applied sciences

MDPI

Article

Effects of the Application of a Plant-Based Compost on Yield and Quality of Industrial Tomato (*Solanum lycopersicum* L.) Grown in Different Soils

Eugenio Cozzolino [1], Antonio Salluzzo [2,*], Luisa del Piano [1], Alessio Vincenzo Tallarita [3,*], Vincenzo Cenvinzo [3], Antonio Cuciniello [1], Antonietta Cerbone [2], Pasquale Lombardi [4] and Gianluca Caruso [3]

1 Council for Agricultural Research and Economics (CREA)—Research Centre for Cereal and Industrial Crops, 81100 Caserta, Italy; eugenio.cozzolino@crea.gov.it (E.C.); luisa.delpiano@crea.gov.it (L.d.P.); antonio.cuciniello@crea.gov.it (A.C.)
2 Territorial and Production Systems Sustainability Department—Research Centre Portici, Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), 80055 Portici, Italy; antonietta.cerbone@enea.it
3 Department of Agricultural Sciences, University of Naples Federico II, 80055 Portici, Italy; vincenzo.cenvinzo2@unina.it (V.C.); gcaruso@unina.it (G.C.)
4 Council for Agricultural Research and Economics (CREA)—Research Centre for Vegetable and Ornamental Crops, 84098 Pontecagnano, Italy; pasquale.lombardi@crea.gov.it
* Correspondence: antonio.salluzzo@enea.it (A.S.); alessiovincenzo.tallarita@unina.it (A.V.T.)

Abstract: The use of plant-based compost has been increasing within environmentally sustainable crop systems, as its incorporation into soil improves its structure and implies a slow release of nutrients to the plants. Due to the limited literature regarding compost application to industrial crops and the important role of the soil type, research was conducted on the industrial tomato (*Solanum lycopersicum* L.) hybrid Coronel F_1 at the Department of Agricultural Sciences of Naples, University Federico II, in 2019 and 2020. The study was based on the factorial combination of three fertilization types (compost, compost + mineral, and mineral) and three soil textures (clayey, loamy, and sandy). The highest crop yield was observed in loamy soil with mineral fertilization (+12.7% compared to clayey and loamy soils; +12.1% and +60.3% compared to compost + mineral and compost, respectively). Compost application increased plant dry weight (+23% compared to mineral fertilization), while sandy soil had a lower dry residue (−3%). The combination of loamy soil and compost exhibited the highest fruit dry matter percentage (approximately 7%). These findings suggest that applying compost to industrial tomato plants, alone or with mineral fertilizers, improves fruit quality and promotes crop system sustainability, and the optimal strategy depends on the target crop and soil type.

Keywords: mineral fertilization; organic fertilization; yield; growth; firmness; dry matter; antioxidants; phenols; lycopene; ascorbic acid

check for updates

Citation: Cozzolino, E.; Salluzzo, A.; Piano, L.d.; Tallarita, A.V.; Cenvinzo, V.; Cuciniello, A.; Cerbone, A.; Lombardi, P.; Caruso, G. Effects of the Application of a Plant-Based Compost on Yield and Quality of Industrial Tomato (*Solanum lycopersicum* L.) Grown in Different Soils. *Appl. Sci.* **2023**, *13*, 8401. https://doi.org/10.3390/app13148401

Academic Editor: Rafael López Núñez

Received: 23 May 2023
Revised: 13 July 2023
Accepted: 17 July 2023
Published: 20 July 2023

1. Introduction

Tomato (*Solanum lycopersicum* L.) is the second most widely cultivated vegetable crop globally, following potato, but it ranks first in terms of its processing value [1]. Tomato processing is crucial on a global scale as it significantly contributes to the world's food supply and agricultural economics.

Industrial tomato is specifically cultivated to produce various products, including canned tomato, paste, and sauce [2]. This type of tomato cultivation involves large-scale farming, requiring intensive use of the soil and its resources due to the high nutrient demands to maximize yields.

The current global conditions highlight the importance of adopting environmentally friendly farming practices for sustainable food production, which has gained increasing attention in developed countries. Soil, as a natural resource, plays a critical role in providing ecological benefits to humans and acts as a core component of the crop system [3]. Soil serves as a medium for plant anchorage, nutrient storage and release, water retention, carbon sequestration, and biodiversity preservation [4]. Different types of soil have varying physical, chemical, and biological characteristics, which can significantly impact the growth and productivity of tomato plants. Proper management of the soil fertility is essential for sustainable crop production, especially considering the increasing pressure from global population growth, which poses a threat to the viability of farming systems [5]. Therefore, the implementation of appropriate practices tailored to specific contexts is essential to preserve environmental integrity [6].

Fertilizers can enhance plant growth, yield, and fruit quality by replenishing the nutrients required for optimal plant metabolism. Traditional fertilizers, such as synthetic chemical fertilizers, have been extensively used in tomato production systems, and they have significant technical and environmental impacts. The latter aspects are primarily influenced by soil characteristics, such as texture, which interact with water and nutrients to determine their availability for plant root absorption, while preventing potential pathogen proliferation [7].

The rising use of compost, an organic fertilizer derived from the decomposition of organic matter, in conjunction with chemical fertilizers represents an integrated nutrient management approach that has been extensively studied for its potential to sustainably enhance both nutrient use efficiency and agricultural productivity. Nutrient use efficiency is commonly described as the soil capacity to adequately provide plants with the required nutrients, thus improving their assimilation and redistribution for optimal growth and productivity [8,9].

Compost gives numerous advantages, improving the soil structure, enhancing nutrient cycling, promoting beneficial microbial activity, and reducing the use of synthetic fertilizers [10,11], making it interesting to investigate its effectiveness as a sustainable alternative to traditional fertilizers.

Composts are frequently used as soil amendments in organic farming, particularly in vegetable systems such as that of the tomato [12]. Composts derived from plant residues are economically sustainable and have a longstanding tradition in many regions. A previous study [13] showed that compost application provided nitrogen excess to crops; therefore, mixture with mineral fertilizers is recommendable.

The application of compost to soil has demonstrated direct and indirect effects, such as increased nitrogen immobilization as well as moisture NH_4^+ retention, reduced N_2O emission, and NH_3 volatilization [14–17].

Based on the studies conducted by Agegnehu et al. [18] and Xin et al. [15], compost application at different crop phenological stages led to higher yields compared to chemical fertilization singly, suggesting more efficient nutrient uptake [19]. Biswas et al. [20] reported that the combined application of compost and N fertilizer elicited gradual nutrient release and enhanced soil biological activity, resulting in a higher wheat yield. Soil fertility is also affected by the significant interactions between soil and compost types [21].

Investigating the impact of different soils and fertilizers on industrial tomato production is of great significance for several reasons. Firstly, it can contribute to the development of sustainable agricultural practices improving soil health, minimizing environmental impact, and supporting long-term productivity. Secondly, it can provide valuable information for tomato growers, enabling them to make aware decisions regarding soil management and fertilizer application strategies.

The aim of this research was to assess the effect of compost on fruit yield and quality of industrial tomato plants grown in different soil types, such as dry residue, organic acids, color, antioxidant compounds, and activity.

2. Materials and Methods

2.1. General Methods

Research was conducted on the industrial tomato (*Solanum lycopersicum* L.) hybrid Coronel F_1 (ISI Sementi, Parma, Italy) at the experimental fields of the Department of Agricultural Sciences of Naples University 'Federico II' (40°49′11″ N, 14°20′28″ E) in 2019 and 2020.

The experimental setup was based on the factorial combination of three fertilization types (compost, compost + mineral 50/50 v, and mineral) and three soil textures (clayey, loamy, and sandy).

The crop nutritional requirements were calculated based on the 'Regional Fertilization Guide of Campania Region' [22].

The physicochemical characteristics of the compost applied were as follows: pH 7.70; humidity, 18.4%; organic carbon, 28.3% d.m.; humic and fulvic carbon, 12.1% d.m.; total N, 2.43% N d.m.; organic N, 94.54% total N; C-N ratio, 11.65; EC, 4.80 dS m^{-1}; Cd, <0.5 mg kg^{-1} d.m.; Cr VI < 0.5 mg kg^{-1} d.m.; Hg < 0.2 mg kg^{-1} d.m.; Ni, 7.5 mg kg^{-1} d.m.; Pb, 13.0 mg kg^{-1} d.m.; Cu, 54.2 mg kg^{-1} d.m.; Zn, 138.8 mg kg^{-1} d.m.; Na, 5471.0 mg kg^{-1} d.m.; available P (P_2O_5), 1.6% d.m.; available K (K_2O), 1.5% d.m.

The compost used in the present research derived from a process of transforming and stabilizing crop organic residues. The transformation process consisted of two stages: the bio-oxidation phase (aerobic and exothermic), characterized by a high rate of degradation achieved through the sanitization of the plant material at a high temperature, and the subsequent ripening or curing phase. In the second stage, to obtain mature compost, microbial consortia (e.g., fungi and actinomycetes) actively degraded starch, cellulose, and lignin.

Based on industrial tomato requirements, ten tons per hectare of compost, and a half dose when combined with mineral fertilizer, were prepared prior to transplant. At the same time, the treatment associated with 100% mineral fertilization consisted of 80 kg·ha^{-1} P_2O_5, 80 K_2O, and 60 N supplied in the form of mineral fertilizer, whereas the remaining 120 kg·ha^{-1} N was given through fertigation during the crops; half-doses were provided corresponding to the combined compost + mineral fertilization treatment. All the mentioned fertilizer amounts, either organic or mineral, were differently increased based on the soil texture: in loamy soil, 25% additional quantities of N, P_2O_5, and K_2O were applied; in sandy soil, 40% increases of the three macro-elements were applied; and in clayey soil, an additional 20% N and 30% P_2O_5 and K_2O were applied.

A randomized complete block design with three replications was used to distribute the treatments in the field, and each experimental unit had a 25 m^2 surface area. A random sample of 100 fruits was collected from 10 plants in each plot, 20 of which were immediately stored at −80 °C and subsequently used for qualitative analyses. The transplant was carried out on 10 and 11 May in 2019 and 2020, respectively, in double rows with a density of 3.2 plants per m^2 in soil mulched with a yellow photo-selective and photo-reflective sheet (Ginegar Plastic, Ginegar, Israel), 25 µm thick. Weekly irrigation was practiced until 10 days prior to the predicted fruit harvest.

Harvest was performed on 23–24 August when 80% of the fruits were ripe, and in each plot, the total number and weight of marketable fruits were measured, whereas the mean fruit weight was determined from 15 fruit samples.

2.2. Chemicals and Instruments

All reagents and standards were of analytical-reagent (AR) grade. L-ascorbic acid (L-AA) (>99.8%), Folin–Ciocalteu's phenol reagent 2N solution (for protein analysis), 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox) (>98%), 2,2-diphenyl-1-picrylhydrazyl (DPPH) (>95%), (+) catechin hydrate (>99%), metaphosphoric acid (MPA) (33.5–36.5%), gallic acid (>98%), sodium hydroxide (>98%), acetic acid (>99%), and ethylenediaminetetraacetic acid disodium salt (EDTA) (98%) were purchased from Sigma-Aldrich (St. Louis, MI, USA) MERCK KGaA affiliate (Darmstadt, Germany); sodium nitrite

(>97%) was from Honeywell Fluka (Seelze, Germany); sodium carbonate anhydrous (RPE), methanol (HPLC grade > 99.9%), n-esane (HPLC grade > 99.9%), and acetone (HPLC grade) were from Carlo Erba Reagents (Cornaredo (MI), Italy); aluminum chloride hexahydrate (99%) was from Titolchimica S.p.A (Pontecchio Polesine (RO), Italy); and butylated hydroxytoluene (BHT) (99%) was from AlfaAesar Thermo Fisher (Kandel, Germany). The color parameters were measured by a UV–Vis Varian Cary 100 Spectrophotometer (Varian Agilent, Santa Clara, CA, USA). The ultrapure water was supplied by an ion exchange system, Milli-Q, which was fed by a reverse-osmosis system, Elix 3, both from Millipore (Merck group, Darmstadt, Germany). A digital penetrometer (T.R. Turoni s.r.l., Forl, Italy) was used for fruit firmness; DBR 35 portable digital refractometer (Sinergica Soluzioni s.r.l., Pescara, Italy) was used to measure total soluble solids content. The acidity (pH value) was determined by a pH meter (MultiLine^{TM} F WTW^{TM}, Wilhelm, Germany) fitted with a WTW—Low-Maintenance SenTix^{TM} 41 pH electrode and a temperature sensor. A cflx-eztomato2 (Hunter Lab) was used to assess fruit color.

2.3. Determination of Physicochemical Parameters

2.3.1. Firmness

This measurement was taken on the two sides of the fruit at the equatorial zone using a digital penetrometer (T.R. Turoni s.r.l., Forl, Italy) with an 8 mm tip. Newtons (N) are used to denote the force used up to 4 mm penetration inside the fruit.

2.3.2. Total Soluble Solids (TSS)

The total soluble solids content (Brix) was determined by putting a fruit juice drop on the screen of a DBR 35 portable digital refractometer (Sinergica Soluzioni s.r.l., Pescara, Italy).

2.3.3. pH and Total Titratable Acidity (TTA)

TTA was determined using the AOAC-approved method [13] by titration with NaOH 0.1 N. The results are given as a percentage of citric acid.

2.3.4. Evaluation of Antioxidant Compounds and Antioxidant Activity

All analyses were carried out on homogeneous samples produced by the following method: Ten tomato fruits were washed in ultrapure water, dried, and stored in an −80 °C freezer. Frozen fruits were sliced with a ceramic blade knife and homogenized in a Grindomix GM300 Retsch knife mill (Haan, Germany). The resultant homogenate was split into sub-samples, preserved at 80 °C, and used for chemical analysis. Morra et al. [23] described in detail the procedures used to determine the content of ascorbic acid, carotenoids, total phenols (TP), total flavonoids, and antioxidant activity. The processes employed are reported below.

2.3.5. Ascorbic Acid

Ascorbic acid extraction (in duplicate for each sample) was carried out according to an AOAC Official Method [24] using a mixture consisting of 30 g L^{-1} metaphosphoric MPA, 80 mL L^{-1} acetic acid, and 1 mmol L^{-1} EDTA as extracting solution (10 mL for 3–4 g homogenate). The colorimetric determination was carried out by the Folin phenol reagent according to Jagota e Dani [25]; 400 µL sample was added with 200 µL of extraction solution, 1.2 mL of ultrapure water, and 200 mL of Folin–Ciocalteu's phenol reagent 2 N (diluted 1:5 with ultrapure water). After 30 min in the dark at room temperature, the absorbance of blue color was measured at 760 nm, quantified using six standard solutions of ascorbic acid (25–150 $\mu g \cdot mL^{-1}$ range), and estimated as above ($R^2 \geq 0.996$) in triplicate.

2.3.6. Lycopene

Lycopene, the major carotenoid in tomatoes, was extracted according to the method described by Periago et al. [26]. Several extractions with a 2:1:1 hexane/acetone/methanol mixture (by volume) are carried out until the tomato pulp is colorless. Special care is taken (use of dark glass vessels at room temperature) to avoid photo-oxidation phenomena. On the combined organic phases, lycopene is spectrophotometrically determined at 503 nm using the Lambert–Beer law ($\varepsilon_M = 17.2 \times 10^4$ M^{-1} cm^{-1}). A more accurate description of the procedure can be found in [23].

2.3.7. In Vitro Chemical Screening of Total Phenols, Total Flavonoids, and Antioxidant Activity

The extraction was performed using the procedure described by Kaur et al. [27] with minimal modifications and as accurately explained in a previous work [23]. Approximately 6 g of tomato fruits (in triplicate) were homogenized in 25 mL of an 80:20 CH_3OH/H_2O mixture and sonicated for 3 h at 40 °C into darkness in an ultrasonic bath (Elmasonic P Elma, Singen, Germany). After centrifugation at 10,000 rpm for 20 min at 4 °C, the top layer was removed and stored at −20 °C until the analyses were done.

The total phenolic content (in duplicate) was calculated using the Folin–Ciocalteu method [28] with minor adjustments [23]. In the tube test, 1 mL H_2O, 100 µL of tomato extract, and 100 µL of Folin–Ciocalteu's phenol reagent 2 N solution were added in sequence, and, after 10 min, 800 µL of Na_2CO_3 75 g/L solution was added so that the final pH was ≥10 (test final volume, 2 mL). After 120 min at room temperature and in darkness, the absorption was measured at 765 nm. The results are expressed as mg of gallic acid equivalent (GAE) per 100 mg of fresh weight (mg GAE 100 g^{-1} f.w.).

The total flavonoid content was measured using a spectrophotometric assay based on the production of aluminum chloride complexes, as published by Zhishen et al. [29], with modifications [23,30]. To make 5 mL, a known volume of tomato extract was poured in a 10 mL volumetric flask and ultrapure water was added. As a result, the following additions were made: 5 min later, 0.3 mL $NaNO_2$ (5% *w*/*v*) and 3 mL $AlCl_3$ (10% *w*/*v*), and 6 min later, 2 mL di NaOH 1 mol L^{-1}. With ultrapure water, the combination was raised to a final volume of 10 mL and left at room temperature for 15 min. The absorbance was then measured at 510 nm. The analyses were performed in duplicate, and the findings are reported as mg catechin equivalent (CE) per 100 g of fresh weight (mg CE 100 g^{-1} f.w.).

The antioxidant activity of the tomato extract was evaluated using the DPPH test, which is based on the antioxidant's ability to scavenge the stable radical DPPH [23,31,32]. A 3.9 mL aliquot of a 0.0634 mM DPPH solution in methanol was added to 0.1 mL of each extract and forcefully shaken. The absorbance of the combination at 515 nm changed, and the antiradical activity of the sample was determined by the proportion of DPPH left after the kinetics reached a steady state (after 150 min) [23]. Trolox equivalency was used as a standard for extract oxidant capacity.

As a result, the calibration curve was built with nine standard solutions containing this antioxidant (range 1.5–20 µM), and the results are represented as mol of Trolox equivalent per 100 g of fresh weight (µmol TE 100 g^{-1} f.w.).

2.4. Statistical Analyses

Data were processed by two-way analysis of variance, and mean separations were performed through Tukey's test, with reference to a 0.05 probability level, using SPSS software version 28. Data expressed as percentages were subjected to angular transformation before processing.

3. Results

No significant differences were recorded between the two research years referring to the variables examined, and therefore, only their average values are reported.

In Table 1, the main effects of the experimental factors applied on the variables examined are presented, whereas no significant interactions arose.

The highest fruit yield was achieved in the loamy soil (8.84 kg m^{-2}), compared to clayey and sandy soils (7.95 and 7.73 kg m^{-2}), respectively.

The loamy soil also showed higher numbers of rotten waste fruits and green waste fruits than the clayey soil, but not significantly different from the sandy soil.

In the loamy soil, the number of fruits per area was about 5% higher than that of both the clayey and sandy soils.

The average fruit weight provided by the loamy soil was 8.2% higher than that under sandy soil, with no significant differences compared to the clayey soil.

In our study, higher plant fresh and dry weights were recorded in the loamy soil, but this was not significant compared to the clay soil in terms of fresh weight.

In our study, the effect of the fertilizers applied led to significant differences in the tomato fruit yield: the highest production was achieved under the application of the mineral fertilizer, followed by the compost–mineral mixture and the compost, respectively. The mineral fertilizer resulted in a 1.12-fold higher yield than the compost–mineral fertilizer and a 1.60-fold higher yield than the application of compost alone.

The application of compost alone showed significantly lower values of rotten waste fruits, while there was no significant difference in the yield of green waste fruits. Despite the yield losses due to the rotten waste fruits, the marketable yield showed the same trend as the total yield, with the highest values corresponding to mineral fertilizer, followed by compost–mineral and compost.

In our study, we observed that the plants grown in loamy soil showed the highest average fresh weight, although it was not significantly different from that of the clayey soil, and dry weight.

The number of fruits per square meter was higher with the mineral fertilizer, by 35% and 16% compared to the compost and compost–mineral, respectively.

The average fruit weight reached the lowest values with the compost application, while there were no significant differences between the other two fertilizer types.

Mineral fertilization positively influenced plant fresh weight the most, followed by the compost–mineral mixture, whereas compost had the same effect on plant dry weight.

In Table 2, the main effects of the experimental treatments on the variables measured are shown, whereas no significant interactions arose. The loamy soil led to the highest titratable acidity and dry residue (°Brix) in tomato fruits, as well as a more intense red color.

No significant differences were recorded between the clayey and sandy soils for all the variables examined.

The soluble solids content was higher in the loamy soil than in the sandy one.

Color followed the same trend as the variables described above.

The application of compost fertilizer resulted in a higher dry residue level (°Brix) by 4% and 10% compared to the compost–mineral and mineral fertilizers, respectively. The fruit color reached higher levels with the compost and the compost–mineral mix, with no statistically significant differences between them.

In this study, a significant interaction arose between the applied experimental treatments regarding fruit dry matter (Figure 1). The highest fruit accumulation of dry matter was recorded under the loamy soil x compost interaction, whereas the lowest was recorded upon sandy soil x mineral fertilizer (−27% compared to the loamy soil x compost interaction).

In clayey soil, the amount of dry matter in the fruit remained unchanged, with no significant interaction with the fertilizer type. Figure 1 shows the dry matter drop with the decrease of compost supply both in loamy and sandy soils.

Regarding quality parameters, significant interactions arose between the experimental factors applied.

Table 1. Mean effects of fertilization type and soil texture on tomato yield and growth indices.

Experimental Factors	Total Yield ($kg \cdot m^{-2}$)	Waste Fruits (Rotten) ($kg \cdot m^{-2}$)	Waste Fruits (Green) ($kg \cdot m^{-2}$)	Marketable Yield ($kg \cdot m^{-2}$)	No. of Fruits per m^2	Mean Fruit Weight (g)	Plant Fresh Weight (g)	Plant Dry Weight (g)
Soil texture								
Clayey (Cl)	7.95 ± 1.55 b	0.12 ± 0.01 b	0.41 ± 0.04 b	7.42 ± 1.54 b	104.33 ± 13.86 b	70.54 ± 7.02 ab	1224.89 ± 106.47 ab	11.12 ± 0.99 b
Loamy (L)	8.84 ± 1.92 a	0.18 ± 0.05 a	0.54 ± 0.11 a	8.12 ± 1.82 a	109.56 ± 17.56 a	73.54 ± 7.21 a	1258.13 ± 113.7 a	11.8 ± 1.16 a
Sandy (S)	7.73 ± 1.53 b	0.15 ± 0.04 ab	0.49 ± 0.11 ab	7.09 ± 1.49 b	103.56 ± 12.69 b	67.95 ± 8.44 b	1204.98 ± 105.22 b	10.99 ± 1.07 b
Fertilization type								
Compost (Co)	6.08 ± 0.38 c	0.12 ± 0.02 b	0.45 ± 0.10	5.51 ± 0.34 c	89.89 ± 3.48 c	61.41 ± 4.13 b	1102.38 ± 0.00 c	12.48 ± 0.00 a
Compost + Mineral (C+M)	8.69 ± 0.65 b	0.16 ± 0.04 a	0.51 ± 0.12	8.02 ± 0.61 b	105.00 ± 5.36 b	76.37 ± 3.74 a	1241.06 ± 37.66 b	11.29 ± 0.47 b
Mineral (M)	9.75 ± 0.76 a	0.16 ± 0.05 a	0.49 ± 0.10	9.10 ± 0.66 a	122.56 ± 6.58 a	74.25 ± 3.4 a	1344.57 ± 30.51 a	10.14 ± 0.50 c
			n.s.					

n.s. not significant. Within each column, means followed by different letters are significantly different according to Tukey's test at $p \leq 0.05$. All data are expressed as mean ± standard deviation.

Table 2. Mean effects of fertilization type and soil texture on tomato carpometric indices.

Experimental Factors	Titratable Acidity (%)	pH	Dry Residue (°Brix)	Firmness ($kg \cdot cm^{-2}$)	Color a/b
Soil texture					
Clayey (Cl)	0.30 ± 0.02 b	4.13 ± 0.07	5.24 ± 0.24 b	0.71 ± 0.05	2.26 ± 0.14 b
Loamy (L)	0.33 ± 0.02 a	4.09 ± 0.08	5.39 ± 0.28 a	0.73 ± 0.05	2.34 ± 0.14 a
Sandy (S)	0.29 ± 0.01 b	4.14 ± 0.11	5.23 ± 0.22 b	0.7 ± 0.06	2.22 ± 0.13 b
		n.s.		n.s.	
Fertilization type					
Compost (Co)	0.31 ± 0.02	4.16 ± 0.11	5.53 ± 0.21 a	0.66 ± 0.03 b	2.32 ± 0.08 a
Compost + Mineral (C+M)	0.30 ± 0.02	4.12 ± 0.08	5.31 ± 0.08 b	0.74 ± 0.04 a	2.39 ± 0.06 a
Mineral (M)	0.31 ± 0.03	4.09 ± 0.06	5.02 ± 0.10 c	0.75 ± 0.02 a	2.11 ± 0.07 b
	n.s.	n.s.			

n.s. not significant. Within each column, means followed by different letters are significantly different according to Tukey's test at $p \leq 0.05$. All data are expressed as mean ± standard deviation.

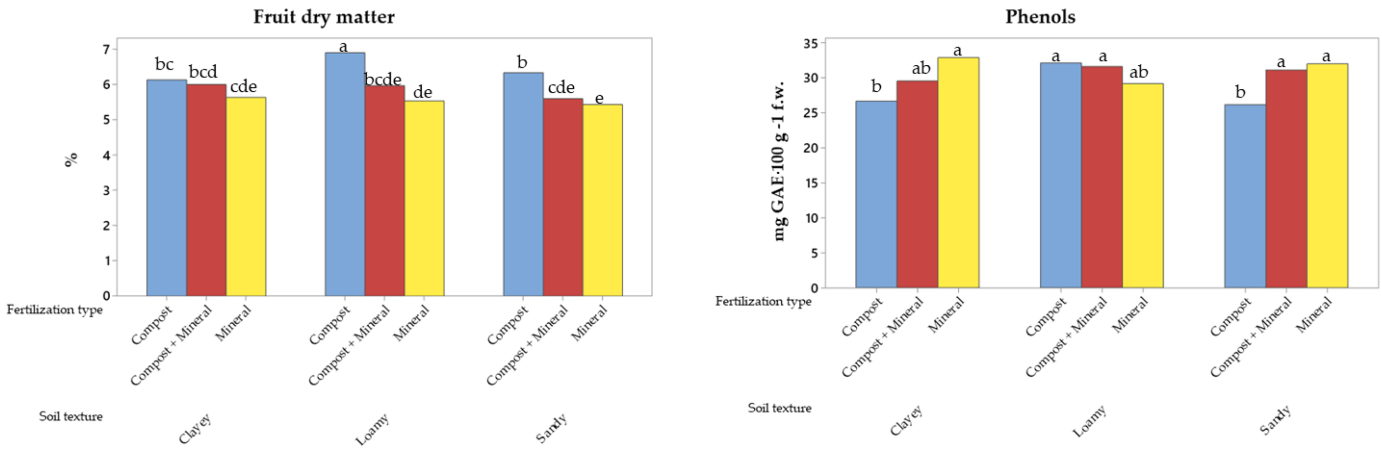

Figure 1. Interaction between fertilization type and soil texture on fruit dry matter and phenols. Different letters mean that the values are significantly different according to Tukey's test at $p \leq 0.05$.

Phenol concentrations in the tomato fruits were lower in the clayey soil x compost and sandy soil x compost, compared to those recorded in clayey soil x mineral, loamy soil x compost, loamy soil x compost + mineral, sandy soil x compost-mineral, and sandy soil x mineral (Figure 1).

The application of different types of fertilizers to loamy soil did not lead to statistical differences, which was different from the clayey and sandy soils where the fruit phenol content was positively affected by the treatments compost + mineral and mineral.

The flavonoids in tomato fruits were more abundant in the loamy soil fertilized with compost compared to the same fertilization in sandy soil (+50%). The two latter interactions did not significantly differ from the other ones regarding the concentration of these antioxidants (Figure 2).

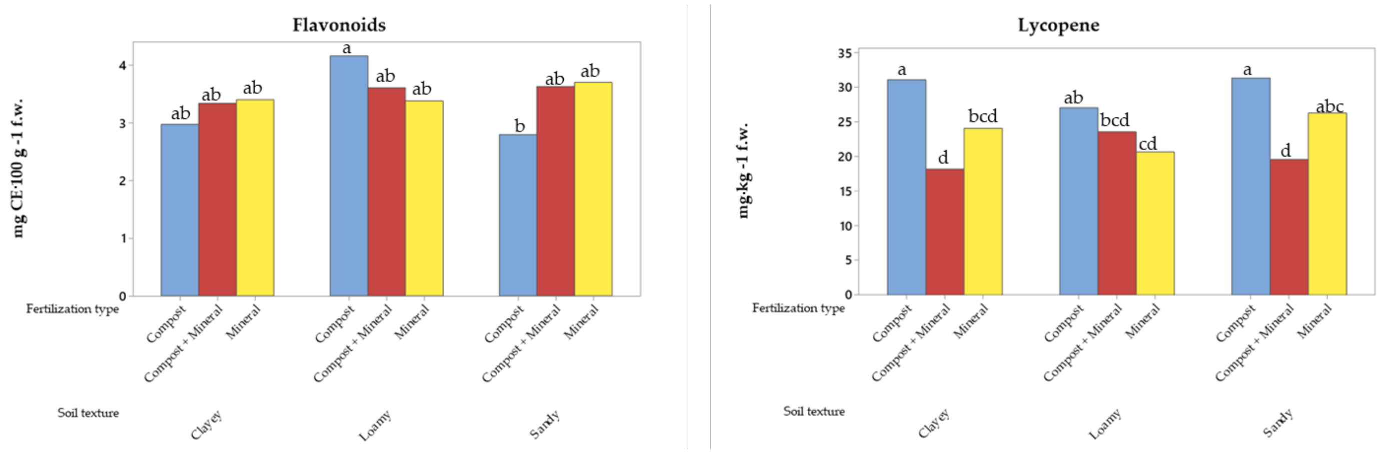

Figure 2. Interaction between fertilization type and soil texture on flavonoids and lycopene concentration. Different letters mean that the values are significantly different according to Tukey's test at $p \leq 0.05$.

As shown in Figure 2, the lycopene content in tomato fruits was better influenced by the clayey soil x compost and sandy soil x compost interactions, compared to those of the clayey soil x compost + mineral (+76%), clayey soil x mineral (+25%), loamy soil x compost + mineral (+26%), loamy soil x mineral (+50%), and sandy soil x compost + mineral (+58%). In the loamy soil, compost fertilization led to a higher lycopene content compared with that of mineral fertilization.

The antioxidant activity in tomato fruits was significantly higher in loamy soil with compost fertilization in comparison with both the clayey and sandy soils treated with compost + mineral fertilization; in addition, it was higher than that recorded for both the sandy and loamy soils minerally fertilized (Figure 3). In this study, the application of compost in different types of soil did not significantly affect the antioxidant activity in tomato fruits; instead, the application of compost + mineral led to higher antioxidant activity in loamy soil. Mineral fertilization led to a lower level of antioxidant activity in the loamy soil compared with that in the clayey one.

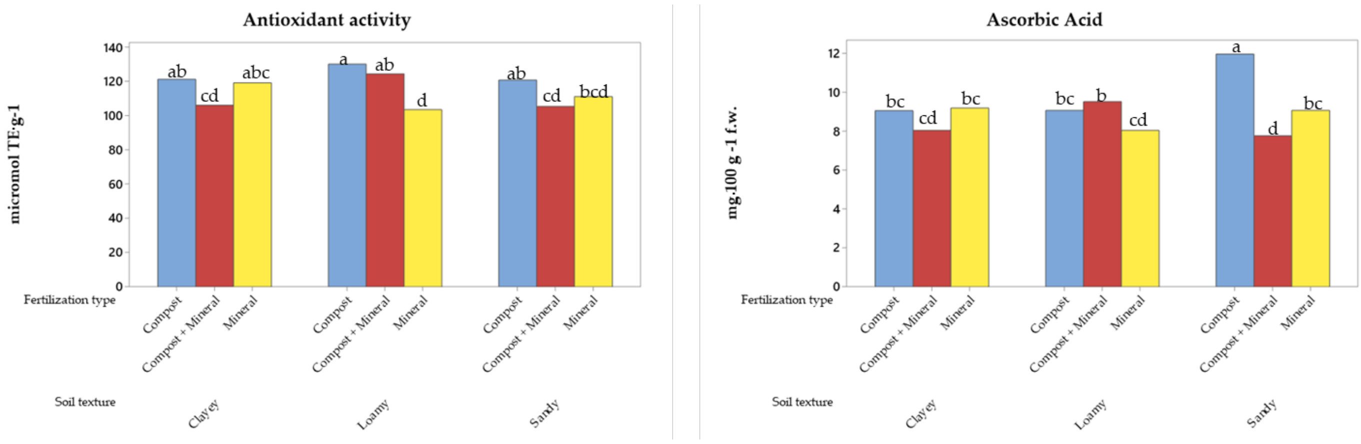

Figure 3. Interaction between fertilization type and soil texture on antioxidant activity and ascorbic acid. Different letters mean that the values are significantly different according to Tukey's test at $p \leq 0.05$.

Ascorbic acid content was positively affected by the sandy soil with compost fertilization, whereas the lowest accumulation was recorded under the sandy soil fertilized with compost + mineral, with no significant differences between the latter treatment and the clayey soil fertilized with compost + mineral and the loamy soil fertilized with mineral (Figure 3). The effect of compost application on ascorbic acid in tomato fruit was significantly higher when applied to sandy soil. The compost + mineral fertilization treatment best affected the ascorbic acid content in loamy soil compared with the other two textures. No differences arose between the soils with the application of mineral fertilization on the mentioned variables.

As can be seen in Figure 4, the principal component analysis showed how the dependent variables responded to the interactions between the experimental treatments applied (Eigenvalues in Table 3).

Specifically, for the first component, the cumulative variability indicated that the key factor was the fertilization type, with the compost, compost + mineral, and only mineral treatments progressing from negative to positive values. For the second component, the variability was primarily associated with soil type.

On the upper left of the graph, variables such as pH, ascorbic acid, and lycopene were higher under compost supply in the sandy and clayey soils.

On the lower left, the compost fertilization associated with the loamy soil enhanced fruit antioxidant activity, dry weight and dry residue, and plant dry matter.

In the lower right-hand quadrant, the expressed variability shows that the mineral fertilizer in the loamy soil led to a higher accumulation of titratable acidity, plant dry weight, flavonoids, and phenols; higher number of rotten fruits and green fruits; and a higher average fruit weight and firmness.

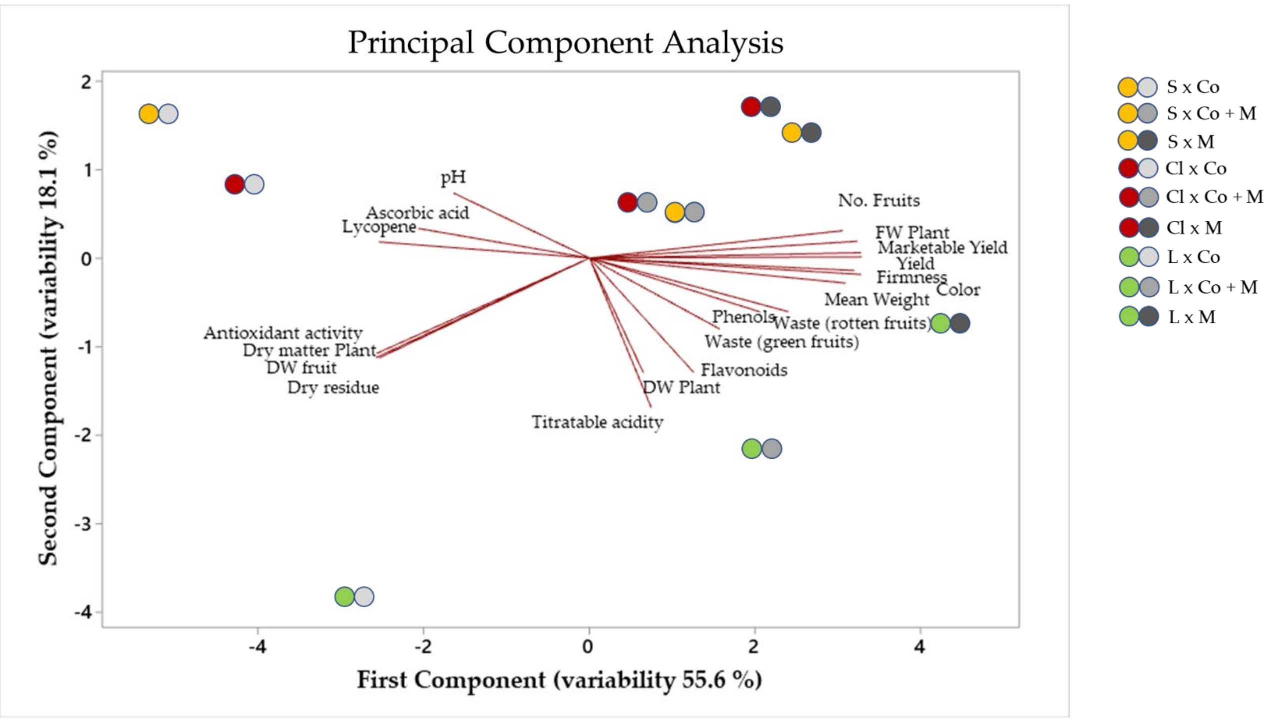

Figure 4. Principal component analysis (PCA). S x Co: Sandy x Compost; S x Co + M: Sandy x Compost + Mineral; S x M: Sandy x Mineral; Cl x Co: Clayey x Compost; Cl x Co + M: Clayey x compost + Mineral; Cl x M: Clayey x Mineral; L x Co: Loamy x Compost; L x Co + M: Loamy x Compost + Mineral; L x M: Loamy x Mineral; FW: fresh weight; DW: dry weight.

Table 3. Eigenvalues and percentage of variance values and factor loadings generated by PCA.

	PC1	PC2
Eigenvalue	11.128	3.606
Variability (%)	55.6	18.1
Cumulative %	55.6	73.7
Flavonoids	0.113	−0.359
Lycopene	−0.228	0.050
Antioxidant activity	−0.176	−0.237
Ascorbic acid	−0.186	0.093
Titratable acidity	0.059	−0.360
pH	−0.147	0.204
Yield	0.295	0.004
Waste fruits (rotten)	0.216	−0.168
Waste fruits (green)	0.141	−0.223
Marketable yield	0.295	0.017
No. of fruits	0.275	0.086
Fruit mean weight	0.278	−0.079
Fruit dry weight	−0.231	−0.299
Dry residue	−0.228	−0.314
Firmness	0.287	−0.039
Color	0.295	−0.051
Plant fresh weight	0.290	0.053
Plant dry weight	0.067	−0.469
Plant dry matter	−0.231	−0.312

4. Discussion

In recent decades, there has been an increasing global concern regarding environmental and soil health. Consequently, modern agricultural practices are being aimed to minimize soil depletion and preserve its fertility and structure, avoiding the excessive use of synthetic fertilizers [10]. Among the agronomic techniques under current development, prominence is being gained by the utilization of compost, which derives from numerous matrices and is produced by a wide range of techniques [10]. A comprehensive review conducted by Zhou et al. [33] elucidated the varying interactions between composts, obtained from different matrices or through distinct techniques, with field crops due to the diverse soil factors, e.g., the microbial community, pH, aeration, water content, nutrient availability, and carbon/nitrogen ratio. A study conducted by Duong et al. [21] demonstrated that various types of compost exhibit distinct effects on soil, particularly in terms of its aggregates and microbial flora, enhancing its suitability for plant growth. In this study, significant interactions between soil texture and fertilization type were observed only for qualitative variables. The yield and fruit number were higher in the loamy soil, probably due to the plants' better utilization of both water and nutrients, particularly nitrogen [34]. This statement is supported by the higher mean fresh weight and dry weight of the plants grown in the loamy soil, resulting in increased water content in the fresh weight and a higher concentration of organic and inorganic molecules in the dry weight, respectively [35]. The number of (rotten) waste fruits could have been due to the lower water availability in loamy soil. Compared to other soil types, clayey soils often have higher potassium levels, thus increasing the availability of this element [36], which generally relates to a decreased amount of waste (green) fruits that are unfit for the tomato market. Some studies have demonstrated that specific compost types can exert significant impacts on crop performance after a long period [37,38], contingent upon the composition of the compost matrix [39,40]. In the present investigation, the compost did not exhibit any positive effects on the yield and growth parameters, except for an enhancement of the plant dry weight. In the study conducted by Mardanluo et al. [41], a positive correlation was observed between soil phosphorus (P) content, titratable acidity, and dry residue in the fruit. The stability of the red color is expressed through the a/b ratio, which is the ratio between the relative intensities of the red (lycopene) and yellow (carotene) pigments; the higher this ratio, the better the quality of the processed product [42]. The loamy soil presumably favored a better ratio between lycopene and carotenoid accumulation in the fruit. The higher dry matter and lower fruit firmness observed upon compost application, compared with mineral fertilization, are probably associated to a gradual and prolonged nutrient release. The compost and compost + mineral treatments supposedly enhanced the biosynthesis of lycopene and carotenoids, thereby contributing to an improved a/b ratio of the fruit color. A study conducted by Wu et al. [7] demonstrated the effect of compost as well as organic and inorganic fertilizers on soil parameters, such as pH levels and microbial flora activity. The vital processes of the microbial flora play a significant role in facilitating the availability of numerous nutrients for plant growth. Wu et al. [7] further affirmed that incorporating compost into the soil not only improved hydraulic conditions but also the exchange of cations and air within the soil (interstitial spaces between soil aggregates). In our study, we recorded a significant interaction between different types of fertilizers and soils on these variables: fruit dry matter, phenols, flavonoids, lycopene, antioxidant activity, and ascorbic acid in tomato fruit. Ruiz-Nieves [43] postulated that the accumulation of dry matter in tomato fruits may be associated with the water availability for plant synthesis of substances contributing to an increase in dry matter content. In our study, we found that the highest accumulation of dry matter was observed in the loamy soil with compost incorporation, presumably encouraged by better conditions for nutrient and water availability compared to the other treatments. The precursors of phenols in tomato include glucose, fructose, and other sugars present in the plant, which are converted into phenols through a series of enzymatic reactions during fruit ripening [44]. Specifically, the enzyme phenylalanine ammonia-lyase (PAL) catalyzes the conversion of the amino acid phenylalanine into cinnamic acid, which in turn serves as a precursor for the synthesis of many phenols in tomato. Subsequently, other enzymes such as cinnamate 4-hydroxylase (C4H) and 4-coumarate:coenzyme A ligase (4CL) convert cinnamic acid into phenolic compounds such as p-coumaric acid, caffeic acid, and ferulic acid [44]. These phenolic compounds are responsible for the antioxidant properties and health benefits associated with tomato consumption. In our study, the accumulation of sugars, which subsequently led to phenol increase, was associated to a well-balanced condition of mineral elements (e.g., N, P, and K) in the following treatments: compost applied to loamy soil and mineral fertilizer applied to clayey and sandy soils. A study conducted by Alhaithloul et al. [45] established a connection between the content and characterization of phenols in tomato fruit and thermal conditions. It is likely that in our study, the increased accumulation of phenols can be attributed to more favorable soil thermal conditions in the loamy + compost treatment compared to those of sandy + compost treatment. In our study, the compost treatment application to clayey and sandy soils probably facilitated the assimilation of potassium, which contributed to a quicker fruit-ripening process that subsequently led to an increase in lycopene [46] content compared to that of fruits not fully ripe, except in the case of the mineral and soil treatment. In our study, the compost treatment application to clayey and sandy soils probably made the assimilation of potassium easier, which contributed to a quicker fruit-ripening process, subsequently resulting in an increase in lycopene [46] content compared to that of fruits not fully ripe, except in the case of the mineral and soil treatment. In our study, the antioxidant activity predominantly correlates with the pattern observed for lycopene, suggesting that lycopene is likely to be the main contributor to this parameter. Ascorbic acid is synthesized from specific precursors in tomato, including D-glucose and D-glucuronate, which are converted into ascorbic acid through a series of enzymatic reactions. Both precursors are transformed into ascorbic acid through a series of metabolic reactions involving enzymes such as D-glucose-6-phosphate dehydrogenase and L-galactone-1,4-lactone dehydrogenase [47]. In the present research, these precursors probably benefited from the availability of nutrients in the compost + sandy soil interaction.

5. Conclusions

From research conducted in southern Italy, it arose that the application of plant-based compost elicited diverse responses in terms of the qualitative variables of industrial tomato fruit, depending on the soil texture. When incorporated into loamy soil, the compost led to a higher dry matter and phenol content in the fruit, compared to compost incorporation into clayey and sandy soils. The antioxidant activity of the tomato fruit was higher when compost was added to loamy soil compared to the same soil supplied only with mineral fertilizer. The highest content of ascorbic acid was achieved with the addition of compost to sandy soil.

In conclusion, this study highlighted significant interactions between fertilization type and soil texture on the qualitative variables of industrial tomato fruit, with a positive influence of compost, indicating the interesting prospects of its application to crop systems as a sustainable agronomic strategy. Future investigations of further tomato aspects would be beneficial to support the present findings.

Author Contributions: Conceptualization, E.C., A.S. and G.C.; methodology, A.S., L.d.P. and A.C. (Antonietta Cerbone); software, A.V.T. and V.C.; validation, E.C., A.V.T. and G.C.; formal analysis, A.S. and A.C. (Antonietta Cerbone); investigation, A.C. (Antonio Cuciniello), L.d.P. and P.L.; resources, E.C.; data curation, L.d.P. and A.V.T.; writing—original draft preparation, E.C. and A.V.T.; writing—review and editing, A.V.T. and G.C.; visualization, A.S.; supervision, A.S. and G.C.; project administration, E.C.; funding acquisition, E.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Available online: https://www.fao.org/faostat/en/#home (accessed on 1 February 2019).
2. De Sio, F.; Rapacciuolo, M.; De Giorgi, A.; Sandei, L.; Giuliano, B.; Tallarita, A.; Golubkina, N.; Sekara, A.; Stoleru, V.; Cuciniello, A.; et al. Industrial processing affects product yield and quality of diced tomato. *Agriculture* **2021**, *11*, 230. [CrossRef]
3. Sofo, A.; Zanella, A.; Ponge, J.F. Soil quality and fertility in sustainable agriculture, with a contribution to the biological classification of agricultural soils. *Soil Use Manag.* **2022**, *38*, 1085–1112. [CrossRef]
4. Babi, K.; Guittonny, M.; Bussière, B.; Larocque, G.R. Effect of soil quality and planting material on the root architecture and the root anchorage of young hybrid poplar plantations on waste rock slopes. *Int. J. Min. Reclam. Environ.* **2022**, *37*, 1–20. [CrossRef]
5. Sokol, N.W.; Slessarev, E.; Marschmann, G.L.; Nicolas, A.; Blazewicz, S.J.; Brodie, E.L.; Firestone, M.K.; Foley, M.M.; Hestrin, R.; Hungate, A.; et al. Life, and death in the soil microbiome: How ecological processes influence biogeochemistry. *Nat. Rev. Microbiol.* **2022**, *20*, 415–430. [CrossRef]
6. Pahalvi, H.N.; Rafiya, L.; Rashid, S.; Nisar, B.; Kamili, A.N. 2021 Chemical fertilizers and their impact on soil health. In *Microbiota and Biofertilizers, Vol 2: Ecofriendly Tools for Reclamation of Degraded Soil Environs*; Springer: Berlin/Heidelberg, Germany, 2021; pp. 1–20.
7. Wu, W.; Lin, Z.; Zhu, X.; Li, G.; Zhang, W.; Chen, Y.; Ren, L.; Lou, S.; Lin, H.; Zhou, H.; et al. Improved tomato yield and quality by altering soil physicochemical properties and nitrification processes in the combined use of organic-inorganic fertilizers. *Eur. J. Soil Biol.* **2022**, *109*, 103384. [CrossRef]
8. Baligar, V.C.; Fageria, N.K.; He, Z.L. Nutrient use efficiency in plants. *Commun. Soil Sci. Plant Anal.* **2001**, *32*, 921–950. [CrossRef]
9. Fixen, P.; Brentrup, F.; Bruulsema, T.; Garcia, F.; Norton, R.; Zingore, S. Nutrient/fertilizer use efficiency: Measurement, current situation and trends. *Manag. Water Fertil. Sustain. Agric. Intensif.* **2015**, *270*, 1–30.
10. Oyetunji, O.; Bolan, N.; Hancock, G. A comprehensive review on enhancing nutrient use efficiency and productivity of broadacre (arable) crops with the combined utilization of compost and fertilizers. *J. Environ. Manag.* **2022**, *317*, 115395. [CrossRef]
11. Abbasi, P.A.; Al-Dahmani, J.; Sahin, F.; Hoitink, H.A.J.; Miller, S.A. Effect of compost amendments on disease severity and yield of tomato in conventional and organic production systems. *Plant Dis.* **2002**, *86*, 156–161. [CrossRef]
12. Singh, R.; Singh, G.S. Traditional agriculture: A climate-smart approach for sustainable food production. *Energy Ecol.* **2017**, *2*, 296–316. [CrossRef]
13. Harindintwali, J.D.; Zhou, J.; Muhoza, B.; Wang, F.; Herzberger, A.; Yu, X. Integrated eco-strategies towards sustainable carbon and nitrogen cycling in agriculture. *J. Environ. Manag.* **2021**, *293*, 112856. [CrossRef] [PubMed]
14. Cai, A.; Xu, H.; Shao, X.; Zhu, P.; Zhang, W.; Xu, M.; Murphy, V.D. Carbon and Nitrogen Mineralization in Relation to Soil Particle-Size Fractions after 32 Years of Chemical and Manure Application in a Continuous Maize Cropping System. *PLoS ONE* **2016**, *11*, e0152521. [CrossRef] [PubMed]
15. Xin, X.; Qin, S.; Zhang, J.; Zhu, A.; Yang, W.; Zhang, X. Yield, phosphorus use efficiency and balance response to substituting long-term chemical fertilizer use with organic manure in a wheat-maize system. *Field Crops Res.* **2017**, *208*, 27–33. [CrossRef]
16. Guangbin, Z.; Kaifu, S.; Xi, M.; Qiong, H.; Jing, M.; Hua, G.; Hua, X. Nitrous oxide emissions, ammonia volatilization, and grain-heavy metal levels during the wheat season: Effect of partial organic substitution for chemical fertilizer. *Agric. Ecosyst. Environ.* **2021**, *311*, 107340. [CrossRef]
17. Agegnehu, G.; Bass, A.M.; Nelson, P.N.; Bird, M.I. Benefits of biochar, compost and biochar–compost for soil quality, maize yield and greenhouse gas emissions in a tropical agricultural soil. *Sci. Total Environ.* **2016**, *543*, 295–306. [CrossRef]
18. Agegnehu, G.; Nelson, P.N.; Bird, M.I. The effects of biochar, compost and their mixture and nitrogen fertilizer on yield and nitrogen use efficiency of barley grown on a Nitisol in the highlands of Ethiopia. *Sci. Total Environ.* **2016**, *569–570*, 869–879. [CrossRef]
19. Amanullah, I.; Al Al Tawaha, A.R.M. Efficacy of pre and post emergence herbicides alone and in combination for effective weeds control without effecting growth and development of maize (*Zea mays* L.). *Russ. Agric. Sci.* **2021**, *47*, 261–269.
20. Biswas, S.S.; Ghosh, A.; Singhal, S.K.; Biswas, D.R.; Roy, T.; Sarkar, A.; Das, D. Phosphorus enriched organic amendments can increase nitrogen use efficiency in wheat. *Commun. Soil Sci. Plant Anal.* **2019**, *50*, 1178–1191. [CrossRef]
21. Duong, T.T.T.; Penfold, C.; Marschner, P. Amending soils of different texture with six compost types: Impact on soil nutrient availability, plant growth and nutrient uptake. *Plant Soil* **2012**, *354*, 197–209. [CrossRef]
22. Available online: http://www.agricoltura.regione.campania.it/concimazione/PRCFA_intro.html (accessed on 22 May 2023).
23. AOAC International. *Official Methods of Analysis of AOAC International*, 17th ed.; AOAC International: Washington, DC, USA, 2002; method 967.21.
24. Morra, L.; Cozzolino, E.; Salluzzo, A.; Modestia, F.; Bilotto, M.; Baiano, S.; del Piano, L. Plant Growth, Yeld and Fruit Quality of Processing Tomato (*Solanum lycopersicon* L.) as affected by the Combination of biodegradable mulching and digestate. *Agronomy* **2021**, *11*, 100. [CrossRef]
25. Jagota, S.K.; Dani, H.M. A new Colorimetric Technique for the estimation of vitamin C using Folin Phenol Reagent. *Anal. Biochem.* **1982**, *127*, 178–182. [CrossRef]
26. Periago, M.J.; Rincon, F.; Aguera, M.D.; Ros, G. Mixture approach for optimizing lycopene extraction from tomato and tomato products. *J. Agric. Food Chem.* **2004**, *52*, 5796–5802. [CrossRef] [PubMed]

27. Kaur, C.; Walia, S.; Nagal, S.; Walia, S.; Singh, J.; Singh, B.B.; Saha, S.; Dingh, B.; Kalia, P.; Jaggi, S.; et al. Functional quality and antioxidant composition of selected tomato (*Solanum lycopersicon* L.) cultivars grown in Northern India. *Food Sci. Technol.* **2013**, *50*, 139–145. [CrossRef]
28. Singleton, V.L.; Rossi, J.A. Colorimetry of total phenolics with phosphomolybdic-phosphotungstic-acid reagents. *Am. J. Enol. Vitic.* **1965**, *16*, 144–158. [CrossRef]
29. Zhishen, J.; Mengcheng, T.; Jianming, W. The determination of flavonoid contents in mulberry and theirscavenging effects on superoxide radicals. *Food Chem.* **1999**, *64*, 555–559. [CrossRef]
30. Pekal, A.; Pyrzynska, K. Evaluation of aluminium complexation for Flavonoid content assay. *Food Anal. Methods* **2014**, *7*, 1776–1782. [CrossRef]
31. Brand-Williams, W.; Cuvelier, M.E.; Berset, C. Use of a free radical method to evaluate antioxidant activity. *J. Food Sci. Technol.* **1995**, *28*, 25–30. [CrossRef]
32. Ozcelik, J.H.; Lee, J.H.; Min, D.B. Effects of light, oxygen and pH on the adsorbance of 2,2-Diphenyl-1-picrilhydrazyl. *J. Food Sci.* **2003**, *68*, 487–490. [CrossRef]
33. Zhou, Y.; Xiao, R.; Klammsteiner, T.; Kong, X.; Yan, B.; Mihai, F.C.; Zhang, Z.; Awasthi, M.K. Recent trends and advances in composting and vermicomposting technologies: A review. *Bioresour. Technol.* **2022**, *360*, 127591. [CrossRef]
34. Ouansafi, S.; Abdelilah, F.; Kabine, M.; Maaghloud, H.; Bellali, F.; El Bouqdaoui, K. The effects of soil proprieties on the yield and the growth of tomato plants and fruits irrigated by treated wastewater. *AIMS Agric. Food* **2019**, *4*, 921–938. [CrossRef]
35. Sorgonà, A.; Abenavoli, M.R.; Cacco, G.; Gelsomino, A. Growth of tomato and zucchini seedlings in orange waste compost media: pH and implication of dosage. *Compost. Sci. Util.* **2011**, *19*, 189–196. [CrossRef]
36. Ddamulira, G.; Idd, R.; Namazzi, S.; Kalali, F.; Mundingotto, J.; Maphosa, M. Nitrogen and potassium fertilizers increase cherry tomato height and yield. *J. Agric. Sci.* **2019**, *11*, 1916–9760. [CrossRef]
37. Kavvadias, V.; Ioannou, Z.; Vavoulidou, E.; Paschalidis, C. Short Term Effects of Chemical Fertilizer, Compost and Zeolite on Yield of Lettuce, Nutrient Composition and Soil Properties. *Agriculture* **2023**, *13*, 1022. [CrossRef]
38. Zhao, X.; Li, B.; Ni, J.; Xie, D. Effect of four crop straws on transformation of organic matter during sewage sludge composting. *J. Integr. Agric.* **2016**, *15*, 232–240. [CrossRef]
39. Sánchez-Monedero, M.A.; Cayuela, M.L.; Sánchez-García, M.; Vandecasteele, B.; D'Hose, T.; López, G.; Mondini, C. Agronomic evaluation of biochar, compost and biochar-blended compost across different cropping systems: Perspective from the European project FERTIPLUS. *Agronomy* **2019**, *9*, 225. [CrossRef]
40. Sayara, T.; Basheer-Salimia, R.; Hawamde, F.; Sánchez, A. Recycling of organic wastes through composting: Process performance and compost application in agriculture. *Agronomy* **2020**, *10*, 1838. [CrossRef]
41. Mardanluo, S.; Souri, M.K.; Ahmadi, M. Plant growth and fruit quality of two pepper cultivars under different potassium levels of nutrient solutions. *J. Plant Nutr.* **2018**, *41*, 1604–1614. [CrossRef]
42. Oke, M.; Ahn, T.; Schofield, A.; Paliyath, G. Effects of phosphorus fertilizer supplementation on processing quality and functional food ingredients in tomato. *J. Agric. Food chem.* **2005**, *53*, 1531–1538. [CrossRef]
43. Ruiz-Nieves, J.M.; Ayala-Garay, O.J.; Serra, V.; Dumont, D.; Vercambre, G.; Génard, M.; Gautier, H. The effects of diurnal temperature rise on tomato fruit quality. Can the management of the greenhouse climate mitigate such effects? *Sci. Hortic.* **2021**, *278*, 109836. [CrossRef]
44. Campos, M.T.; Maia, L.F.; Dos Santos, H.F.; Edwards, H.G.; de Oliveira, L.F. Revealing the chemical synergism in coloring tomatoes by Raman spectroscopy. *J. Raman Spectrosc.* **2022**. [CrossRef]
45. Alhaithloul, H.A.; Galal, F.H.; Seufi, A.M. Effect of extreme temperature changes on phenolic, flavonoid contents and antioxidant activity of tomato seedlings (*Solanum lycopersicum* L.). *PeerJ* **2021**, *9*, e11193. [CrossRef] [PubMed]
46. Vasileva, V.H.; Dinev, N.S. Mineral content and quality parameters of tomato fruits as affected by different potassium fertilization treatments and cultivar specifics. Indian J. *Agric. Res.* **2021**, *55*, 169–174.
47. Zheng, X.; Gong, M.; Zhang, Q.; Tan, H.; Li, L.; Tang, Y.; Deng, W. Metabolism and regulation of ascorbic acid in fruits. *Plants* **2022**, *11*, 1602. [CrossRef] [PubMed]