agronomy

MDPI

Article

Evaluation of Processing Tomato Pomace after Composting on Soil Properties, Yield, and Quality of Processing Tomato in Greece

Ioanna Kakabouki [1,*], Antigolena Folina [1], Aspasia Efthimiadou [2], Stella Karydogianni [1], Charikleia Zisi [1], Varvara Kouneli [1], Nikolaos C. Kapsalis [3], Nikolaos Katsenios [2] and Ilias Travlos [1]

[1] Laboratory of Agronomy, Department of Crop Science, Agricultural University of Athens, 11855 Athens, Greece; folinanti@gmail.com (A.F.); stella.karidogianni@hotmail.com (S.K.); xarikleiazisi@gmail.com (C.Z.); kounelivarvara@gmail.com (V.K.); travlos@aua.gr (I.T.)
[2] Institute of Soil and Water Resources, Department of Soil Science of Athens, Hellenic Agricultural Organization DEMETER, Sofokli Venizelou 1, 14123 Lykovrissi, Greece; sissyefthimiadou@gmail.com (A.E.); nkatsenios@gmail.com (N.K.)
[3] KYKNOS S.A. Greek Canning Company, Pyrgos, 27200 Savalia, Greece; nikolas.kapsalis@gmail.com
* Correspondence: i.kakabouki@gmail.com

Abstract: While processing tomato cultivation (*Solanum lycopersicum* L.) is considered one of the most important industrial crops in Greece, a waste known as tomato pomace is growing significantly high. Notably, the tomato pomace presents enormous opportunities for the creations of organic fertilizers. The aim of this study was to investigate the use of tomato pomace as a fertilizer in the same crop. A field experiment was established at the Agricultural University of Athens during 2018 and 2019 in a randomized complete design with five treatments (control, inorganic NPK (NPK), Tomato pomace and Biocycle Humus Soil (Tp and BHS), Tomato pomace and Farmyard manure (Tp and FYM), and Tomato pomace and Compost (Tp and CM). Physical soil properties such as soil porosity and penetration resistance were improved by the application of organic blends. Additionally, soil nitrogen content ranged from 0.10% (control and NPK) to 0.13% (Tp and FYM). A significant increase of yield was noticed under organic fertilization where the highest yield of 8.00 tn ha^{-1} was recorded in Tp and BHS (2018). Lycopene content was significantly affected by fertilization and its highest values were 87.25 (Tp and BHS; 2018), and 88.82 mg kg^{-1} fresh (Tp and FYM; 2019). Regarding fruit firmness, the three organic blends did not have statistically significant difference. In addition, the Total Soluble Solids (TSS) was significantly affected by the fertilization and the maximum value was 4.80 oBrix (Tp and CM; 2018). In brief, tomato pomace blended with organic fertilizers was yielded considerable since it improved soil quality and increased yield.

Keywords: processing tomato pomace; soil properties; fertilization; processing tomato; lycopene

Citation: Kakabouki, I.; Folina, A.; Efthimiadou, A.; Karydogianni, S.; Zisi, C.; Kouneli, V.; Kapsalis, N.C.; Katsenios, N.; Travlos, I. Evaluation of Processing Tomato Pomace after Composting on Soil Properties, Yield, and Quality of Processing Tomato in Greece. *Agronomy* **2021**, *11*, 88. https://doi.org/10.3390/agronomy11010088

Received: 13 December 2020
Accepted: 31 December 2020
Published: 5 January 2021

1. Introduction

The tomato (*Solanum lycopersicum* L.) is one of the most significant vegetables worldwide, as it ranks second in production and consumption after potatoes, and has been conceded for its various health benefits, being rich in carotenoids (lutein, lycopene), vitamin C, antioxidants, potassium, and low in cholesterol [1–4]. There are two categories of tomato cultivation; the fresh consumption and the processing tomato cultivation, which is about converting the tomatoes into various other products besides using it as a vegetable (tomato juice, paste, purée, ketchup, sauce, and salsa). The preliminary 2020 total Association Méditeranéenne International de la Tomate—Mediterranean International Association of the Processing Tomato (AMITOM) countries production is at 17.46 million tons, while specifically in Greece the final volume is 430,000 tones [5]. Tomato crops are one of the most demanding crops in terms of water and fertilizer [6]. Especially, nitrogen fertilization plays an important role in plant growth, photosynthesis, and quality of the fruits, while the overall uptake is around 300 kg N ha^{-1} [7]. Nevertheless, the growing density of population and food demands have led to the excessive and widespread application of fertilizers use to meet the need of people [8].

This has led to huge and irreversible environmental impacts and undesirable consequences of degradation in soil, water, and air quality. Soil acidification and nitrous oxide (N_2O) emissions are accountable for global warming and nitrogen groundwater leaching. Furthermore, ammonia based- nitrogen fertilizers have provoked soil acidity and infertility, while health problems have occurred due to groundwater contamination of nitrate- nitrogen [9]. In addition, Zisi et al. (2020) showed that ammonia-based fertilizers have a negative impact on the ecosystem, as they caused mortality in earthworms, which are bio-indicators [10]. Therefore, it is necessary the reduction of soil N losses by increasing N-use efficiency and enhance soil N storage.

On the other hand, because of the huge increase of food production, a major issue regarding the accumulation, handling, and disposal of processing waste that have negatives environmental impacts has been created. About 250 million tons of byproducts and waste are produced per year, while 30 to 50% of those come from fruit and vegetables [11].

The use of processing tomato waste as an organic fertilizer can be an alternative and sustainable solution of all the mentioned issues. Specifically, massive amounts of tomato byproducts are created, which are known as tomato pomace [12]. Pomace consists primarily of skins, pulp and seeds that remain after the fruit has been disrupted and pressed, while it constitutes 4% of the fruit weight. Due to high levels of carbohydrates (25–50%), pomace is an assumed source of beneficial micro-organisms growth in soil [13]. Protein content varies between 15.4 to 23.7%, total fats 5.4 to 20.5% and mineral content range between 4.4 to 6.8% [12]. Tomato pomace leftovers can be used as animal feed due to its ingredients, as mentioned above, especially in poultry.

Continuous cropping without rotations, the large use of inorganic fertilizers, and non-selective pesticides are responsible for the soil quality loss. Soil quality and soil organic matter are interrelated characteristics, so the high level of organic matter in processing tomato pomace compost is going to stimulate the soil quality and improve the plant growing conditions. Soil compost amendments are beneficial in many ways as they contain a full spectrum of essential plant nutrients, release the nutrients slowly, adjust pH levels to the optimum range for nutrient availability to plants, increase the microbial activity and biodiversity and enhance the root system [14]. Processing tomato pomace can represent the source of organic matter that will be composted and returned to soil. According to the literature, there were ideas to direct integration of processing tomato pomace into soil, but it failed in controlling nematode *Meloidogyne incognita* infestation [15]. An effective sanitation of processing tomato wastes is mandatory, it suppresses pathogens and stabilizes organic matter because of the higher temperatures and the growth of aerobic microorganisms [16,17]. Additionally, from a recent study we carried out in Greece, we used the leftovers of tomato pomace as fertilizer in sweet maize cultivation, where its use showed positive results in plant growth [18]. Therefore, they could be used as fertilizer in other crops as well.

This may be the key to take advantage of the huge masses of waste organic matter of processing tomato and minimize the above-mentioned environmental issues, as well as to diminish the degradation in soil, water, and air quality. The objective of this study was to evaluate the influence of processing tomato pomace composts in the soil properties and in tomato crop yield and quality characteristics in typical clay-loam Mediterranean soil.

2. Materials and Methods

2.1. Experimental Design

A field experiment with processing tomato (*Solanum lycopersicum* Mill. 'Heinz 3402' F1) cultivation was undertaken in two crop seasons of 2018 and 2019, from May until August, at the Agricultural University of Athens, located at latitude 37°59′1.70″ N, longitude: 23°42′7.04″ E and altitude: 29 m above sea level. The experiment was settled on clay loam soil (with the following characteristics: 29.8% clay, 34.3% silt, and 35.9% sand), while the main soil physic-chemical properties were pH 7.29 (1:1 H_2O), organic matter 1.47%. It was abundant in potassium (K) 201 mg kg^{-1} soil, it had total available phosphorus (P) of 13.2 mg kg^{-1} soil, total available nitrate-nitrogen (NO_3 -N) of 12.4 mg kg $^{-1}$ soil and the $CaCO_3$ percentage was 15.99% [19]. All field, cultivation, and crop measures were applied in accordance with organic agricultural technology recommendation [20]. Weather conditions (mean air temperature and total rainfall) are shown in Figure 1, during the growing period, which were obtained from the weather station of Agricultural University of Athens.

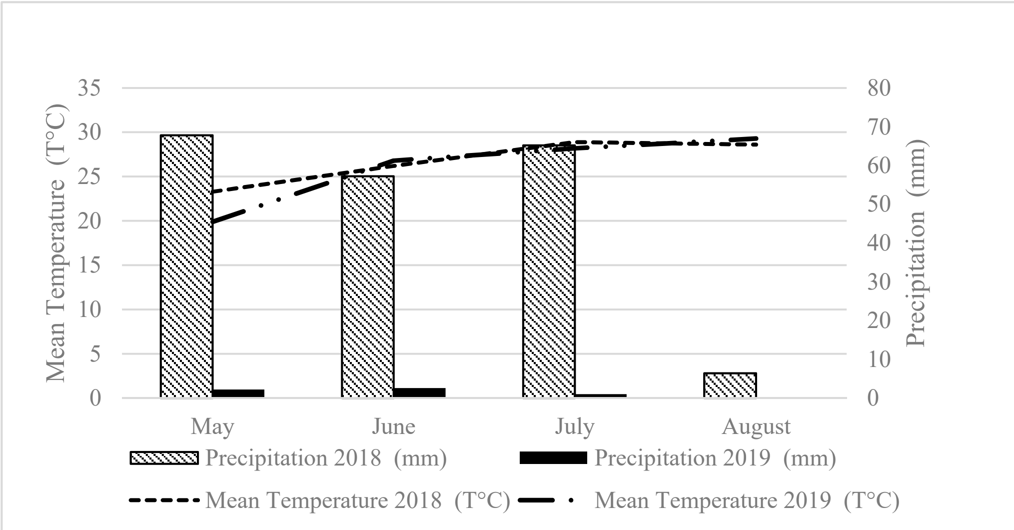

Figure 1. Meteorological data at experimental area for the growing seasons 2018 and 2019.

The total precipitation was 196.6 mm in 2018, and 5.8 mm in 2019.

The experimental facility covers an area of 800 m^2 and it was laid out in a completely randomized design (CRD) (Table S1), with four replications and five fertilization treatments: control (untreated), inorganic fertilizer NPK (20:10:10, 200 kg N ha^{-1}, 100 kg P_2O_5 ha^{-1}, 100 kg K_2O ha^{-1}), processing tomato pomace with biocyclic humus soil (50% tomato pomace + 50% biocyclic humus soil) at a rate of 3000 kg ha^{-1}, tomato pomace with manure (50% tomato pomace +50% farm yard manure) at a rate of 3000 kg ha^{-1}, and tomato pomace with compost (50% compost +50% processing tomato pomace; 3000 kg ha^{-1}). The plot size was 40 m^2. Soil was prepared by ploughing at a depth of about 25 cm. The fertilizers manually applied presowing on topsoil and were harrowed in. Processing tomato seedlings transplantation was held on the 3rd and 5th of May for 2018 and 2019, respectively. Processed tomato seedlings (*Solanum lycopersicum* Mill. cv. Heinz 3402 F1) were manually transplanted, inter row spacing was 50 cm and intra row spacing was 30 cm. The irrigation was held by hand and ceased on the 1st and 3rd of August for 2018 and 2019 respectively. During the experimental period, weeds were controlled by hand almost every three weeks. Throughout the experimental period, there was no incidence of pest or disease on the processed tomato crop.

2.2. Biocyclic Humus Soil

The biocyclic humus soil, with 2.8 g total nitrogen, 0.8 g P_2O_5, 0.6 g total potassium, 7.6 units electrical conductivity (1:5) pH, cation exchange capacity (C.E.C.) meq 91.9 per 100 g humus soil, was made from 100% plant materials and mostly from by-products from olive oil mills. The raw materials, which were sourced from Biocycle Vegan Company were 50% olive leaves, 30% olive pomace, 10% grape pomace, and 10% ripe humus soil. An aerobe composting process was followed in rows with a height of 1.5 m and a width of 2.5 m. A compost windrow turner was used to obtain the aeration and hydration of the raw materials. After five to six months of the composting process, a mature substrate quality compost was achieved. To turn the mature compost into humus soil, a three-year maturation process followed. The outcoming material was beyond the maturation of the substrate and had a more soil-like structure suitable for direct planting. It was certificated according to the Biocyclic Vegan Standard, which became a global standard and a full member of the IFOAM's Organic Family of Standards in December 2017 [21]. The characteristics of processing tomato pomace composts used as soil amendments are presented in Table 1. According to the European Commission, it does not meet the physical and chemical properties for compost to be used as a fertilizer for 100% tomato pomace, but it can be used in a mixture.

Table 1. Characteristics of tomato pomace composts used as soil amendments.

	Organic Matter (%)	EC (mS cm^{-1})	pH	N Total (%)	P Olsen (ppm)	K (ppm)	Mg (ppm)
Tp and BHS	51	1.71	7.28	2.78	14	31	0.78
Tp and FYM	54	1.68	7.41	3.1	21	33	0.66
Tp and CM	41	1.74	7.36	2.88	16	31	0.32

Tp and BHS: tomato pomace and biocycle humus soil; Tp and FYM: tomato pomace and farmyard manure; Tp and CM: tomato pomace and compost.

2.3. Plant Material

The processing tomato hybrid that was grown was Heinz 3402 F1. It is suitable for mechanical harvesting; its growing cycle is 120 days. It is tolerant to *Verticillium* sp., *Fusarium* sp., *Meloidogyne* sp., and *Pseudomonas syringae.* It gives excellent yields in both dry and wet field conditions. The fruits are smooth, uniform, ≅ 66 g with ° Brix = 5.1 on average. They are also well preserved thanks to the characteristic of prolonged maintenance of the hybrid in the field.

2.4. Soil and Root Measurements

As for soil measurements, penetration resistance (PR) was measured to a depth of 0 to 30 cm, with digital penetrologger (Model, 06.15, Eijkelkamp.Eq. Ltd, Giesbeek, The Netherlands). Mean weight diameter (MWD) of soil aggregates was determined using the oscillation device Analysette 3 (Spartan, Fritsch Ltd., Oberstein, Germany) at 110 days after transplanting. The oscillation time was 4 min., using 2 kg of air-dried soil from a depth of 0 to 60 cm and sieve mesh sizes of 20 to 40, 10 to 20, 5 to 10, 2 to 5, and <2 mm. The MWD is equal to the sum of the products of the average diameter, xi, each fraction of size and proportional weight, *wi*, of the corresponding size fraction, and it was calculated using the Equation (1) given by Van Bavel (1949):

$$\text{MWD} = \sum_{i=1}^{n} xiwi, \quad (1)$$

where xi is the mean diameter of each size fraction/size class midpoint, and wi is the proposition of the total sample weight occurring in the corresponding size fraction [22].

The total porosity (St) of soil was estimated using the Equation (2) [23]:

$$St(\%) = \frac{-1 - Db}{Dp}, \quad (2)$$

where St is the total pore spaces, Dp is the particle density (2.5 g cm^{-3}), and Db is the soil bulk density.

The soil total nitrogen was determined by the Kjeldahl method, using a Buchi 316 device for burning. Basal soil respiration (CO_2-C) was determined using the titration method [24]. The organic matter was determined by the Walkey-Black method [17], for the 0 to 15 cm depth for every plot. Root samples were collected by a cylindrical auger (25 cm length, 10 cm diameter), from the 0 to 30 cm and 30 to 60 cm layers, at the midpoint between successive plants within a row. Three samples per layer per plot were analyzed at 110 DAT. For each sample, the roots were separated from the soil after being soaked in a solution of water + $(NaPO_3)_6$ + Na_2CO_3 for 24 h and then decanted into a 0.1% trypan blue FAA staining solution (a mixture of 10% formalin, 50% ethanol and 5% acetic acid solutions). For the determination of root length density (RLD), the root samples were placed on a high-resolution scanner (Epson Perfection V330 Photo; Seiko Epson Corp., Nagano-ken, Japan) using DT software (Delta-T Scan version 2.04; Delta-T Devices Ltd., Burwell, Cambridge, UK) [25]. The root mass density (RMD) was determined after drying for 48 h at 70 °C. The percentage of root length colonized by AM fungi was determined microscopically with the gridline-intersection method at a magnification of ×30 to ×40 [26].

Regarding to the roots, the samples were collected in six different DAT (20, 40, 60, 80, 100, and 120 DAT) with two samples per treatment. They were washed over a 5 mm mesh sieve. In addition, a formalin/acetic acid/alcohol (FAA) staining solution was used. Root density (cm of root 100 cm^{-3} soil), root surface (cm^2 of root 100 cm^{-3} soil), as well as root volume (cm^3 of root 100 cm^{-3} soil) were determined in millimeters using a high-resolution scanner, using DT-software (Delta-T Scan version 2.04; Delta Devices Ltd., Burwell, Cambridge, UK) [27].

2.5. Vegetation and Yield Measurements

Dry weight per plant, which include roots, stem and leaves, was measured. For these measurements, tomato plants were allowed to grow for 110 days and then four randomly selected plants were carefully removed from each plot and transferred to the lab. The plant samples were dried for 72 h at 64 °C and then measurements were taken.

Data were collected from four randomly selected plants from each plot; viz., fruit yield number of fruits $plant^{-1}$, fruit diameter, average fruit weight (g) and yield (ha^{-1}). Fruit diameter (mm) was determined by a Starrett EC799A-6/150 electronic digital caliper (L.S. Starrett Co., Athol, MA, USA) with an exactness of 0.02 mm.

2.6. Quality Traits Methods

Seven to 10 mature fruits per plot, selected at random, were picked using four randomly selected plants to estimate the quality characteristics. The samples were stored in the freezer until the final measurements. More specifically, fruit firmness was measured, after freezing, on the equator of each fruit by recording the endurance to puncture, making use of a Chatillon DFIS-10 penetrometer (John Chatillon, Greensboro, NC, USA), which was set up on a Chatillon TCM 201-M motorized force test stand (John Chatillon and Sons, Inc., Greensboro, NC 27425, USA), while it was adjusted to a 6.3 mm-diameter conical needle penetrating to a depth of 0.6 cm at a constant speed of 200 mm min^{-1}. Fruit skin color was periodically measured with a tristimulus Minolta Chromameter CR300 colorimeter (Konica Minolta, Inc., Sakai, Osaka 590-8551, Japan). Data were expressed as *L** (dark/light), *a** (green/red) and *b** (blue/yellow) values. Measurements occurred on each fruit (at the equatorial area of the pericarp) and mean values were then estimated. Color index (*CI*) was calculated using the following formula [28]:

$$CI = 1000a^*L^* - 1b^* - 1.$$

Lycopene assessment was directed through an ultrasonic-assisted extraction (UAE) and the experimental results were analyzed by response surface methodology (RSM) adjusted according to Eh and Teoh (2012) [29]. Lycopene molar extinction $\varepsilon = 17.2 \times 104\ M^{-1}\ cm^{-1}$ in n-hexane was used for lycopene content determination [30]. The lycopene concentration was expressed as mg kg^{-1} fresh weight [31]. Total soluble solids content (TSS) was determined by the hand-held refractometer Schmidt & Hänsch HR32B (Schmid & Haensch GmbH & Co., 13403 Berlin, Germany), owing a susceptibility of 0.2 °Bx.

To measure titratable acidity, samples of N/50 NaOH using 1% phenolphthalein (1 g phenolphthalein in 100 mL of 95% ethyl alcohol) were applied as the indicator and TTA was calculated as the percentage of citric acid, as the conventional method expressing the acidity of tomato [32]. Two matured fruits from two plants per plot that were selected randomly with a titration of 10 mL of diluted tomato were used.

The software SigmaPlot 12 statistical (Systat Software Inc., San Jose, CA, USA) was used for the evaluation of the experimental data, using a randomized complete block design (RCBD). Values were compared by analysis of variance (ANOVA) and the mean values were compared using Tukey's test ($p < 0.05$). Correlation analyses were performed to observe the existence of relatedness between yield and quality characteristics; while it was assessed using Pearson's correlation. All comparisons were accomplished using the least significant difference (LSD) test at the 5% level of probability.

3. Results

3.1. Soil Characteristics

Soil characteristics as affected by different fertilizations are presented in Table 2. Soil porosity was significantly raised after the application of organic blends. This increase was up to 12.32% (year A) and 33% (year B), which is the comparison between control and the highest value (Tp and BHS for both years). The highest value was noticed in Tp and BHS (46.49%; year A, and 54.87%; year B) which had no statistically significant difference with Tp and FYM (46.17%) in 2018. Soil porosity under inorganic fertilization was observed to be lower than the control in the first year, in contrast to the second year (41.39% and 43% respectively), however, there is no statistically significant difference.

Table 2. Soil characteristics as effected by fertilizer treatments (control, NPK, Tp and BHS, Tp and FYM, and Tp and CM).

Fertilizers	Total Soil Porosity (%)	Pen Resistance (MPa)	Soil Organic Matter (%)	MWD (mm)	Soil N Total (%)	CO_2 mg/100 g/ 24 h /25 °C	Root Density (mm.cm^{-3})	AMF (%)
				2018				
Control	41.39 ^{a}	2.53 ^{b}	2.34 ^{a}	10.14 ^{a}	0.101 ^{a}	48.50 ^{a}	2.10 ^{a}	31.53 ^{a}
NPK	41.36 ^{a}	2.50 ^{b}	2.35 ^{a}	9.81 ^{a}	0.106 ^{a}	46.25 ^{a}	2.25 ^{a}	34.11 ^{a}
Tp and BHS	46.49 ^{b}	2.21 ^{a}	2.63 ^{b}	13.42 ^{b}	0.123 ^{b}	74.25 ^{b}	3.20 ^{b}	47.41 ^{b}
Tp and FYM	46.17 ^{b}	2.21 ^{a}	2.81 ^{c}	12.97 ^{bc}	0.132 ^{b}	90.75 ^{c}	3.08 ^{bc}	46.60 ^{bc}
Tp and CM	44.74 ^{c}	2.20 ^{a}	2.59 ^{b}	12.50 ^{c}	0.127 ^{b}	64.50 ^{d}	2.93 ^{c}	43.85 ^{c}
				2019				
Control	41.25 a	2.61 ^{c}	2.3 ^{a}	9.88 ^{a}	0.101 ^{a}	52.2 ^{a}	2.22 ^{a}	33.30 ^{a}
NPK	43.0 a	2.52 ^{c}	2.37 ^{a}	9.92 ^{a}	0.111 ^{a}	47.21 ^{a}	2.31 ^{a}	36.40 ^{a}
Tp and BHS	54.87	2.16 ^{a}	2.7 ^{b}	13.4 ^{b}	0.124 ^{b}	81.22 ^{b}	3.10 ^{b}	55.20 ^{c}
Tp and FYM	46.22	2.20 ^{b}	2.84 ^{c}	13.24 ^{b}	0.136 ^{c}	98.32 ^{c}	2.99 ^{b}	49.00 ^{b}
Tpand CM	44.01	2.27 ^{b}	2.67 ^{b}	12.82 ^{b}	0.128 ^{b}	70.24 ^{b}	2.87 ^{b}	44.40 ^{b}
$F_{fertil,2018}$	42.08 ***	9.34 ***	81.81 ***	155.49 ***	125.15 ***	87.75 ***	197.25 ***	113.26 ***
$F_{fertil,2019}$	30.07 **	7.22 **	77.7 **	117.2 ***	89.8 **	92.2 ***	111.12 ***	122.2 ***
$F_{year \times fertil}$	ns	ns	ns	ns	ns	ns	ns	ns

Tp and BHS: tomato pomace and biocycle humus soil; Tp and FYM: tomato pomace and farmyard manure; Tp and CM: tomato pomace and compost. F-test ratios are from ANOVA. Different letters within a column indicate significant differences according to Tukey's test. Significance levels: ** $p < 0.01$; *** $p < 0.001$; ns, not significant ($p > 0.05$).

In 2018, organic blends did not significantly differ among them (Table 2) while in 2019 Tp and BHS (2.16 MPa) differed with Tp and FYM (2.20 MPa), and Tp and CM (2.27 MPa). Values of penetration resistance ranged from 2.16 (Tp and BHS; 2018) to 2.61 MPa (control; 2019). In second year, penetration resistance decreased under organic fertilization.

Furthermore, organic treatments had positive effects on organic matter compared with control and inorganic fertilizer treatments. Tp and BHS and Tp and CM did not significantly differ in both years. In Tp and FYM, higher values were observed (2.81%; 2018, and 2.84%; 2019) and these values were 19.5%, and 19.8% higher than the inorganic fertilizer. Additionally, statistically significant, lower MWD ($p < 0.001$) was found in control (10.14 mm; 2018, and 9.88; 2019) and inorganic fertilizer (9.81 mm; 2018, and 9.92; 2019) compared to organic blends (Table 2). The highest value was noticed under Tp and BHS (13.42 mm) and lowest under NPK (9.81 mm) in the first year, and in the control (9.88 mm) in second year. Regarding the N total, it was significantly affected by fertilization and the values varied between 0.101% (control) and 0.136% (Tp and FYM).

As shown in Table 2, organic fertilization obviously enhanced the total soil microbial activity versus the control and inorganic. Only the chemical fertilizer had a less pronounced effect. Under Tp and FYM, highest value of CO_2 respiration was observed (90.75, and 98.32 mg per 100 g soil). CO_2 respirations was almost double under Tp and FYM compared to NPK (46.25, and 46.25 mg per 100 g soil).

Root density differed significantly with repeated treatments. In Tp and BHS, the highest value was observed (3.2, and 3.2 mm cm^{-3}). Tp and BHS had no statistically significant difference with Tp and FYM. In addition, root growth did not differ in control and NPK (Table 2).

In addition, fertilization was a crucial factor for AMF in processing the tomato crop. The highest value was 47.41, and 55.2% in Tp and BHS (2018 and 2019, respectively) and the lowest was in the control for both years. NPK and control did not statistically differ.

3.2. Agronomic Characteristics

Plant dry weight was significantly increased with the application of organic blends compared to NPK (Table 3). Tp and BHS (151.5; 2019, and 144.1; 2019) had no statistical difference with Tp and FYM (144.7; 2018, and 134.2; 2019). In Tp and BHS, almost 36 and 33% higher plant dry weight than NPK for each year was reported. The mean fruit weight of the processing tomato is presented in Table 3. Mean fruit weight had a considerable turn-up with organic blends contrary to NPK. The highest value was remarked under Tp and BHS (56.75, 54.87 g per fruit for 2018, and 2019, respectively). The control had no statistically significant difference with the Tp and CM (Table 3).

Table 3. Dry weight (g $plant^{-1}$), mean fruit weight (g $fruit^{-1}$), yield ($tn.ha^{-1}$), lycopene content (mg kg^{-1} fresh) as effected by fertilizer treatments (control, NPK, Tp and BHS, Tp and FYM, and Tp and CM).

Fertilizers	Plant Dry Weight (g $Plant^{-1}$)	Mean Fruit Weight (g $Fruit^{-1}$)	Yield ($tn.ha^{-1}$)	Lycopene Content (mg kg^{-1} Fresh)
		2018		
Control	97 ^{a}	45.75 ^{a}	5.58 ^{a}	76.50 ^{a}
NPK	111.5 ^{b}	47.25 ^{b}	7.57 ^{b}	74.75 ^{a}
Tp and BHS	151.5 ^{c}	56.75 ^{c}	8.00 ^{c}	87.25 ^{b}
Tp and FYM	144.7 ^{c}	55.25 ^{c}	7.65 ^{b}	85.75 ^{b}
Tp and CM	129.2 ^{d}	48·00 ^{b}	7.60 ^{b}	84.50 ^{b}
		2019		
Control	102 ^{a}	44.61 ^{a}	5.4 ^{a}	66.7 ^{a}
NPK	107.7 ^{b}	46.72 ^{b}	6.88 ^{b}	67.1 ^{a}
Tp and BHS	144.1 ^{c}	54.87 ^{c}	7.92 ^{c}	84.2 ^{b}
Tp and FYM	134.2 ^{c}	51.25 ^{c}	7.41 ^{c}	88.8 ^{b}
Tp and CM	133.3 ^{c}	49.2 ^{cb}	7.11 ^{b}	83.3 ^{b}
$F_{fertil,2018}$	133.86 ***	65.12 ***	70.63 ***	34.53 ***
$F_{fertil,2019}$	134.7 **	63.2 ***	67.71 ***	35.62 ***
$F_{year \times fertil}$	ns	ns	ns	ns

Tp and BHS: tomato pomace and biocycle humus soil; Tp and FYM: tomato pomace and farmyard manure; Tp and CM: tomato pomace and compost. F-test ratios are from ANOVA. Different letters within a column indicate significant differences according to Tukey's test. Significance levels: ** $p < 0.01$; *** $p < 0.001$; ns, not significant ($p > 0.05$).

Referring to the yield, significant differences were recorded in relation to the applied fertilizer. The yield ranged from 5.4 (control; 2019) to 8 tn ha^{-1} (Tp and BHS; 2018) (Table 3). In the first year, under Tp and BHS, the yield was reported 5.6% higher than NPK while in the second year it was 15.1%.

Lycopene content was significantly affected by fertilization (Table 3). The highest values were 87.25 (Tp and BHS; 2018) and 88.8.2 mg kg^{-1} fresh. (Tp and FYM; 2019). Lycopene content under Tp and FYM had no statistically significant difference with Tp and CM. In the first year, the lowest value of lycopene content was 74.75 mg kg^{-1} fresh (NPK) and it did not differ with the control (76.5 mg kg^{-1} fresh).

3.3. *Quality Characteristics*

Fruit firmness values ranged from 4.21 kg cm^{-2} (NPK; 2019) to 4.60 kg cm^{-2} (control; 2018, and Tp & BHS; 2019). The three organic blends did not have a statistically significant difference (Table 4).

Table 4. Quality characteristics as affected by fertilizer treatments (control, NPK, Tp and BHS, Tp and FYM, and Tp and CM).

Fertilizers	Fruit Firmness (kg cm^{-2})	TSS (○Brix)	TA (% Citric Acid *w*/*w*)
	2018		
Control	4.60 ^{a}	4.28 ^{a}	0.25 ^{a}
NPK	4.33 ^{b}	4.58 ^{b}	0.27 ^{b}
Tp and BHS	4.50 ^{ab}	4.75 ^{c}	0.29 ^{c}
Tp and FYM	4.42 ^{ab}	4.61 ^{b}	0.30 ^{c}
Tp and CM	4.55 ^{ab}	4.80 ^{c}	0.28 ^{bc}
	2019		
Control	4.55 ^{a}	4.17 ^{a}	0.22 ^{a}
NPK	4.21 ^{b}	4.49 ^{b}	0.29 ^{b}
Tp and BHS	4.60 ^{a}	4.66 ^{c}	0.29 ^{b}
Tp and FYM	4.52 ^{a}	4.48 ^{b}	0.31 ^{c}
Tp and CM	4.49 ^{a}	4.70 ^{c}	0.27 ^{b}
$F_{fertil,\ 2018}$	21.34 **	7.36 **	1.28 **
$F_{fert,\ 2019}$	17.72 **	6.68 **	1.47 **
$F_{year \times fertil}$	ns	ns	ns

Tp and BHS: tomato pomace and biocycle humus soil; Tp and FYM: tomato pomace and farmyard manure; Tp and CM: tomato pomace and compost. F-test ratios are from ANOVA. Different letters within a column indicate significant differences according to Tukey's test. Significance levels: ** $p < 0.01$; ns, not significant ($p > 0.05$).

TSS was significantly affected by fertilization. NPK had no statistically significant difference with the Tp and FYM (Table 4). However, in organic blends with organic waste TSS values were higher than NPK. According to our results, the highest TSS value was reported in Tp and CM (4.8 °Brix).

The highest value of TA was reported in Tp and FYM (0.30, and 0.31% citric acid *w*/*w* for 2018, and 2019, respectively). Even though in organic mixtures (Tp and CM, Tp and FYM, and Tp and BHS) with tomato processing, waste was not statistically differenced for the first year while in the second year Tp and FYM differed with Tp and CM and Tp and BHS.

4. Discussion

Concerning the porosity, Kakabouki et al. (2019) and Pagliai et al. (2004), reported that the application of manure had the most beneficial effects on total porosity compared to inorganic fertilization, which comes to an agreement with our study. Increasing the porosity, to a certain extent, has a beneficial effect on the growth of the crop [33,34]. This effect is owed to two main causes: reduced mechanical resistance of soil to root penetration and better oxygen supply to roots [35]. Application of organic fertilizers and natural waste, due to the high percentage of organic matter they contain (Table 2), has a beneficial effect on soil structure quality, which becomes apparent with the decrease of the apparent bulk density, increase of the macroporous, and the percentage of filtered water. Indeed, penetration resistance was significantly lowered by both organic and inorganic fertilization ($p < 0.001$; Table 2).

Root density significantly increased with the increase of soil porosity (r = 0.937, $p < 0.001$; Table 5) and the reduction of penetration resistance ($r = -0.838$, $p < 0.001$; Table 5). These results are similar with Colombi and Keller (2019) who observed that root growth is facilitated with specific physical characteristics of the improvement of compacted soil [36]. Moreover, a positive correlation was noticed between dry weight per plant with soil porosity (r = 0.891, $p < 0.001$) and the negative correlation one with penetration resistance ($r = -0.811$, $p < 0.001$). These two physical soil characteristics finally affect yield.

Table 5. Pearson's correlation coefficient (r) between soil and agronomic characteristics.

	Root Density ($mm.cm^{-3}$)	**AMF (%)**	**Dry Weight/Plant**	**Mean Weight Per Fruit (mm)**	**Yield ($tn.ha^{-1}$)**	**Lycopene Content (mg kg $Fresh^{-1}$)**
Soil porosity (%)	0.937 ***	0.927 ***	0.891 ***	0.795 ***	0.624 **	0.898 ***
Pen. Res (Mpa)	−0.838 ***	−0.811 ***	−0.808 ***	−0.642 **	−0.612 **	−0.761 ***
Organic matter (%)	0.881 ***	0.889 ***	0.788 ***	0.676 ***	0.589 **	0.852 ***
MWD (mm)	0.950 ***	0.940 ***	0.847 ***	0.697 ***	0.597 **	0.965 ***
N total (%)	0.841 ***	0.867 ***	0.814 ***	0.685 ***	0.622 **	0.820 ***
CO_2 (mg/100 g/ 24 h /25 °C)	0.8397 ***	0.849 ***	0.811 ***	0.761 ***	0.519 *	0.789 ***
Root Density ($mm.cm^{-3}$)	-	0.994 ***	0.918 ***	0.776 ***	0.737 ***	0.905 ***
AMF (%)	0.994 ***	-	0.908 ***	0.762 ***	0.732 ***	0.901 ***

Significance levels: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ns, not significant ($p > 0.05$).

The increase of soil organic matter was due to higher organic matter content in blends compared to inorganic. Kammoun-Rigane et al. (2011) mentioned that a crucial factor for soil quality is the pre-existing organic matter [37]. On the contrary, our results mentioned that soil quality is significantly affected by the technical specifications of each applied fertilizer. Provided fertilizer has a high organic content, and soil will be enriched with organic matter. Similar studies showed an increase in soil organic matter with compost application [38] and organic fertilizers restored the nutrition C and the organic matter content of the soil [39,40]. Zebarth et al. (1999) observed that organic waste amendments benefits soil [41]. According to our results, tomato pomace combined with a variety of organic fertilizers markedly increased soil organic matter. This agrees with the biocyclic vegan standard, which exclusively uses plant origin raw materials to produce hummus soil [42]. In addition, root mass can contribute to soil organic matter content [43]. This result agreed with our results; root density, and soil organic matter had a positive correlation ($p < 0.001$, r = 0.881; Table 5).

As previously mentioned, the highest value of MWD was observed under Tp and BHS. Similar results were mentioned by Kakabouki et al. (2019) [33]. DMW difference between organic blends and mineral fertilizer is on account of soil bulk density. While soil bulk density increased and porosity decreased, DWM was reduced [44]. Moreover, Zhang and Fang (2007) showed that physical soil properties were improved under manure application, and the volume of micropores were reduced while macropores increased [45]. Soil structure was characterized through MWD, which is an important indicator for physical soil properties [33]. Root growth had a positive correlation with MWD ($r = 0.950$, $p < 0.001$). In addition, Kakabouki et al. (2020) noticed that the slow release of nitrogen facilitates root growth [46].

A lot of research observed that organic fertilization increased N total compared to mineral fertilization [47,48]. The difference of the N total could be caused by the variant of soil organic matter. Kakabouki et al. (2019) observed that soil organic matter is a major source of organic nitrogen [33]. The raised organic matter in mixtures with compost and tomato residues prompted high total nitrogen values. Additionally, Meng et (2015) observed that mineral nitrogen is denitrified, volatilized, and leached, hence the N total is lower than organic [49]. Soil N total had a significant positive correlation with AMF ($r = 0.867\%$, $p < 0.001$) by virtue of glomalin capability to restrain substantial amounts N, which is a protein produced by AMF [50].

Our results about the total microbial activity are in line with Debosz et al. (2002) [51]. Kakabouki et al. (2019) said that soil organic matter is a remarkable substrate for microbial activity [33]. A lot of research, in contrast, observed that microbial activity indirectly affects by fertilization [52,53]. Besides, Dietrich et al. (2017) highlighted that increased microbial activity significantly rose the stored nitrogen, thus fertilization, program. This result is in line with our results; the higher the organic matter, the more soil microbial activity under the exact same treatment (TP and FYM).

Root growth did not differ in the control and NPK (Table 2). Root growth is a property that can inform about the absorption of water and nutrient uptakes that are necessary for plant growth [54,55]. While soil porosity increased, root development rose due to higher oxygen concertation in soil ($r = 0.937$, $p < 0.001$; Table 5). Furthermore, root density and AMF were positive correlated ($p < 0.001$, $r = 0.994$; Table 5). Provided AMF, root growth will be higher, which will allow for better absorption of nutrients, and increased yield.

In addition, fertilization was a crucial factor for AMF in processing tomato crop, while the highest value was in Tp and BHS. A lot of research obtained the opposite results; with the application of mineral fertilization AMF did not reduce, and the yield was significantly high too. However, the effect of inorganic resources and land use on glomalin content is discrepant [50]. AMF in organic blends were important and higher compared to the inorganic fertilizer. This result is completely in accord with Bilalis and Karamanos (2010) who mentioned that organic fertilization significantly rises the AMF rate in comparison with the control [56]. In processing tomatoes, field crop, AMF, and fry weight had a positive correlation ($p < 0.001$, $r = 0.908$; Table 5). In the same results, root colonization levels were positively correlated with the growth of tomatoes, which was obtained by many researchers [57,58]. On the contrary, Ziane et al. (2017) reported that the plants without fertilization had high mycorrhizal root colonization and low growth due to the deficiency of nutrients [59]. Furthermore, a positive correlation was highlighted between the yield and AMF ($p < 0.001$ $r = 0.732$; Table 5). Processing tomatoes yielded higher with more AMF. A positive relationship between AMF and soil organic matter (%) was reported ($r = 0.889$, $p < 0.001$). AMF procures glomalin, which is a related soil protein (GRSPs). Glomalin is considered an important segment of soil organic matter [60]. Besides organic matter, AMF had a significant positive correlation with soil N total ($r = 0.867$, $p < 0.001$) since glomalin could restrain substantial amounts N [50].

The application of organic blends positively affected plant dry weight and mean fruit weight. These results are opposite to Bilalis et al. (2017) who reported that dry weight per plant was higher under inorganic fertilization and Bilalis et al. (2018) reported opposite results; inorganic fertilization was given the highest mean fruit weight (63.6 g) [61,62]. Plant dry weight and mean fruit weight had a positive correlation with root density ($r = 0.918$, $p < 0.001$, and $r = 0.776$, $p < 0.001$ respectively; Table 5); incidental to root density increase was better plant nutrition and higher development. Additionally, plant dry weight and mean weight per fruit had a significant correlation with N total ($p < 0.001$, $r = 0.814$, and

$r = 0.685$, $p < 0.001$ correspondingly; Table 5). According to Filgueira (2000), vegetation, fruit growth and number of fruits per plant growth are positively related to nitrogen content [63].

Referring to the yield, significant differences were recorded in relation to the applied fertilizer. Many researchers reported that the tomato processing yield is a positive response to inorganic fertilization [62,64]. Specially, Lahoz et al. (2016) reported that organic farming presented a 36% lower production than conventional [65]. Nevertheless, in our study, the yield was higher under organic blends fertilizers. Similar results occurred for Eisenbach et al. (2018) [66]. This can be explained by the fact that in this application the growth of roots is improved, which is responsible for the intake of nutrients and water. Furthermore, Asri et al. (2015) reported that treatments with humic acid are positively correlated with the performance of processed tomatoes [67]. A positive correlation was observed between yield and soil N total ($r = 0.622$, $p < 0.01$) and root density ($r = 0.776$, $p < 0.001$).

The highest values of lycopene content were under Tp and FYM. Lahoz et al. (2016), conversely, reported that levels of lycopene were not affected by the cultivation system [65]. Under organic blends, lycopene was significantly increased. Pieper and Barrett (2009) also mentioned higher lycopene content in organic tomatoes (estimated at 12.75 g kg^{-1} dry weight). Pieper and Barrett (2009) highlighted that the variation of lycopene based on fresh weight may be in view of dilution [68]. Our findings showed a significant positive correlation of lycopene content with root growth ($p < 0.001$, $r = 0.905$) and AMF ($p < 0.001$, r= 0.901).

An important index for the quality assessment of tomatoes is fruit firmness, which is considered as an essential trait that indicates the quality of tomato fruit [69]. Fruit firmness is a crucial index for processing tomato crops, since accurate assessment of fruit firmness allows appropriate decisions to be made in regard to how your produce is treated. In our experiment, fruit firmness was significantly affected by organic and inorganic fertilization (Table 4). Our results agreed with Viskelis et al. (2015) [70]. Although Bilalis et al. (2017) reported that fertilization did not affect fruit firmness of processing tomatoes [61]. In addition, Petropoulos et al. (2020) reported the highest value in control (4.46 kg cm^{-2}) [64]. The difference in values of fruit firmness is owed to the nitrogen content in fruit; according to Knee (2002), the fruit firmness is negatively related to the increased nitrogen content in fruit, as nitrogen affects cellular properties [71]. Our results are in accord with Knee (2002) considering that in the control the highest value of N total (Table 2) and highest fruit firmness were observed (Table 4).

Soluble solids are a large fraction of the total solids in tomatoes and an indicator of sweetness. Petropoulos et al. (2020), in contrast, reported that the TSS content was higher in manure treatment (5.44 °Brix) [64]. According our results, the highest TSS value was reported in Tp and CM (4.8 °Brix). This outcome is in agreement with Bilalis et al. (2017) who noticed the highest TSS value under compost treatment (4.4 °Brix) [61]. TSS is dependent on nitrogen rate fertilization; the increase of applied nitrogen rate increased the TSS [72]. It is considerable that under organic mixtures, TSS values were indicated in the highest quality for paste since the TSS range is 4.8 to 8.8 °Brix [73,74]. On the contrary, 4.28, and 4.17 (control); 4.58, and 4.49 (NPK); 4.61, and 4.48 (Tp and FYM) are consider low quality in industrial processing for the production of paste.

Ilic et al. (2015) reported that fruit quality was characterized by titratable acidity [75]. The analysis of variance revealed that titratable acidity (TA) was actually affected by fertilization, while the highest values were observed in Tp and FYM. These results agreed with Dinu et al. (2018) [76]. TA values were significantly increased compared to inorganic fertilization. Pieper and Barrett (2009) reported the same outcome [68]. TA depends on fruit maturity; while fruit maturity increased, TA decreased [74]. Regarding our results, we can assume that control and NPK were in the right maturity stage at harvest since tomatoes from all different fertilization treatments were harvested on the same day.

5. Conclusions

In this study, we evaluated a pre-harvest factor, which is the fertilization in processing tomato crop. The waste of processing tomatoes were used as a fertilizer blended with organic fertilizers. Altogether, the result of this study showed that processing tomatoes in mixtures with organic fertilizers significantly improved soil quality, plant development, yield, and the quality characteristics of processing tomato. It was reported that the application of a manure mixture had the most beneficial effects on total porosity. AMF was significantly increased under organic blends. A high percentage of AMF produced glomalin, which is an important component of soil organic matter, and hence soil quality is improving. According to our results, not only nitrogen fertilization rates significantly affected the vegetative growth and total yield of processing tomato, but also the nitrogen source. The yield was significantly increased owing to soil N total and root density. The overall increase of soil N and the parallel increase of TSS were revealed. For the increase of TA, we could consider that organic mixtures with tomato waste privileged fruit ripening; on the same harvest date, they were more mature. A sustainable suggestion for utilization of processing tomato residues is presented. Providing composted tomato waste with common organic fertilizers, a solution of processing waste and an increased yield and quality of tomatoes will be achieved.

Supplementary Materials: The following are available online at https://www.mdpi.com/2073-4395/11/1/88/s1, Table S1: Experimental design.

Author Contributions: Conceptualization, S.K.; methodology, I.K., A.F., A.E., S.K., C.Z., V.K., N.C.K., N.K., I.T.; validation, I.K., A.E., I.T.; formal analysis, I.K., A.F., A.E., S.K., C.Z., V.K., N.C.K., N.K., I.T. investigation, I.K., A.F., A.E., S.K., C.Z., V.K., N.C.K., N.K.; data curation, I.K., A.F., A.E., S.K., C.Z., V.K., N.C.K., N.K.; writing original draft preparation, I.K., A.F., S.K., C.Z., V.K., N.C.K., N.K.; writing review and editing, I.K., A.E., A.F., I.T.; visualization, I.K., A.F.,A.E., S.K., V.K., N.C.K., N.K. and I.T.; supervision, I.K., A.E., I.T., N.K.; project administration, N.C.K. All authors have read and agreed to the published version of the manuscript.

Funding: "Sustainable Exploitation of Tomato Processing Industry by Products (Tomatocycle)" funded under the RIS3 Priority Sector Support "Development of Transnational Research Projects for Small and Medium-Sized Enterprises" under the Operational Program "Western Greece 2014-2020. EU MANUNET".

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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

Abbreviations

Tp	Tomato pomace
AMF	Arbuscular Mycorrhizal Fungi
DAT	Days After Transplanting
NPK	Inorganic Fertilizer
N	Nitrogen
TA	Titratable Acidity
TSS	Total Soluble solids
BHS	Biocyclic Humus Soil
MWD	Mean Weight Diameter
FYM	Farmyard Manure
CM	Compost
CRD	Completely Randomized design
RLD	Root length density
RMD	Root mass density
CI	Color index

References

1. Kalogeropoulos, N.; Chiou, A.; Pyriochou, V.; Peristeraki, A.; Karathanos, V.T. Bioactive phytochemicals in industrial tomatoes and their processing byproducts. *LWT Food Sci. Technol.* **2012**, *49*, 213–216. [CrossRef]
2. Capanoglu, E.; Beekwilder, J.; Boyacioglu, D.; De Vos, R.C.; Hall, R.D. The effect of industrial food processing on potentially health-beneficial tomato antioxidants. *Crit. Rev. Food Sci. Nutr.* **2010**, *50*, 919–930. [CrossRef] [PubMed]
3. Friedman, M.; Fitch, T.E.; Yokoyama, W.E. Lowering of plasma LDL cholesterol in hamsters by the tomato glycoalkaloid tomatine. *Food Chem. Toxicol.* **2000**, *38*, 549–553. [CrossRef]
4. Migliori, C.A.; Salvati, L.; Di Cesare, L.F.; Scalzo, R.L.; Parisi, M. Effects of preharvest applications of natural antimicrobial products on tomato fruit decay and quality during long-term storage. *Sci. Hortic.* **2017**, *222*, 193–202. [CrossRef]
5. World Processing Tomato Council. WPTC Crop Update and World. 2020. Available online: https://www.wptc.to/releases-wptc.php (accessed on 22 October 2020).
6. Khan, M.; Khan, M.J.; Ahmad, S.; Ali, A.; Khan, N.; Fahad, M.A. Effect of Different Nitrogen Doses and Deficit Irrigation on Nitrogen Use Efficiency and Growth Parameters of Tomato Crop under Drip Irrigation System. *Sarhad J. Agric.* **2020**, *36*. [CrossRef]
7. Ronga, D.; Caradonia, F.; Parisi, M.; Bezzi, G.; Parisi, B.; Allesina, G.; Francia, E. Using digestate and biochar as fertilizers to improve processing tomato production sustainability. *Agronomy* **2020**, *10*, 138. [CrossRef]
8. Stuart, D.; Schewe, R.L.; McDermott, M. Reducing nitrogen fertilizer application as a climate change mitigation strategy: Understanding farmer decision-making and potential barriers to change in the US. *Land Use Policy* **2014**, *36*, 210–218. [CrossRef]
9. Sainju, U.M.; Ghimire, R.; Pradhan, G.P. Nitrogen Fertilization I: Impact on Crop, Soil, and Environment. In *Nitrogen Fixation*; Rigobelo, E.C., Pereira Serra, A., Eds.; IntechOpen: London, UK, 2019. [CrossRef]
10. Zisi, C.; Karydogianni, S.; Kakabouki, I.; Stavropoulos, P.; Folina, A.E.; Bilalis, D. Effects of nitrogen fertilizers with two different inhibitors (urease and nitrification) on the survival and activity of earthworms (*Octodrilus complanatus*). *J. Elem.* **2020**, *25*, 1449–1461. [CrossRef]
11. Kasapidou, E.; Sossidou, E.N.; Mitilagka, P. Fruit and Vegetable Co-Products as Functional Feed Ingredients in Farm Animal Nutrition for Improved Product Quality. *Agriculture* **2015**, *5*, 1020–1034. [CrossRef]
12. Del Valle, M.; Cámara, M.; Torija, M.E. Chemical characterization of tomato pomace. *J. Sci. Food Agric.* **2006**, *86*, 1232–1236. [CrossRef]
13. Achmon, Y.; Harrold, D.R.; Claypool, J.T.; Stapleton, J.J.; VanderGheynst, J.S.; Simmons, C.W. Assesment of tomato and wine processing solid wastes as soil amendments for biosolqarization. *Waste Manag.* **2016**, *48*, 156–164. [CrossRef] [PubMed]
14. Pane, C.; Spaccini, R.; Piccolo, A.; Scala, F.; Bonanomi, G. Compost amendments enhance peat suppressiveness to Pythium ultimum, Rhizoctonia solani and Sclerotinia minor. *Biol. Control.* **2011**, *56*, 115–124. [CrossRef]
15. López-Pérez, J.A.; Roubtsova, T.; Ploeg, A. Effect of three plant residues and chicken manure used as biofumigants at three temperatures on Meloidogyne incognita infestation of tomato in greenhouse experiments. *J. Nematol.* **2005**, *37*, 489–494. [PubMed]
16. Avgelis, A.D.; Manios, V.I. Elimination of tomato mosaic virus by composting tomato residues. *Neth. J. Plant Pathol.* **1989**, *95*, 167–170. [CrossRef]
17. Ghaly, A.E.; Alkoaik, F.; Snow, A. Inactivation of Botrytis cinerea during thermophilic composting of greenhouse tomato plant residues. *Appl. Biochem. Biotechnol.* **2006**, *133*, 59–75. [CrossRef]
18. Kakabouki, I.; Efthimiadou, A.; Folina, A.; Zisi, C.; Karydogianni, S. Effect of different tomato pomace compost as organic fertilizer in sweet maize crop. *Commun. Soil Sci. Plant Anal.* **2020**, *51*, 2858–2872. [CrossRef]
19. Walkley, A.; Black, I.A. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Sci.* **1934**, *37*, 29–38. [CrossRef]
20. The Council of the European Union. *Council Regulation (EC) No. 834/2007 On Organic Production and Labeling of Organic Products and Repealing Regulation (EEC) No. 2092/91*; The Council of the European Union: Brussel, Belgium, 2007.
21. The International Biocyclic Vegan Network. The Biocyclic Vegan Standard (English). 2019. Available online: http://www.biocyclic-vegan.org/about-us/ (accessed on 15 March 2019).
22. Van Bavel, C.M. MWD of soil aggregates as a statistical index of aggregation. *Soil Sci. Soc. Am. Proc.* **1949**, *14*, 20–23. [CrossRef]
23. Flint, A.; Flint, L.E. Particle density. In *Laboratory Methods, Methods of Soil Analysis: Part 4—Physical Methods*; Dane, J.H., Topp, G.C., Eds.; SSSA: Madison, WI, USA, 2002; pp. 229–240. [CrossRef]
24. Isermeyer, H. Eine einfache Methode zur Bestimmung der Bodenatmung und der Karbonate im Boden. *Soil Sci.* **1952**, *56*, 26–58.
25. Kokko, E.G.; Volkmar, K.M.; Gowen, B.; Entz, T. Determination of total root surface area in soil core samples by image analysis. *Soil Tillage Res.* **1993**, *26*, 33–43. [CrossRef]
26. Giovannetti, M.; Mosse, B. An evaluation of techniques for measuring vesicular arbuscular mycorrhizal infection in roots. *New Phytol.* **1980**, *84*, 489–500. [CrossRef]
27. Bilalis, D.; Katsenios, N.; Efthimiadou, A.; Efthimiadis, P.; Karkanis, A. Pulsed electromagnetic fields effect in oregano rooting and vegetative propagation: A potential new organic method. *Acta Agric. Scand. Sect. B Soil Plant Sci.* **2012**, *62*, 94–99. [CrossRef]
28. Jimenez-Cuesta, M.; Cuquerella, J.; Martinez-Javega, J.M. Determination of color index for citrus degreening. *Proc. Int. Soc. Citric.* **1981**, *2*, 750–753.
29. Eh, A.L.-S.; Teoh, S.-G. Novel modified ultrasonication technique for the extraction of lycopene. *Ultrason. Sonochem.* **2012**, *19*, 151–159. [CrossRef]

30. Fish, W.W.; Perkins-Veazie, P.; Collins, J.K. A quantitative assay for lycopene that utilizes reduced volumes of organic solvents. *J. Food Compos. Anal.* **2002**, *15*, 309–317. [CrossRef]
31. Sadler, G.; Davis, J.; Dezman, D. Rapid extraction of lycopene and β-carotene from reconstituted tomato paste and pink grapefruit homogenates. *J. Food Sci.* **1990**, *55*, 1460–1461. [CrossRef]
32. Harold, E.; Kirk, R.S.; Sawyer, R. *Pearson's Analysis of Foods*, 8th ed.; Churchill Livingstone: Edinburgh/London, UK; Melbourne, VIC, Australia; New York, NY, USA, 1981; pp. 536–538.
33. Kakabouki, I.; Roussis, I.; Hela, D.; Papastylianou, P.; Folina, A.; Bilalis, D. Root growth dynamics and productivity of quinoa (*Chenopodium quinoa* Willd.) in response to fertilization and soil tillage. *Folia Hortic.* **2019**, *31*, 285–299. [CrossRef]
34. Pagliai, M.; Vignozzi, N.; Pellegrini, S. Soil structure and the effect of management practices. *Soil Tillage Res.* **2004**, *79*, 131–143. [CrossRef]
35. Bengough, A.G.; Mullins, C.E. Mechanical impedance to root growth: A review of experimental techniques and root growth responses. *J. Soil Sci.* **1990**, *41*, 341–358. [CrossRef]
36. Colombi, T.; Keller, T. Developing strategies to recover crop productivity after soil compaction—A plant eco-physiological perspective. *Soil Tillage Res.* **2019**, *191*, 156–161. [CrossRef]
37. Kammoun Rigane, M.; Medhioub, K. Assessment of properties of Tunisian agricultural waste composts: Application as components in reconstituted anthropic soils and their effects on tomato yield and quality. *Res. Cons. Rec.* **2011**, *55*, 785–792. [CrossRef]
38. Casado-Vela, J.; Sélles, S.; Díaz-Crespo, M.; Navarro-Pedreño, J.; Mataix-Beneyto, J.; Gómez, I. Effect of composted sewage sludge application to soil on sweet pepper crop (*Capsicum annuum* var. annuum) grow under tow exploitation regimes. *Waste Manag.* **2007**, *27*, 1509–1518. [CrossRef]
39. Abdelhamid, M.T.; Horiuchi, T.; Oba, S. Composting of rice straw with oilseed rape cake and poultry manure and its effects on faba bean (*Vicia faba* L.) growth and soil properties. *Bio. Technol.* **2004**, *93*, 183–189. [CrossRef] [PubMed]
40. Hu, Z.; Lane, R.; Wen, Z. Composting clam processing waste in a laboratory and pilot scale in vessel system. *Waste Manag.* **2009**, *29*, 180–185. [CrossRef]
41. Zebarth, B.J.; Neilsen, G.H.; Hogue, E.; Neilsen, D. Influence of organic waste amendments on selected soil physical and chemical properties. *Can. J. Soil Sci.* **1999**, *79*, 501–504. [CrossRef]
42. Biocyclic Network Services Ltd. Biocyclic-Vegan Network. 2018. Available online: http://www.biocyclicnetwork.net/die-biozyklischen-standards.html (accessed on 1 September 2018).
43. Eichler-Löbermann, B.; Köhne, S.; Kowalski, B.; Schnug, E. Effect of catch cropping on phosphorus bioavailability in comparison to organic and inorganic fertilization. *J. Plant Nutr.* **2008**, *31*, 659–676. [CrossRef]
44. Ogunwole, J.O.; Ogunleye, P.O. Surface soil aggregation, trace, and heavy metal enrichment under long-term application of farm yard manure and mineral fertilizers. *Commun. Soil Sci. Plant Anal.* **2004**, *35*, 1505–1516. [CrossRef]
45. Zhang, M.K.; Fang, L.P. Effect of tillage, fertilizer and green manure cropping on soil quality at an abandoned brick making site. *Soil Tillage Res.* **2007**, *93*, 87–93. [CrossRef]
46. Kakabouki, I.; Karydogianni, S.; Zisi, C.; Folina, A. Effect of fertilization with N-inhibitors on root and crop development of flaxseed crop (*Linum usitatissimum* L.). *AGRIVITA J. Agric. Sci.* **2020**, *42*, 411–424. [CrossRef]
47. Šimon, T.; Czakó, A. Influence of long-term application of organic and inorganic fertilizers on soil properties. *Plant Soil Environ.* **2014**, *60*, 314–319. [CrossRef]
48. Mahmood, F.; Khan, I.; Ashraf, U.; Shahzad, T.; Hussain, S.; Shahid, M.; Ullah, S. Effects of organic and inorganic manures on maize and their residual impact on soil physico-chemical properties. *J. Soil Sci. Plant Nutr.* **2017**, *17*, 22–32. [CrossRef]
49. Meng, L.; Ding, W.X.; Cai, Z.C. Long-term application of organic manure and nitrogen fertilizer on N2O emissions, soil quality and crop production in a sandy loam soil. *Soil Biol. Biochem.* **2005**, *37*, 2037–2045. [CrossRef]
50. Treseder, K.K.; Turner, K.M. Glomalin in ecosystems. *Soil Sci. Soc. Am. J.* **2007**, *71*, 1257–1266. [CrossRef]
51. Debosz, K.; Petersen, S.O.; Kure, L.K.; Ambus, P. Evaluating effects of sewage sludge and household compost on soil physical, chemical and microbiological properties. *Appl. Soil Ecol.* **2002**, *19*, 237–248. [CrossRef]
52. Dietrich, P.; Buchmann, T.; Cesarz, S.; Eisenhauer, N.; Roscher, C. Fertilization, soil and plant community characteristics determine soil microbial activity in managed temperate grasslands. *Plant Soil* **2017**, *419*, 189–199. [CrossRef]
53. Thakur, M.P.; Milcu, A.; Manning, P.; Niklaus, P.A.; Roscher, C.; Power, S.; Reich, P.B.; Scheu, S.; Tilman, D.; Ai, F.; et al. Plant diversity drives soil microbial biomass carbon in grasslands irrespective of global environmental change factors. *Glob. Change Biol.* **2015**, *2*, 4076–4085. [CrossRef] [PubMed]
54. Costa, C.; Dwyer, L.M.; Zhou, X.; Dutilleul, P.; Hamel, C.; Reid, L.M.; Smith, D.L. Root morphology of contrasting maize genotypes. *Agron. J.* **2002**, *94*, 96–101. [CrossRef]
55. Fageria, N.K.; dos Santos, A.B. Lowland rice growth and development and nutrient uptake during growth cycle. *J. Plant Nutr.* **2013**, *36*, 1841–1852. [CrossRef]
56. Bilalis, D.J.; Karamanos, A.J. Organic Maize Growth and Mycorrhizal Root Colonization Response to Tillage and Organic Fertilization. *J. Sustain. Agric.* **2010**, *34*, 836–849. [CrossRef]
57. Zhongqun, H.; Chaoxing, H.; Zhibin, Z.; Zhirong, Z.; Huaisong, W. Changes of antioxidative enzymes and cell membrane osmosis in tomato colonized by arbuscular mycorrhizae under NaCl stress. *Colloids Surf. B Biointerfaces* **2007**, *59*, 128–133.

58. Tahat, M.M.; Kamaruzaman, S.; Radziah, O.; Kadir, J.; Masdek, H.N. Response of (Lycopersicon esculentum Mill.) to different arbuscular mycorrhizal fungi species. *Asian J. Plant Sci.* **2008**, *7*, 479–484. [CrossRef]
59. Ziane, H.; Meddad-Hamza, A.; Beddiar, A.; Gianinazzi, S. Effects of arbuscular mycorrhizal fungi and fertilization levels on industrial tomato growth and production. *Int. J. Agric. Biol.* **2017**, *19*, 341–347. [CrossRef]
60. Celik, I.; Ortas, I.; Kilic, S. Effects of compost, mycorrhiza, manure and fertilizer on some physical properties of a Chromoxerert soil. *Soil Tillage Res.* **2004**, *78*, 59–67. [CrossRef]
61. Bilalis, D.; Roussis, I.; Fuentes, F.; Kakabouki, I.; Travlos, I. Organic Agriculture and Innovative Crops under Mediterranean Conditions. *Not. Bot. Horti Agrobo.* **2017**, *45*, 323–331. [CrossRef]
62. Bilalis, D.; Krokida, M.; Roussis, I.; Papastylianou, P.; Travlos, I.; Cheimona, N.; Dede, A. Effects of organic and inorganic fertilization on yield and quality of processing tomato (*Lycopersicon esculentum* Mill.). *Folia Hortic.* **2018**, *30*, 321–332. [CrossRef]
63. Filgueira, F.A.R. *Novo Manual de Olericultura: Agrotecnologia Moderna na Produção e Comercialização de Hortaliças*; Universidade Federal de Viçosa: Vicosa, MG, Brazil, 2000; pp. 189–234.
64. Petropoulos, S.A.; Xyrafis, E.; Polyzos, N.; Antoniadis, V.; Fernandes, Â.; Barros, L.; Ferreira, I.C. The Optimization of Nitrogen Fertilization Regulates Crop Performance and Quality of Processing Tomato (Solanum Lycopersicum, L. cv. Heinz 3402). *Agronomy* **2020**, *10*, 715. [CrossRef]
65. Lahoz, I.; Leiva-Brondo, M.; Martí, R.; Macua, J.I.; Campillo, C.; Roselló, S.; Cebolla-Cornejo, J. Influence of high lycopene varieties and organic farming on the production and quality of processing tomato. *Sci. Hortic.* **2016**, *4*, 128–137. [CrossRef]
66. Eisenbach, D.L.; Folina, A.; Zisi, C.; Roussis, I.; Tabaxi, I.; Papastylianou, P.; Efthimiadou, A.; Bilalis, J.D. Effect of *biocyclic humus soil* on yield and quality parameters of sweet potato (*Ipomoea batatas* L.). *Agronomy* **2018**, *LXI*, 210–217.
67. Asri, F.O.; Demitras, E.I.; Ari, N. Changes in fruit yield, quality and nutrient concentrations in response to soil humic acid applications in processing tomato. *Bulg. J. Agric. Sci.* **2015**, *21*, 585–591.
68. Pieper, J.R.; Barrett, D.M. Effects of organic and conventional production systems on quality and nutritional parameters of processing tomatoes. *J. Sci. Food Agric.* **2009**, *89*, 177–194. [CrossRef]
69. Liu, J.; Liu, L.; Li, Y.; Jia, C.; Zhang, J.; Miao, H.; Hu, W.; Wang, Z.; Xu, B.; Jin, Z. Role for the banana AGAMOUS-like gene *MaMADS7* in regulation of fruit ripening and quality. *Physiol. Plant.* **2015**, *155*, 217–231. [CrossRef] [PubMed]
70. Viskelis, P.; Radzevicius, A.; Urbonaviciene, D.; Viskelis, J.; Karkleliene, R.; Bobinas, C. Biochemical parameters in tomato fruits from different cultivars as functional foods for agricultural, industrial, and pharmaceutical uses. In *Plants for the Future*; El-Shemy, H., Ed.; InTechOpen: Rijeka, Croatia, 2015. [CrossRef]
71. Knee, M. *Fruit Quality and Its Biological Basis*; Sheffield Academic Press: Sheffield, UK, 2002.
72. Etissa, E.; Dechassa, N.; Alamirew, T.; Alemayehu, Y.; Dessalegne, L. Response of fruit quality of tomato grown under varying inorganic N and P fertilizer rates under furrow irrigated and rainfed production conditions. *Int. J. Dev. Sustain.* **2014**, *3*, 371–387.
73. Kumar, S.; Das, D.K.; Singh, A.K.; Prasad, U.S. Changes in non-volatile organic acid composition and pH during maturation and ripening of two mango cultivars. *Indian J. Plant Physiol.* **1993**, *36*, 107–111.
74. Teka, T.A. Analysis of the effect of maturity stage on the postharvest biochemical quality characteristics of tomato (*Lycopersicon esculentum* Mill.) fruit. *Int. Res. J. Pharm. Appl. Sci.* **2013**, *3*, 180–186.
75. Ilić, Z.S.; Milenković, L.; Šunić, L.; Fallik, E. Effect of coloured shade-nets on plant leaf parameters and tomato fruit quality. *J. Sci. Food Agric.* **2015**, *95*, 2660–2667. [CrossRef]
76. Dinu, M.; Soare, R.; Dumitru, M.G. The effect of organic fertilization on fruit production and quality of tomatoes grown in the solar. *Ann. Univ. Craiova Agric. Montanology Cadastre Ser.* **2018**, *47*, 112–118.