agar (Merck KGaA), a selective and differential chromogenic culture medium [39]. Harvested fruits were placed in sterile plastic bags (one fruit per bag), which were then filled with 225 mL of sterile Butterfield phosphate buffered water ( $42.5 \text{ g L}^{-1} \text{ KH}_2\text{PO}_4$ , pH 7.2, Merck) and shaken gently to rinse off most of the bacteria present. Under sterile conditions, 1 mL of the solution was applied to a 0.45-µm membrane in vacuum for isolation of coliform cultures. Inoculated membrane was transferred to a Petri dish containing ChromoCult® Coliform Agar, and incubated at 35 °C for 24–48 h. Pink colonies resulting from salmon–galactoside cleavage by β-d-galactosidase were classified as total coliform counts, while 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 [40]. Fruits were then disinfected by multiple washings with chlorine solution, cut in four pieces, and placed in sterile plastic bags (one fruit cut per bag) with the Butterfield phosphate buffered water, gently shaken to rinse the possible bacteria present inside the fruit. Similarly, soil samples (n = 5) were tested for bacteria units' presence (total coliform and *Escherichia coli*).

### 2.5. Statistical Analysis

Data were tested for normality and then subjected to analysis of variance (ANOVA). Significant differences between mean values were separated by using Duncan's Multiple Range Test ( $p = 0.05$ ) following one-way ANOVA. Correlation coefficients were also tested for the effects of the three factors (compost, fertilizer, treated wastewater) on the tomato crop; statistical analysis was performed with the aid of SPSS (SPSS Inc., Chicago, IL, USA). Pairwise metabolite effect correlations were calculated by Pearson's correlation test using the R program.

## 3. Results and Discussion

Linear correlation coefficients were determined and are presented in detail in Table S1. The correlation coefficient ( $r$ ) and  $p$ -values between the analyzed factors (compost, fertilizer, and TWW) and tomato growth, physiology, and fruit quality-related parameters are given. Compost application in different ratios was positively correlated with stem diameter, plant biomass, leaf content for K, Na and N, fruit number, fruit marketability, color  $a^*$  and CI, fruit EC, TSS and TA, but negatively correlated with physiology parameters (photosynthesis, stomatal conductance, internal CO<sub>2</sub> concentration, and chlorophyll fluorescence), fruit fresh weight and size. Fertilizer application was positively correlated with plant height, number of leaves, flowers and fruits produced, plant biomass, yield, and photosynthesis, but negatively correlated with plant dry matter content. The application of TWW



was positively correlated with the number of leaves and flowers, plant biomass, leaf content of P and Na, fruit CI, fruit EC, TSS, ripening, ascorbic acid, and content of phenols, but negatively correlated with plant dry matter content, internal CO<sub>2</sub> concentration, and fruit color *L*\*.

### 3.1. Substrate Properties

Municipal solid waste is a valuable raw material for the horticultural industry; being 60%–90% biodegradable, it can be used as a bulking material to absorb excess water [41]. The addition of municipal solid waste compost as an organic component into the soil increased the levels of organic matter, the pH and the EC of the substrate (Table 1), and these results are consistent with reported findings [17,42]. A higher amount of MSW compost in the soil resulted in increased content of N, P, and K, which altered the nutrient status of the medium, while the increased Na content might cause saline effects during plant growth. Similar observations with increased P levels by adding MSW compost were reported by Zhang et al. [43]. The presence of organic matter in the soil plays an important role in the nutrient storage and circulation that will be used for plant production [44]. The increased C/N ratio followed by the increased ratio of compost in the soil can possibly decrease the available N in plants, as N will be used partially for the decomposition of organic matter by microorganisms. Weber et al. [45] stated that the slow and continuous release of N from the compost into the soil increases not only the soil fertility but also the mineralization conditions of organic matter, reducing N leaching and the risk of groundwater contamination by nitrate [46]. Waste application caused an increase of soil EC, a result that was also stated in previous studies (as reviewed by Asgharipour and Armin [47]), as EC is well linked to organic matter content in soil [48]. Growing media containing MSW compost up to 20% had acceptable EC values, as low soluble salt levels (EC <3.5 mS cm<sup>−1</sup>) are preferred for potting compost [49]. Increased nutrient levels in soil after immersing compost reduce the activity of soil microorganisms [50] and promote the micronutrient absorption by the plants [1]. The beneficial effects of composts on soil characteristics, however, depend on soil texture, moisture content, levels of organic matter and minerals [7], but this should always be assessed together with the potential detrimental effects from the various contaminants introduced to the soil, such as heavy metals [14,45].

**Table 1.** Physicochemical properties of growing media consisting of soil and municipal solid waste compost (C) resulting in five substrates.

	Organic Matter (%)	Organic C (%)	pH	EC (mS cm <sup>−1</sup> )	Total N (%)	C/N	P (mg kg <sup>−1</sup> )	K (mg kg <sup>−1</sup> )	Na (mg kg <sup>−1</sup> )
0% C	0.825	0.48	6.94	0.71	0.014	21.7	21.73	5.55	0.32
5% C	1.513	0.88	7.17	1.38	0.024	31.9	31.97	11.38	10.24
10% C	2.098	1.22	7.33	2.03	0.056	53.8	53.79	25.93	26.11
20% C	2.304	1.34	7.51	3.39	0.081	58.4	58.45	43.40	40.99
40% C	4.506	2.61	7.58	7.35	0.168	79.8	79.88	124.37	117.02

### 3.2. Effect on Plant Growth and Yield

Plants grown in mixtures with compost did not differ in height, but both fertigation and TWW increased the plant height (Table 2). In previous studies on pepper (*Capsicum annuum* L.), plants grown in ≥10% C were taller when compared with plants grown in soil, following 105 d of growth [11]. Irrigation with TWW also increased the plant height, compared with plants irrigated with tap water, being in agreement with previous studies on tomato (*S. lycopersicum* Mill.), cucumber (*Cucumis sativus* L.), and pepper (*C. annuum* L.) [29,39]. Plants grown in compost-based media had a higher number of leaves (up to 37.6%), compared to the control (soil); however, when fertigation took place, this effect did not persist when TWW was used. Plants grown in compost (40% C) had thicker stems, compared to control and 5% C treatments, as it was also evidenced in the pepper crop grown in the same type of compost [11]. Fertigation in ≥10% C media (≥10% C + Fert) increased the number of flowers produced

and resulted in thicker stems, probably due to the better nutrient balance with the compost application of higher rates and/or fertigation. However, such effects were not evident when TWW was used instead of tap water for irrigation. The increased levels of compost (i.e., 20%–40% C) in the growing media, the fertigation, and/or the TWW use increased the upper biomass production, compared to the soil and/or lower compost levels in the media, being in accordance with the increased biomass on MSW-compost-treated tea plants (*Camellia sinensis* L.) [51] and pepper [39]. Furthermore, MSW compost at 40 ton ha<sup>−1</sup> as soil amendment increased *Mesembryanthemum edule* biomass production as well as polyphenols and antioxidant capacity levels [52]. In some cases the fertigation in the high compost rates media decreased the dry matter content of the upper plant biomass, and this was also observed in pepper by Dagianta et al. [39]. Ribeiro et al. [17] reported decreased plant growth with >20% C because of a high level of salts in potted geraniums (*Pelargonium x hortorum* Bailey). Dagianta et al. [39] reported increased plant biomass in TWW and/or fertigated pepper grown in soil.

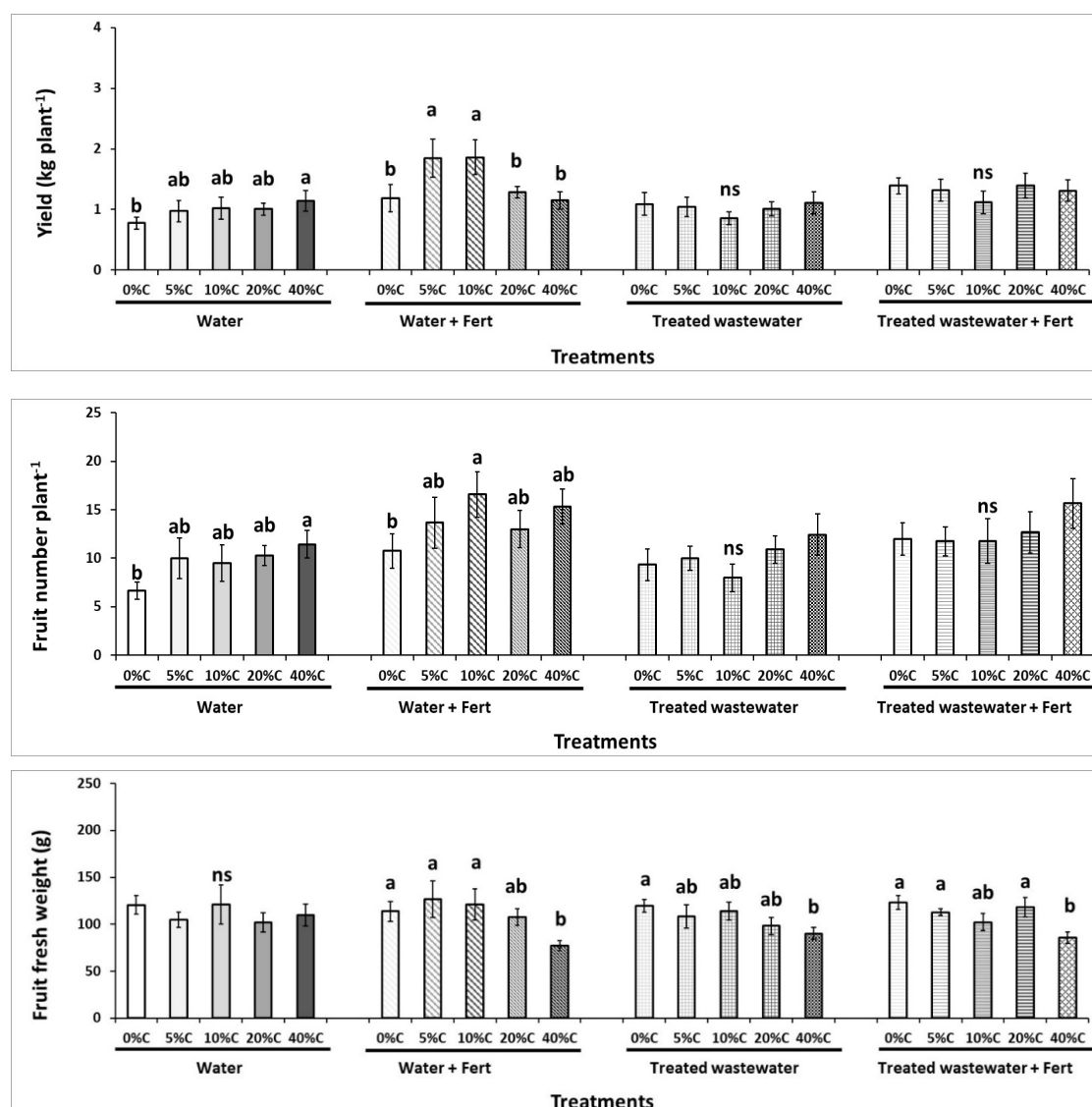
**Table 2.** Effects of municipal solid waste compost (C; 0%–5%–10%–20%–40%) in soil irrigated with water (W) or treated wastewater (TWW) and with fertilizers (+Fert/−Fert) on plant height (cm), leaf number, flower number, stem diameter (mm), upper biomass fresh fruit (g plant<sup>−1</sup>), and upper biomass dry matter (%) in a greenhouse tomato crop.

	Compost	Height (cm)	Leaf No	Flower No	Stem Diameter (mm)	Biomass (g plant <sup>−1</sup> )	Biomass Dry Content (%)
Water/−Fert (W)	0% C	115.83 ± 9.37a	12.3 ± 0.9a	5.1 ± 0.7b	8.01 ± 0.43b	315.51 ± 13.23b	35.67 ± 1.97a
	5% C	96.91 ± 6.10a	13.3 ± 1.2a	4.8 ± 0.7b	8.57 ± 0.46b	320.80 ± 8.62ab	37.50 ± 3.12a
	10% C	106.50 ± 9.99a	13.1 ± 1.4a	7.1 ± 0.9ab	9.26 ± 0.24ab	345.67 ± 18.09ab	36.33 ± 8.41a
	20% C	109.41 ± 9.09a	13.0 ± 1.5a	5.6 ± 1.3b	8.75 ± 0.59ab	360.05 ± 21.99a	34.61 ± 5.18a
	40% C	108.66 ± 8.98a	13.3 ± 1.0a	8.6 ± 0.8a	9.93 ± 0.31a	376.08 ± 17.48a	35.55 ± 5.51a
Water/+Fert (W+F)	0% C	120.08 ± 13.99a	13.3 ± 1.7b	8.3 ± 0.8ab	8.08 ± 0.57b	331.55 ± 20.03c	39.65 ± 4.88a
	5% C	137.66 ± 8.19a	16.8 ± 1.1a	7.8 ± 0.9b	9.29 ± 0.40ab	398.70 ± 6.22b	28.81 ± 2.15b
	10% C	136.33 ± 9.99a	18.3 ± 0.9a	11.1 ± 1.0a	9.62 ± 0.57a	401.65 ± 16.36b	30.46 ± 2.93b
	20% C	125.5 ± 4.19a	16.0 ± 0.8a	10.9 ± 1.1a	9.72 ± 0.44a	442.51 ± 19.74b	25.38 ± 1.24b
	40% C	125.75 ± 3.49a	17.0 ± 0.5a	10.8 ± 1.0a	9.71 ± 0.32a	514.73 ± 20.21a	21.58 ± 1.48b
Treated wastewater/−Fert (TWW)	0% C	120.66 ± 11.66a	15.8 ± 1.8a	9.8 ± 1.6a	8.75 ± 0.25a	400.21 ± 17.38b	23.87 ± 0.65a
	5% C	114.50 ± 6.22a	15.5 ± 1.0a	8.5 ± 0.8a	8.51 ± 0.44a	382.67 ± 23.20b	26.18 ± 1.59a
	10% C	125.33 ± 4.22a	18.3 ± 0.6a	8.0 ± 0.7a	9.58 ± 0.58a	449.53 ± 15.73ab	21.34 ± 0.86a
	20% C	107.33 ± 4.51a	18.1 ± 1.6a	8.3 ± 0.8a	8.54 ± 0.23a	429.46 ± 12.13ab	21.80 ± 0.85a
	40% C	120.66 ± 7.37a	16.8 ± 1.3a	7.6 ± 1.3a	9.87 ± 0.79a	501.86 ± 39.79a	21.49 ± 1.46a
Treated wastewater/+Fert (TWW+F)	0% C	137.00 ± 6.97a	18.5 ± 0.7a	11.1 ± 0.9a	9.25 ± 0.67a	451.55 ± 18.43b	22.14 ± 1.29ab
	5% C	138.83 ± 11.82a	19.3 ± 1.9a	12.3 ± 2.5a	9.37 ± 0.63a	507.48 ± 48.99ab	22.74 ± 1.14a
	10% C	131.00 ± 6.47a	20.6 ± 1.6a	11.1 ± 1.7a	9.02 ± 0.61a	474.61 ± 16.81ab	21.70 ± 1.11ab
	20% C	132.83 ± 6.26a	21.1 ± 1.6a	12.5 ± 1.2a	9.40 ± 0.36a	545.28 ± 56.91ab	19.35 ± 1.72b
	40% C	129.83 ± 4.05a	21.1 ± 1.8a	10.1 ± 0.9a	10.07 ± 0.33a	571.45 ± 15.90a	19.31 ± 1.09b

<sup>Y</sup> values (n = 6) in columns followed by the same letter for each water/fertilizer applications are not significantly different.  $p \leq 0.05$ .

Plant yield was significantly ( $p < 0.05$ ) increased in 40% C, compared to the plants grown in soil (control) and this was attributed to the increased number of fruits produced rather than the fruit's fresh weight (Figure 1). Shanmugam and Warman [53] also reported increased yield in strawberries grown in sandy-loam soil and subjected to 37.5 ton ha<sup>−1</sup> of MSW compost. Similarly, Fagnano et al. [54] reported increased lettuce yield in plants grown in 10, 30, and 60 ton ha<sup>−1</sup>, compared to control treatment. This could possibly be due to the lower N concentration in soils for the control plants, as the levels used in that study were similar to ours (16, 32, and 64 ton ha<sup>−1</sup> for the 10% C, 20% C and 40% C treatments, respectively). This contrasts with previous studies on pepper, as plant yield decreased in 40% MSW compost [39]. When fertigation was applied with tap water, plant yield was higher in plants grown in 5%–10% C-based media, compared to the control and to the higher rates of compost (i.e.,  $\geq 20\%$ ), with increased fruit number in 10% C+Fert and increased fruit fresh weight in  $\leq 10\%$  C+Fert treatments. Warman et al. [55] reported decreased yield in squash over a 3-year study when MSW compost was applied in different ratios, compared with the fertilized (NPK) soil or a mixture of fertilized soil+MSW compost. This agrees with the present findings, as tomato yield decreased with the combination of high rates of compost and fertilizers. Nevertheless, some studies showed that inorganic fertilizers are

superior to the MSW composts in supplying available N, while others showed increased yields in some crops following MSW compost application, and this depends on species/cultivar and salt resistance levels of the examined crops [7]. In such a way, MSW compost rates must be regulated based on the electrical conductivity of the applied compost and the species salt tolerance to avoid salt stress effects and unfavorable impacts on plant growth.



**Figure 1.** Effects of municipal solid waste compost (C; 0%-5%-10%-20%-40%) in soil irrigated with water (W) or treated wastewater (TWW) and with fertilizers (+Fert/-Fert) on yield (g plant<sup>-1</sup>), fruit number per plant, and fruit fresh weight (g) in a greenhouse tomato crop. Data are means  $\pm$  SE ( $n = 9$  plants) and significant differences ( $p < 0.05$ ) among treatments are indicated by different letters. ns: not significant.

The application of wastewater in agriculture is an efficient strategy to meet the high demand for water for irrigation, and the exploitation of brackish water is attracting research interest despite the consumer concern [28]. Several researches on vegetables investigated the effects of wastewater on agriculture, including radish (*Raphanus sativum* L.) [30], tomato (*S. lycopersicum* Mill.) [29,33,56,57], cucumber (*C. sativus* L.) [28,29], eggplant (*Solanum melogena* L.) [32,57], cauliflower (*Brassica oleracea* var. botrytis), red cabbage (*Brassica oleracea* var. capitata) [31], and ornamentals [34,36]. In the present study, plants irrigated with TWW and/or fertigation (TWW+Fert) did not differ in yield and/or number of fruits produced, but fruit weight decreased with high compost rates (i.e., 40% C), compared with lower



compost rates and relevant control. Similarly, Kiziloglu et al. [31] found no changes in cauliflower and red cabbage yields after wastewater application. The use of TWW was reported to increase the available N in the root zone of tomato and eggplant, and that was observed to increase the yield [32,57]. In lettuce, wastewater irrigation changed the soil's physicochemical properties and microbial load [58].

### 3.3. Effect on Plant Physiology

Compost ratios did not affect the tomato plant physiology as leaf photosynthesis (averaged as  $7.68 \mu\text{mol m}^{-2} \text{s}^{-1}$ ), leaf stomatal conductance (averaged as  $0.23 \mu\text{mol m}^{-2} \text{s}^{-1}$ ), internal  $\text{CO}_2$  concentration (averaged as  $309.63 \mu\text{mol mol}^{-1}$ ), and chlorophyll fluorescence (averaged as 0.72 Fv/Fm) remained at similar levels among the examined compost ratios (0%-5%-10%-20%-40% C) used (Figure 2). This indicates the similar behavior of the crops during cultivation, with no changes in physiological aspects in terms of photosynthetic metabolism. Similar findings were observed in *Cichorium spinosum* grown in pots with MSW compost of  $60 \text{ t ha}^{-1}$ , as total chlorophylls were unaffected [59]. Fertilization with tap water in  $\geq 10\%$  C decreased leaf stomatal conductance, while internal  $\text{CO}_2$  concentration decreased in  $\geq 20\%$  C+Fert. The use of TWW in 40% C decreased (up to 43.1% and 31.2%) photosynthesis and internal  $\text{CO}_2$  concentration, respectively. The combination of TWW and fertilization also decreased plant physiology attributes with more profound effects in 40% C treatments.

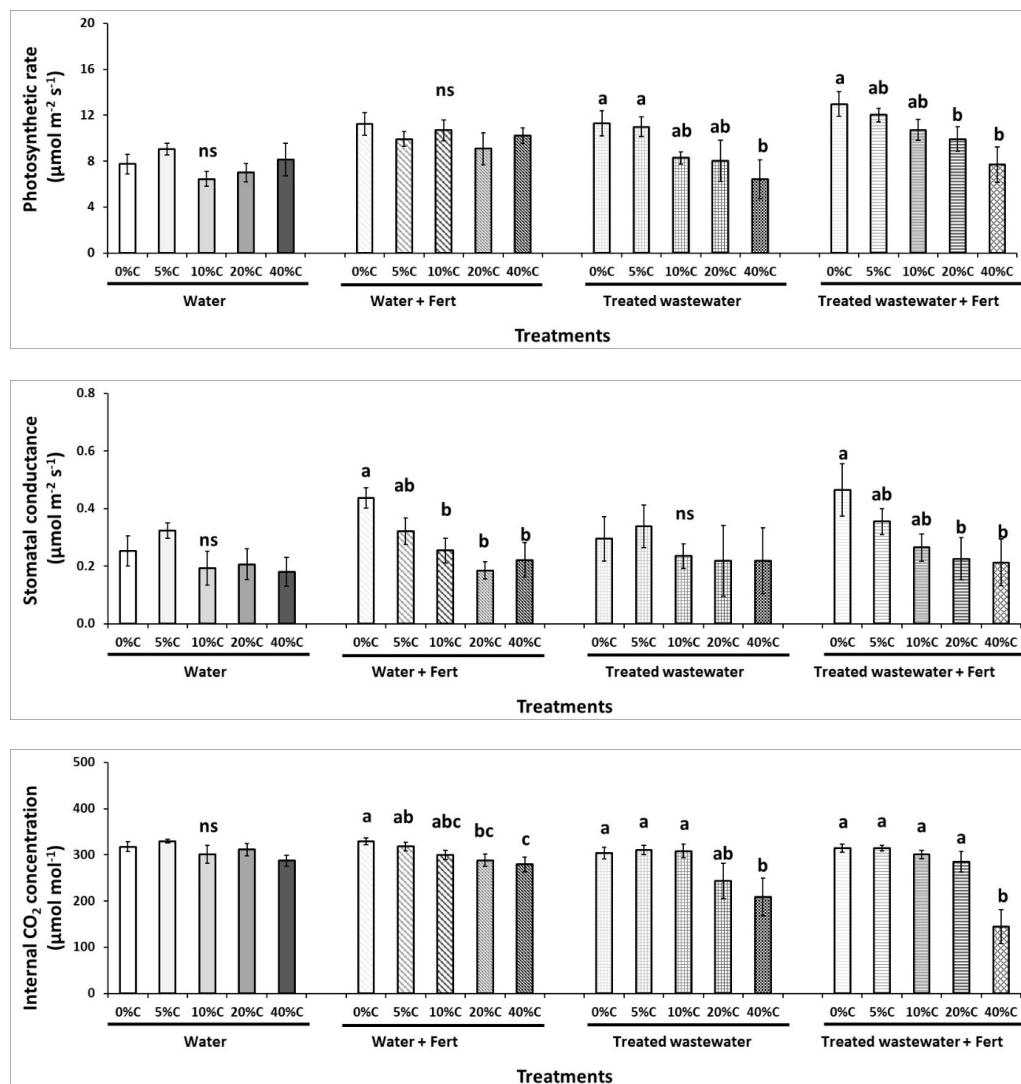
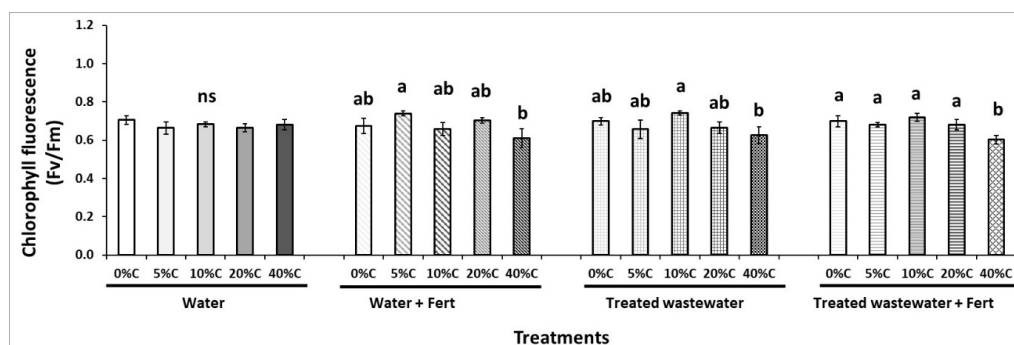


Figure 2. Cont.



**Figure 2.** Effects of municipal solid waste compost (C; 0%-5%-10%-20%-40%) in soil irrigated with water (W) or treated wastewater (TWW) and with fertilizers (+Fert/-Fert) on leaf photosynthetic rate ( $P_n$ :  $\mu\text{mol m}^{-2} \text{s}^{-1}$ ), leaf stomatal conductance ( $g_s$ :  $\mu\text{mol m}^{-2} \text{s}^{-1}$ ), leaf internal  $\text{CO}_2$  concentration ( $c_i$ :  $\mu\text{mol mol}^{-1}$ ), and chlorophyll fluorescence ( $F_v/F_m$ ) in a greenhouse tomato crop. Data are means  $\pm$  SE ( $n = 6$ ) and significant differences ( $p < 0.05$ ) among treatments are indicated by different letters. ns: not significant.

### 3.4. Effects on Leaf Element Content

Tomato leaf nutrient content is presented in Table 3. Plants grown in  $\geq 40\%$  C had higher N content, compared to plants grown in soil (control), while increased K and Na levels were found in plants grown in  $\geq 20\%$  C in comparison to the control treatment, agreeing with previous studies on lettuce grown in different MSW compost ratios [54]. Fertilization in compost-based media increased further the accumulation of N, K, and Na (Table 3). Plants irrigated with TWW had higher N, K, and Na content at  $\geq 40\%$  C, while the combination of TWW and fertilization resulted in increased N (at  $\geq 20\%$  C) and K (at  $\geq 40\%$  C) content, compared with the relevant control. The P content did not differ among the examined treatments and ranged from 1.11 to 1.38  $\text{mg kg}^{-1}$  dry weight. The increased mineral content from the compost addition to the soil was reported in pepper [39] and squash [15] crops. Indeed, the increased nutrient levels observed with fertilization and/or TWW application is related to the extra nutrients that fertilizers and TWW contained and that were bioavailable. Municipal wastewater contains relatively high amounts of Na, as in the present work, and this Na accumulated in leaves after the TWW application. Papafilippaki et al. [60] reported that MSW compost increases the EC of soils, along with Na and Cl content in plants, and this is in line with the outcomes of the current work. The same authors reported that high Na levels in soil fail to adversely impact plant growth and yield in a salt-tolerant crop (*C. spinosum*); however, salt accumulation of the fertilizers with high rates of the MSW compost application did not benefit tomato yield.

**Table 3.** Effects of municipal solid waste compost (C; 0%-5%-10%-20%-40%) in soil irrigated with water (W) or treated wastewater (TWW) and with fertilizers (+Fert/-Fert) on leaf elemental (N, K, P, and Na in  $\text{mg kg}^{-1}$ ) content in a greenhouse tomato crop.

	Compost	N	K	P	Na
Water/-Fert (W)	0% C	44.52 $\pm$ 0.77bc	51.15 $\pm$ 0.88c	1.17 $\pm$ 0.04a	8.56 $\pm$ 0.56c
	5% C	33.22 $\pm$ 2.76c	38.18 $\pm$ 3.17c	1.11 $\pm$ 0.04a	10.94 $\pm$ 0.68c
	10% C	37.85 $\pm$ 11.06c	43.51 $\pm$ 9.71c	1.12 $\pm$ 0.04a	9.24 $\pm$ 4.41c
	20% C	61.32 $\pm$ 5.98b	78.08 $\pm$ 6.16b	1.17 $\pm$ 0.05a	24.17 $\pm$ 0.91b
	40% C	85.54 $\pm$ 5.56a	109.99 $\pm$ 9.66a	1.16 $\pm$ 0.02a	41.47 $\pm$ 5.13a
Water/+Fert (W+F)	0% C	58.09 $\pm$ 11.92b	66.77 $\pm$ 13.68b	1.26 $\pm$ 0.03a	15.34 $\pm$ 1.22c
	5% C	50.86 $\pm$ 1.81b	58.46 $\pm$ 2.08b	1.21 $\pm$ 0.04a	13.99 $\pm$ 1.48c
	10% C	63.32 $\pm$ 10.11b	72.76 $\pm$ 12.42b	1.28 $\pm$ 0.03a	24.17 $\pm$ 4.71bc
	20% C	63.84 $\pm$ 8.45b	75.41 $\pm$ 8.48b	1.21 $\pm$ 0.02a	30.95 $\pm$ 4.81b
	40% C	99.52 $\pm$ 0.25a	133.93 $\pm$ 2.91a	1.18 $\pm$ 0.01a	45.88 $\pm$ 4.33a

Table 3. Cont.

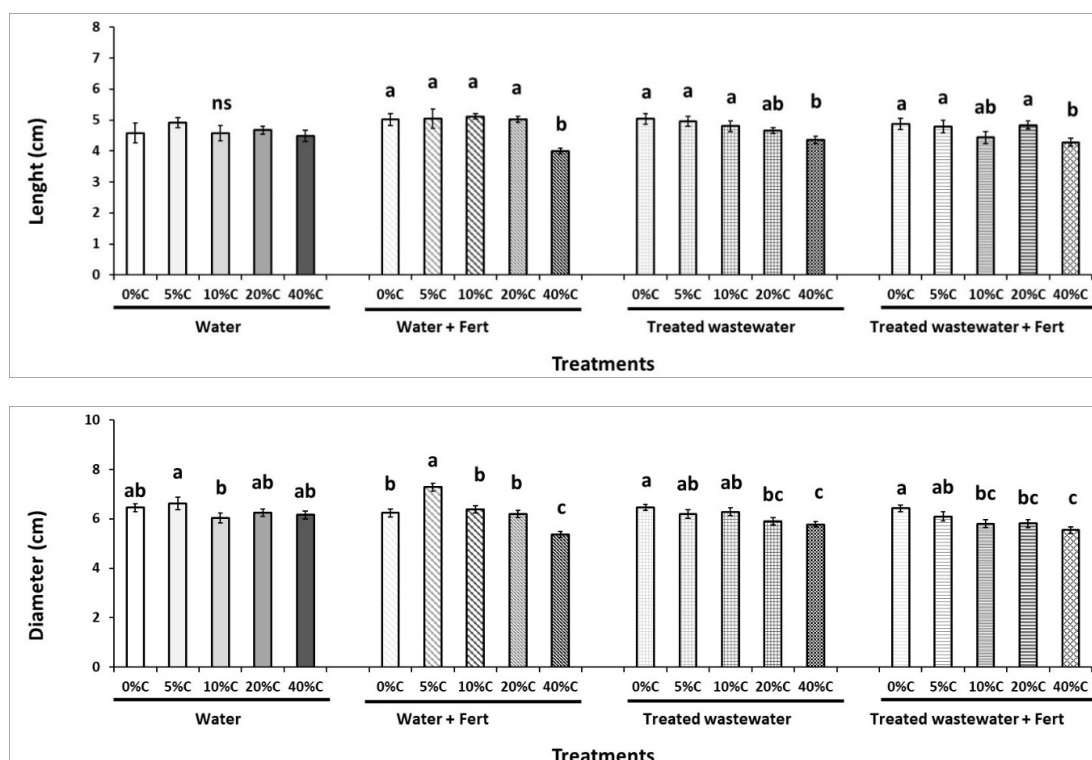
	Compost	N	K	P	Na
Treated wastewater/-Fert (TWW)	0% C	32.64 ± 1.51b	37.52 ± 1.73b	1.35 ± 0.05a	49.95 ± 7.32b
	5% C	38.71 ± 2.29b	44.51 ± 2.64b	1.38 ± 0.02a	49.24 ± 1.17b
	10% C	55.49 ± 13.01ab	63.78 ± 14.95b	1.21 ± 0.07a	52.66 ± 6.47b
	20% C	47.54 ± 6.72b	60.79 ± 8.67b	1.35 ± 0.01a	49.61 ± 2.65b
	40% C	76.98 ± 7.99a	98.69 ± 11.65a	1.32 ± 0.09a	86.93 ± 5.61a
Treated wastewater/+Fert (TWW+F)	0% C	32.45 ± 5.65b	38.85 ± 7.61b	1.31 ± 0.08a	48.61 ± 12.65a
	5% C	49.42 ± 5.94ab	56.81 ± 6.82ab	1.21 ± 0.02a	48.59 ± 8.84a
	10% C	55.21 ± 2.79ab	63.95 ± 3.21ab	1.36 ± 0.04a	47.91 ± 4.41a
	20% C	61.86 ± 4.26a	71.09 ± 4.89ab	1.27 ± 0.09a	63.18 ± 8.32a
	40% C	65.16 ± 9.41a	84.06 ± 11.62a	1.18 ± 0.07a	57.41 ± 9.45a

<sup>Y</sup> values (n = 4) in columns followed by the same letter for each water/fertilizer applications are not significantly different.  $p \leq 0.05$ .

### 3.5. Effect on Fruit Quality

Fruit fresh weight was unaffected by the ratio of the compost used in the growing media but changed when plants were subjected to fertigation and/or irrigation with TWW (Figure 1). Therefore, fruit fresh weight was significantly ( $p < 0.05$ ) decreased (up to 32.2%) in plants grown in  $\geq 40\%$  C+Fert, decreased (up to 24.6%) in plants grown in  $\geq 40\%$  C+TWW, and decreased (up to 30.4%) in plants subjected to  $\geq 40\%$  C+TWW+Fert when compared with the relevant control treatment. Similar findings were observed in pepper crops cultivated in a high ratio of MSW compost [11] and pepper crops irrigated with TWW with additional fertilizers [39]. This indicates that the increased nutrition that was obtained either by high rates of compost or by using treated wastewater with fertilizers negatively affected fruit fresh weight. Fruit size varied among the different treatments (Figure 3). Fruit length and diameter decreased at high compost ratio ( $\geq 40\%$  C) used in the growing media with fertilizers and/or TWW applications, compared to the control treatment. Fruit diameter increased at 5% C in plants subjected to fertilizers (5% C+Fert), compared to the relevant control (0% C+Fert). Uniform fruit size is of importance for marketability of the produce, but most importantly for the postharvest storage and management of the fresh commodities.

Fruit color was less affected by the examined treatments as presented in Table 4, while no differences were found in fruit color ( $L^*$ ,  $a^*$ ,  $b^*$  and color index (CI)) in different compost-based media. Tomato redness (color  $a^*$ ) was increased at  $\geq 20\%$  C+Fert, compared with the control and 5% C+Fert. Fruit lightness ( $L^*$ ) and color  $b^*$  were increased but color index was decreased at  $\leq 5\%$  C+TWW+Fert.



**Figure 3.** Effects of municipal solid waste compost (C; 0%-5%-10%-20%-40%) in soil irrigated with water (W) or treated wastewater (TWW) and with fertilizers (+Fert/-Fert) on fruit size (length, diameter in cm) in a greenhouse tomato crop. Data are means  $\pm$  SE ( $n$  = at least 30) and significant differences ( $p < 0.05$ ) among treatments are indicated by different letters. ns: not significant.

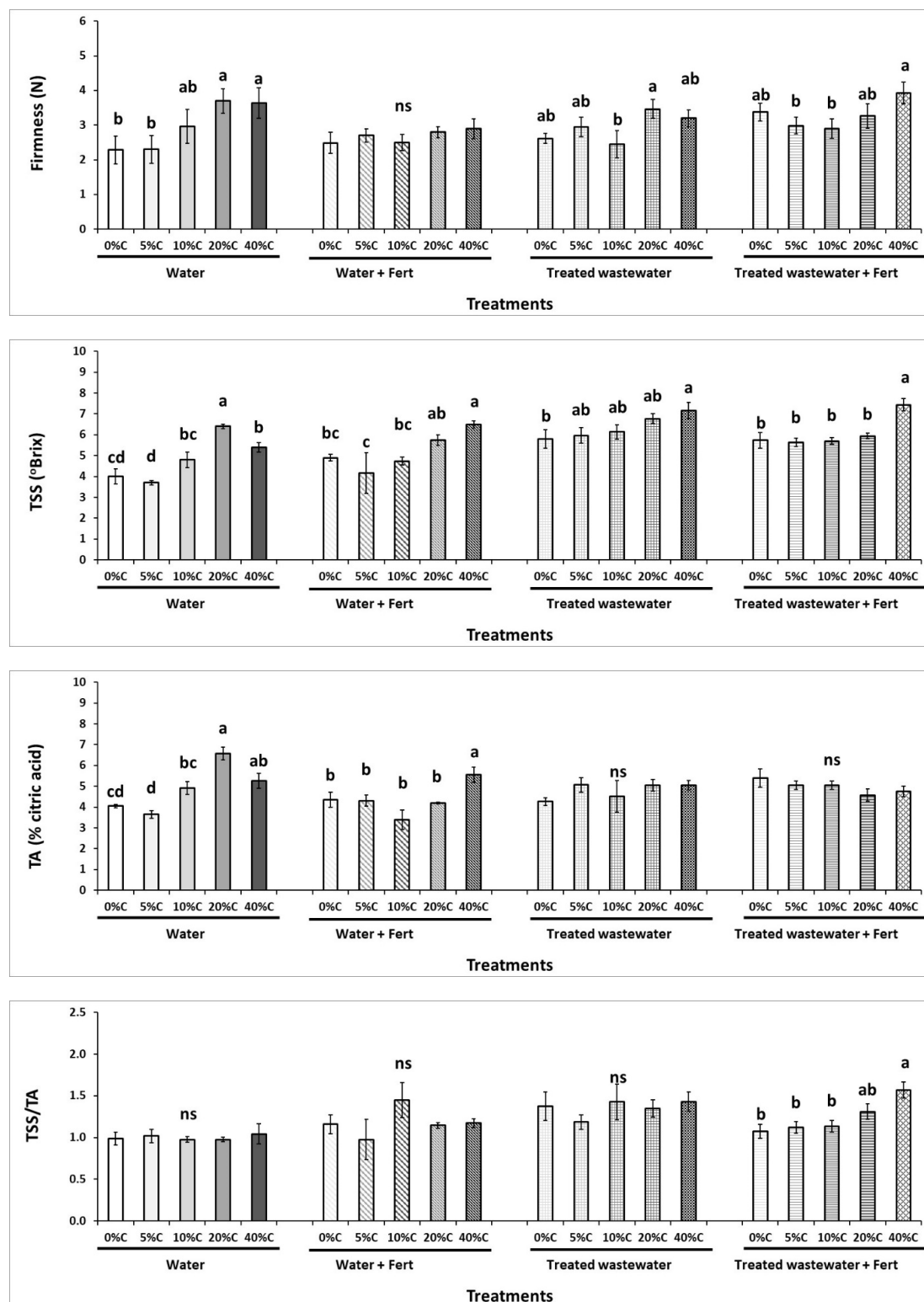
**Table 4.** Effects of municipal solid waste compost (C; 0%-5%-10%-20%-40%) in soil irrigated with water (W) or treated wastewater (TWW) and with fertilizers (+Fert/-Fert) on fruit color ( $L^*$ ,  $a^*$ ,  $b^*$ , color index) in a greenhouse tomato crop.

	Compost	Color $L^*$	Color $a^*$	Color $b^*$	Color Index
Water/-Fert (W)	0% C	34.76 $\pm$ 0.92a	18.38 $\pm$ 0.79a	15.29 $\pm$ 1.18a	33.88 $\pm$ 2.19a
	5% C	38.01 $\pm$ 2.20a	16.24 $\pm$ 2.66a	17.11 $\pm$ 2.04a	31.32 $\pm$ 4.76a
	10% C	35.61 $\pm$ 0.85a	15.47 $\pm$ 0.91a	14.99 $\pm$ 0.91a	30.26 $\pm$ 2.12a
	20% C	36.49 $\pm$ 0.98a	17.39 $\pm$ 2.12a	14.61 $\pm$ 0.73a	32.45 $\pm$ 4.24a
	40% C	36.48 $\pm$ 1.01a	16.56 $\pm$ 1.72a	15.14 $\pm$ 0.93a	34.57 $\pm$ 3.61a
Water/+Fert (W+F)	0% C	36.71 $\pm$ 0.88a	16.81 $\pm$ 1.18b	16.38 $\pm$ 0.98a	30.59 $\pm$ 2.71a
	5% C	35.06 $\pm$ 1.36a	16.78 $\pm$ 1.72b	13.82 $\pm$ 0.78a	37.45 $\pm$ 3.63a
	10% C	35.71 $\pm$ 0.69a	18.79 $\pm$ 0.77ab	16.08 $\pm$ 1.01a	34.83 $\pm$ 2.25a
	20% C	35.62 $\pm$ 0.67a	20.51 $\pm$ 0.52a	15.34 $\pm$ 0.89a	38.46 $\pm$ 2.72a
	40% C	36.02 $\pm$ 0.63a	20.32 $\pm$ 0.82a	15.61 $\pm$ 0.87a	37.56 $\pm$ 2.12a
Treated wastewater/-Fert (TWW)	0% C	34.85 $\pm$ 0.93a	17.76 $\pm$ 0.85a	15.16 $\pm$ 1.06ab	38.36 $\pm$ 2.06a
	5% C	34.15 $\pm$ 0.57a	18.47 $\pm$ 0.77a	13.02 $\pm$ 0.32b	42.96 $\pm$ 1.82a
	10% C	34.74 $\pm$ 0.73a	19.66 $\pm$ 0.49a	14.11 $\pm$ 0.91ab	39.55 $\pm$ 3.46a
	20% C	36.20 $\pm$ 0.71a	19.96 $\pm$ 1.33a	15.75 $\pm$ 0.78a	37.41 $\pm$ 2.86a
	40% C	34.20 $\pm$ 0.44a	20.92 $\pm$ 0.69a	13.51 $\pm$ 0.46b	44.64 $\pm$ 1.77a
Treated wastewater/+Fert (TWW+F)	0% C	35.14 $\pm$ 0.68a	19.77 $\pm$ 0.56a	15.78 $\pm$ 0.86a	36.36 $\pm$ 2.21b
	5% C	36.84 $\pm$ 0.69a	20.49 $\pm$ 0.52a	16.87 $\pm$ 0.92a	34.41 $\pm$ 2.02b
	10% C	35.24 $\pm$ 0.91ab	19.01 $\pm$ 1.08a	14.37 $\pm$ 0.74ab	41.59 $\pm$ 2.98a
	20% C	35.26 $\pm$ 0.67ab	19.59 $\pm$ 0.71a	14.74 $\pm$ 0.97ab	38.67 $\pm$ 2.09ab
	40% C	34.63 $\pm$ 0.46b	19.25 $\pm$ 0.57a	13.75 $\pm$ 0.57b	42.01 $\pm$ 2.01a

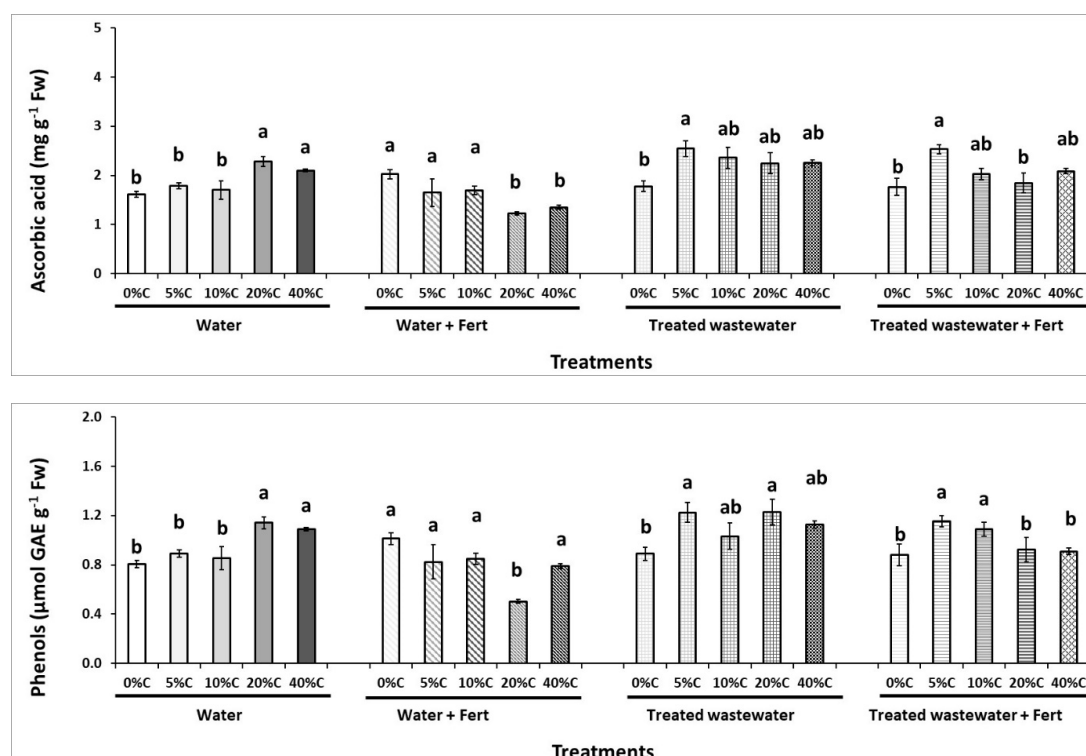
<sup>Y</sup> values ( $n$  = at least 15) in columns followed by the same letter for each water/fertilizer applications are not significantly different.  $p \leq 0.05$ .

Fruit firmness was maintained in fruits from plants grown in  $\geq 20\%$  C, compared to the control and 5% C treatment, while fertigation alleviated these changes and firmness remained at similar levels (averaged as 2.67 N) among treatments (Figure 4). Fruits harvested from plants grown with TWW and/or fertigation did not show a specific trend in their firmness. Fruit firmness maintenance prolongs storage for the commodity and maintains the quality of the fruit, as tomato is a climacteric fruit and can still ripen after harvest [61]. Total soluble solids increased in fruits harvested from plants grown in high compost ratios or subjected to fertigation and/or TWW (Figure 4). TSS were increased (up to 60%) at  $\geq 20\%$  C when compared to the control (soil) or low compost-based media. Similarly, TSS increased up to 32.7%, 22.4%, and 30.4% at 40% C+Fert, 40% C+TWW, and 40% C+TWW+Fert, respectively, compared to the relevant control. Titratable acidity had a similar trend with TSS for plants grown in soil and C-based media and irrigated (or fertigated) with tap water, and this resulted in an unchanged ripening index (i.e., similar TSS/TA ratio). In case of TWW+Fert applications, the TSS/TA followed the TSS trend (i.e., increased values at the high compost ratio). Hargreaves et al. [62] reported that sweetness indicated by the TSS/TA ratio in strawberries was unaffected by the different MSW compost levels, agreeing with the present findings. Ascorbic acid of tomatoes increased at  $\geq 20\%$  C and decreased at  $\geq 20\%$  C+Fert treatments (Figure 5). However, in cases of TWW and/or Fert, ascorbic acid revealed the highest levels at 5% of compost-based media. In previous studies, irrigation with treated wastewater did not affect tomato fruit fresh weight, TSS, titratable acidity, and dry matter content [32]. In contrast Al-Lahham et al. [63] reported a decrease of 1.5% in the TSS, 5.78 N in firmness, and 5.1% in weight loss of tomato fruit following TWW application. Total phenols content increased at  $\geq 20\%$  C and decreased at the 20% C+Fert treatment, compared with the control. Interestingly, when TWW and fertigation were combined, total phenols content was higher in 5%–10% compost-based media. Dagianta et al. [39] reported that total phenols content decreased (up to 41%) in peppers harvested from plants grown in substrate with  $>20\%$  C. Fresh produce of high phenolic levels is appreciated because of the correlated higher antioxidant activity, which protects tissue oxidation by scavenging free radicals and inhibiting lipid peroxidation, and thereby advancing the nutritional quality of the fresh produce [64].



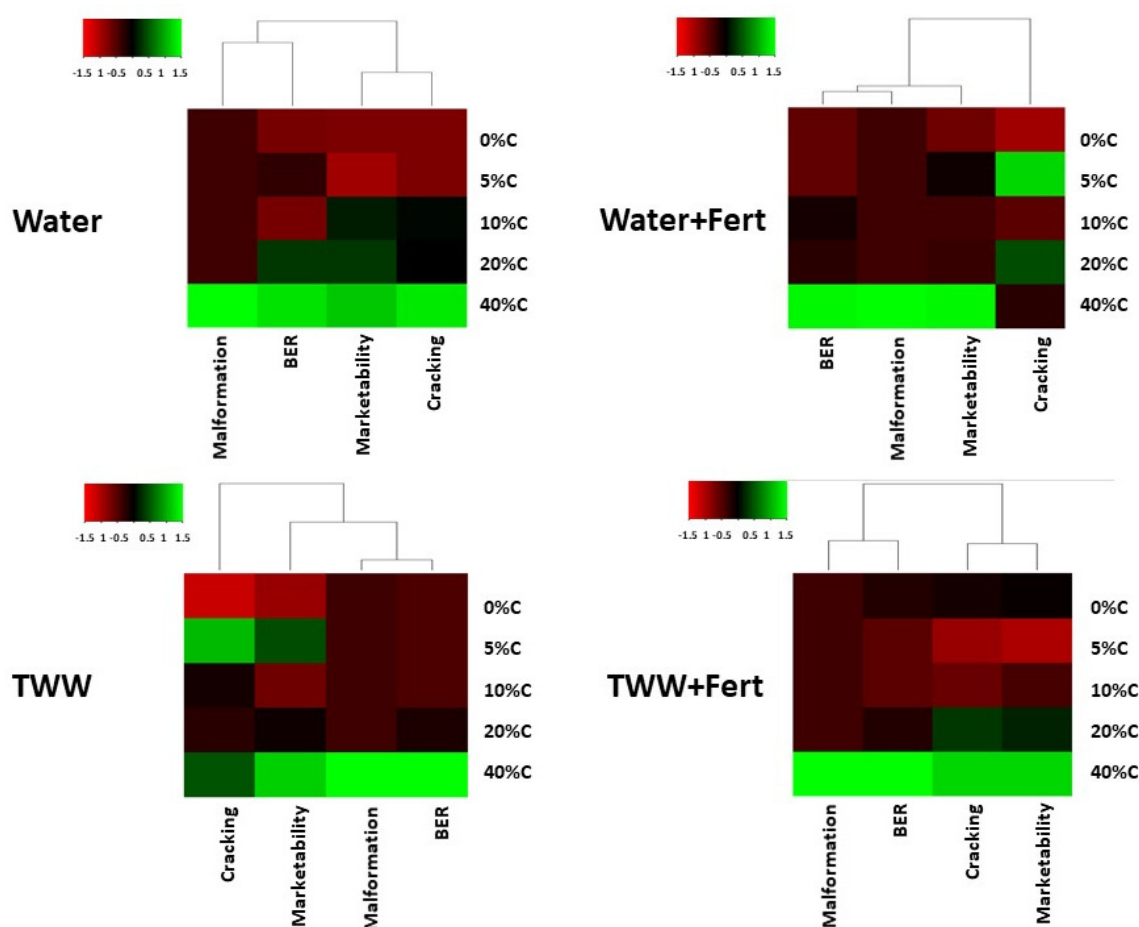


**Figure 4.** Effects of municipal solid waste compost (C; 0%-5%-10%-20%-40%) in soil irrigated with water (W) or treated wastewater (TWW) and with fertilizers (+Fert/-Fert) on fruit firmness (N), total soluble solids (TSS; in °Brix), titratable acidity (TA; in % of citric acid) and the ripening index (TSS/TA) in a greenhouse tomato crop. Data are means  $\pm$  SE ( $n = 12$ ) and significant differences ( $p < 0.05$ ) among treatments are indicated by different letters. ns: not significant.



**Figure 5.** Effects of municipal solid waste compost (C; 0%-5%-10%-20%-40%) in soil irrigated with water (W) or treated wastewater (TWW) and with fertilizers (+Fert/-Fert) on fruit ascorbic acid (mg g<sup>-1</sup> Fw) and total phenolics (μmol GAE g<sup>-1</sup> fresh weight-Fw) in a greenhouse tomato crop. Data are means ± SE (n = 12) and significant differences ( $p < 0.05$ ) among treatments are indicated by different letters. ns: not significant.

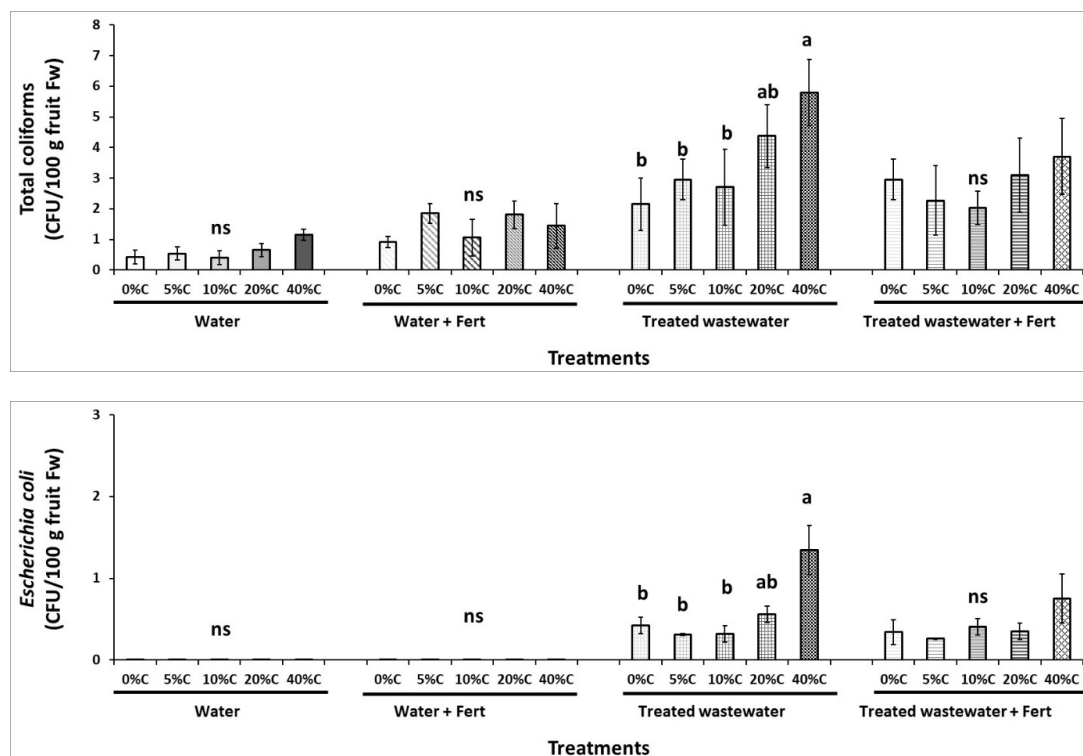
Taking into consideration the scale (out of 4 units) of fruit marketability, with higher values reflecting lower marketability (i.e., malformation, wounds, infection), it was observed that decreased marketability, symptoms of blossom end rot (BER), malformation, and cracking were observed at 40% C (Figure 6), being in agreement with previous results from pepper crops grown in MSW compost [11]. Similar observations were found in the case of 40% C+TWW+Fert treatment. Less marketable produce, malformation, and BER symptoms were also higher at 40% C+Fert and 40% C+TWW, while cracking was increased at the equivalent 5% of compost (5% C+Fert and 5% C+TWW).



**Figure 6.** Effects of municipal solid waste compost (C; 0%-5%-10%-20%-40%) in soil irrigated with water (W) or treated wastewater (TWW) and with fertilizers (+Fert/-Fert) on marketability, blossom end rot (BER), cracking, and malformation of tomato fruit in a greenhouse tomato crop. Red shades indicate lower levels (less than  $-1.5$ -fold), deep red corresponds to  $-1$ -fold, black signifies that the level is not different from the control, deep green corresponds to  $1$ -fold, clear green indicates that the level is more than  $1.5$  higher than the control. Values are expressed in percentage.

Fruits harvested from plants grown in soil and compost-based media irrigated with tap water did not differ on total coliform units, while *E. coli* was absent (Figure 7). However, when plants were irrigated with TWW, total coliforms increased (2.7 times) at 40% C, compared with  $\leq 10\%$  C and soil treatment, and this was also reflected by the increased *E. coli* values ( $1.34 \text{ CFU } 100 \text{ g}^{-1}$  of fresh weight). When TWW was combined with fertigation, there were no differences in total coliform and *E. coli* among the examined compost-based media. However, the maximum load that was found in 40% C+TWW and averaged  $5.79 \text{ CFU } 100 \text{ g}^{-1}$  of fresh weight for total coliforms appeared lower than the levels reported by Cirelli et al. [32] in tomato and eggplant. The presence of *E. coli* in pepper, eggplant, and tomato crops irrigated with TWW was reported previously [32,39]. Selected fruits were tested for infection from bacteria entering the fruit and were found to be not contaminated (data not shown), indicating that bacteria did not pass through the tissue of the plant. However, this fact needs to be looked at more closely in the future, eliminating any splashing and possible transfer of bacteria on and inside the fruit, before arriving at any final conclusions. Cirelli et al. [32] reported that tomato and eggplant fruit that were in contact with soil or plastic cover material had increased microbial load, compared with the fruits that had no contact with soil; they had negligible or no microbial amount. Noticeably, the bacteria load in the soil was almost 1000 times higher than that on fruits, being in line with previous studies on tomato and cucumber [29] and pepper [39] crops irrigated with tertiary-treated wastewater. Application of wastewater in tomato crops led to increased microbial

contamination (*E. coli* and fecal streptococci) on the surface of the soil [33]. Utilization of untreated municipal wastewater for irrigation purposes is associated with a high number of risks, affecting crop yield and quality but also increasing the levels of pathogens, as it may be highly contaminated [65]. To that point, treating wastewater is important for improving its quality and safety [28,65].



**Figure 7.** Effects of municipal solid waste compost (C; 0%-5%-10%-20%-40%) in soil irrigated with water (W) or treated wastewater (TWW) and with fertilizers (+Fert/-Fert) on bacteria (total coliform and *Escherichia coli*) units (CFU/100 g fruit fw) on the fruits in a greenhouse tomato crop. Data are means  $\pm$  SE ( $n = 23$ ) and significant differences ( $p < 0.05$ ) among treatments are indicated by different letters. ns: not significant.

One risk of using MSW compost is the potential accumulation of heavy metals that could have negative effects on the environment [7]. However, the risk of the presence of heavy metals in the food chain is negligible, as reported in four lettuce cultivars grown in MSW compost-based media [66]. Municipal wastewater irrigation in a controlled manner is considered to be environmentally friendly. Wastewater management practices help to reduce ecosystem contamination from the direct drainage of wastewater into surface or groundwater [67]. Furthermore, wastewater is a valuable source of plant nutrients (exchangeable Na, K, Ca, Mg, and P) and organic matter, which are required to maintain the fertility and productivity of arid soils. However, the microbial load present in wastewater may have a negative impact on plant growth and yield. The use of TWW for production of vegetables, considered as edible fresh produce, requires more exploitation. In addition, the negligible microbial contamination of pepper fruit indicated the possible use of TWW in agriculture [39]. However, the treated wastewater can be an alternative means of irrigation in vegetables, i.e., tomatoes, to be consumed after cooking but not taken as raw, provided the contingency of the effluent is controlled continuously to avoid contamination [63]. Cirelli et al. [32] reported that tomato and eggplant fruits that were in contact with soil or plastic had increased fecal coliform, fecal streptococci, *E. coli* (only for tomato), but *Salmonella* was absent; whereas fruits not in contact with soil revealed negligible or no amounts. Therefore, alternative cultivation practices might be required when the plants are irrigated with TWW, by modifying the pruning and fruit thinning, as the first fruits could be produced at higher levels of the plant (considering

the vertical plant growth system), compared to soil. In this case, any TWW splashing of fruits can be minimized. The present findings can have a wide validity in vegetable crops such as cucumber, pepper, eggplant, etc., by considering an intensive cultivation scheme in greenhouses and pruning cultivation practices applied by the farmer.

#### 4. Conclusions

The application of municipal solid waste compost and treated wastewater in agriculture is gaining increased interest, as both can not only be effective ways of waste management and recycling, but also mineral sources for crop needs. However, the safety of their use in agriculture was discussed because of concerns about their levels of salts, heavy metals, and microbial load. In the present study, compost increased the physiochemical properties and mineral content of the substrates, while fertigation and TWW contributed mostly to the latter. The increased mineral levels in the substrate were reflected in the increased levels of N, K, and Na in tomato leaves. Compost up to 20% was demonstrated to be a suitable soil amendment for crop production, while a greater ratio (i.e., 40% C) possibly caused salt accumulation in the soil and negatively affected crop production. The combination of compost with fertigation and/or TWW supported further tomato growth and yield; positive effects were mainly observed when low compost levels were applied combined with fertigation and/or TWW. This highlights the importance of compost ratio adjustment according to the compost EC levels. Fruit quality as indicated by increased TSS, TA, ascorbic acid and total phenolics benefited from the high ratios of compost and/or fertigation and TWW, but marketability did not. Microbial load after the use of TWW is of consideration, as high levels can be present on the substrate but lower levels can be found on the fruit, mainly due to splashing or fruit contact with the soil, indicating the importance of reconsidering the current cultivation practices applied to tomatoes, especially the adapted pruning system.

**Supplementary Materials:** The following are available online at <http://www.mdpi.com/2071-1050/12/10/4287/s1>, **Table S1.** Correlations coefficients and (*p*-values) between compost, fertilizer and treated wastewater (TWW) with tomato attributes.

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