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ORIGINAL PAPER

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TOMATO *(Solanum esculentum* Mill.) YIELD AND NUTRITIONAL TRAITS ENHANCEMENT AS AFFECTED BY BIOCHAR, ORGANIC AND INORGANIC FERTILIZERS

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ABSTRACT

This experiment studied the effects of biochar and chicken manure tea compost on growth, productivity, and nutritional traits of tomato (*Solanum esculentum* Mill.). A factorial based experiment within complete randomized block design with three replications was conducted to evaluate the traits. The results showed that the biochar + chemical fertilizer (T_1B_1) contained the significantly highest values of soil EC (1.81 dsm^{-1}), total N (0.39%), available P (156.92 ppm), available K (442.22 ppm), leaf N (3.54%), leaf K (6.73%), and shoot dry weight (463 g). The treatment of (T_1B_1) increased the production of tomatoes by 393.9% above the control soil conditions. Significant differences in fruit quality were observed. The biochar + chicken manure compost tea (1 : 4) (T_3B_1) treatment contained the highest values of total polyphenols (378.83 mg) and vitamin C (29.03 mg/100 g^{-1}), it but did not significantly affect total soluble solid and titratable acidity values on average compared with control conditions. However, the application of biochar at 10 tons ha^{-1} cannot fully substitute for fertilizers. Therefore, nutrition management can be achieved by biochar plus inorganic and organic fertilizer to increase tomato productivity and quality, respectively.

Key words: chicken manure, compost tea, fruit quality, *Solanum esculentum* Mill., soil properties, wood biochar

INTRODUCTION

Biochar is a carbon rich substance when any biomass (e.g., wood) is heated with limited oxygen [Lehmann and Joseph 2009]. Biochar has been shown to increase cation exchange capacity, nutrient cycling, and the ability of soils to store both water and nutrient elements as well as water use efficiency, and thereby, crop productivity [Larid et al. 2010]. A reduction in nutrient leaching [Paneque et al. 2016], soil N2O emission [He et al. 2019], and amplified microbial population and activity have also been observed with the application of biochar [Lehmann et al. 2011, Sharifi et al. 2019]. These characteristics make biochar an excellent soil amendment for applications in sustainable agriculture [Lehmann and Joseph 2009]. Both positive and negative yield reactions have been reported for a wide variety of crops as a result of biochar application to soils [Agegnehu et al. 2017]. Alburquerque et al. [2014] described an increase in plant production for very high application rates of ash-rich biochar under controlled greenhouse conditions. Generally, crop

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residue and wood biomass contain low nutrient contents, in part due to losses of pyrolytic nitrogen and the low initial ash content. Because of their low nitrogen, phosphorous, and potassium contents, these plant-based biochars are not rich enough in terms of available nutrients when compared to traditional fertilizers [Cantrell et al. 2012]. The use of agrochemicals to increase crop yield and the application of synthetic N fertilizers are receiving more attention because of environmental pollution [Monterumici et al. 2015]. Manures used in soils usually lose nutrients, mainly nitrogen, through volatilization. Hence, they are suitable for use as compost [Carrera et al. 2007, Hoseinzade et al. 2016]. Tiquia et al. [2000] reported that composted chicken manure included a more humified (stabilized) organic matter in contrast with un-composted chicken litter (a mixture of chicken manure, waste feed, feathers, and sawdust). Yield increases relative to a control have frequently been reported to be directly attributable to the addition of biochar and biochar plus compost as well as fertilizers [Ahmad et al. 2014, Agegnehu et al. 2017]. The use of biochar and compost to soil can change the organic matter status which is connected to the release of nutrients such as N. Reactions will likely refer to the type and rate of amendment applied to soil as well as on soil properties such as soil C, pH, CEC and other components of soil fertility [Agegnehu et al. 2017]. The basic differences between organic and conventional production systems may change the nutritive composition of plants containing secondary plant metabolites [Vallverdu-Queralt et al. 2012]. Kopta and Pokluda [2013] achieved results that indicated selected radish cultivars contained the highest contents of nutritionally important compounds in organic growing conditions. The popularity of organic food products is increasing among users who are developing their knowledge about health and environmental protection [Satyapriya et al. 2019]. Future work is expected on field studies of biochars for comparison of biochar nutrient against biochar-compost, type and rate of biochar application for better commercialization of biochar usage [Agegnehu et al. 2017].

The objective of this work was to investigate the effects of biochar and different forms of organic and chemical fertilizers on tomato fruit production and quality under greenhouse conditions. It was hypothesized that the addition of 10 tons ha^{-1} of biochar [Jeffrey et al. 2011], particularly when accompanied by organic and chemical fertilizers, will enhance tomato yield and nutritional traits in comparison to the un-amended control. Furthermore, the current work compared the effects of different levels of chicken manure compost tea, fresh chicken manure, and chemical fertilizer in the presence and absence of biochar on tomato growth productivity.

MATERIALS AND METHODS

Experimental setup. This study was conducted from October 2017 to February 2018 in a greenhouse in Aman Abad, a town close to the city of Arak, Central Province, Iran (Lat. 34°5'30"N; Long. 44°41'30"E; 1700 m above sea level). A factorial experiment based on a complete randomized block design with three replications was considered. Factors included biochar in two levels (including 0 and 10 tons ha^{-1}) and organic and chemical nutrition in six levels, including fresh chicken manure, three levels of chicken manure compost tea, chemical fertilizers of WUXAL (Macromix and Polymicro), and water as control (Tab. 1). Soil type was sandy clay loam with a pH of 7.24 and 0.3% organic matter.

Biochar and chicken manure compost tea preparation. Fresh chicken manure was collected from Tehran University chicken farm. In the first step, the

Table 1. Characteristics of chemical fertilizers of (WUXAL) used in the experiment

WUXAL	W/W%										
	N	P_2O_5	K_2O	MgO	B	Cu	Fe	Mn	Zn	Mo	SO_3
Macromix	16	16	12	–	0.02	0.05	0.1	0.05	0.05	0.001	–
Polymicro	10	–	10	3	0.02	0.5	0.5	1	0.05	0.001	7.5

best extraction time (2, 4, 6, days) for the preparation of chicken manure compost tea was determined. Extract concentrations examined were 1 : 4, 1 : 8, and 1 : 12 chicken manure-to-water ratio by w/v. Chicken manure was extracted with water 6 days before being applied in the greenhouse. Manures were placed in cheese cloth and suspended in a barrel; then, tepid water was added (1 : 4, 1 : 8, 1 : 12 w/v). The extracts were aerated and allowed to ferment at ambient temperatures for 6 days. The quantities of compost tea, chemical fertilizers and chicken manure applied were based on the usual amounts applied by local farmers, i.e. 10 tons ha^{-1}, 1 liter ha^{-1} every week, and 30 tons ha^{-1}, respectively. Tomato seeds of the Izmir variety were grown for four weeks. Biochar was applied one week before tomato transplanting (where applicable) by adding it to the transplanting hole at a depth of 30 cm and rate of 333 g/hole corresponding to 10 t ha^{-1} [Hossain et al. 2010, Jeffery et al. 2011]. Biochar was obtained from the oak wood of forest tree in Mazandaran province (northern part of Iran) through pyrolysis at a temperature of 550°C [Hossain et al. 2010]. Seedlings of uniform size were transplanted under drip irrigation at a rate of 3 plants per m^2 on October 12, 2017.

Soil and plant analyses. After the tomato plants were harvested, soil samples were collected from each plot at depths of 0–0.3 m. Total N content, pH, EC, CEC, and available phosphorus (P) and potassium (K) were determined [Agegnehu et al. 2016]. Total nitrogen was measured using the Kjeldahl method [Bremner 1965]. CEC [Rhoades 1982], and available plant P and K were analyzed using the Olsen method [Olsen et al. 1954], and the 1-N ammonium acetate method [Thomas 1982], respectively. Eighty days after transplanting, N, P, and K contents in the tomato plant shoots were measured on three plants from each plot and averaged for each treatment. The N content of shoots was determined after digestion, distillation, and titration using the Kjeldahl method (Gerhardf model Vapodest) based on Jackson [1962]. Total K content was determined using wet digestion method and by hydrogen peroxide and salicylic acid [Black et al. 1965], with a flame photometer (Jelway-pfp7model). P content was colorimetrically measured with a spectrophotometer (Pharmacia model LKB-Novaspec-11) [Murphy and Riley 1962]. At the end of the growth period, after harvesting the tomatoes, the total above ground biomass of the tomato plants was oven-dried at 70°C for 48 h and weighed.

Fruit yield and quality measurement. Ripened tomato fruits were harvested and the weight of fruit was calculated immediately. Some quality parameters of each plot were determined. Soluble solid content (Brix) was evaluated using a portable refractometer (DR-101, Kruss, Germany). Titratable acidity (TA) (g 100 g^{-1} f.w as citric acid), and vitamin C (VC) (mg 100 g^{-1} f.w. as ascorbic acid) contents were determined using standard methods of analysis [AOAC, 1990]. Total polyphenol (TP) results were stated as mg of gallic acid equivalents (GAE) 100 g^{-1} dry material. For the analysis of total phenolic compounds, fresh tomatoes were finely sliced and frozen prior to freeze-drying, after which they were powdered and stored at –20°C [Martinez-Valverde 2002], with minor modifications. All analyses were carried out in triplicate.

Statistical analysis. All data was statistically analyzed using SPSS-16 software with analysis of variance. Treatment means were compared using Duncan's multiple range test for the main effect of biochar plus organic and inorganic fertilizers on plant growth, fruit yield, and quality properties. The differences were significant at $p < 0.05$.

RESULTS

The physical and chemical characteristics of the soil, biochar and chemical analysis of the fresh chicken manure, and chicken manure compost tea are presented in Tables 2 and 3, respectively. The soil type of the experimental greenhouse was sandy clay loam with a pH of 7.24 and low in organic matter. The SEM morphological description of the biochar external surface after interaction with soil is shown in Fig. 1. The exterior of a typical woody biochar showed smooth surfaces due to high C content and organo-mineral matters on the surface.

Effect of biochar and fertilizer application on soil parameters. Table 4 shows the changes in the chemical properties of the soil of different treatments caused by the application of biochar, chemical and organic fertilizers. As shown in Table 4, the values of soil EC, total nitrogen, available phosphorus, and available potassium of the soil increased significantly under the addition of biochar, organic and inorganic fertilizers

Table 2. Chemical and physical characteristics of soil and biochar used in the experiment

	EC (ds/m)	pH	TNV (%)	OM (%)	N (%)	Ava. P (ppm)	P_2O_5 (%)	Ava. K (ppm)	K_2O (%)	CEC (cmol/kg)	Soil Texture	O.C (%)	C/N
Soil	1.04	7.24	8.1	0.3	0.26	204.72	–	125.7	–	10.12	S.C.L	–	–
Biochar	0.84	7.51	–	–	0.86	–	0.18	–	0.45	18.9	–	16.08	18.69

EC: electrical conductivity, TNV: total neutralizing value, OM: organic matter, Ava.: available, CEC: cation exchange capacity, O.C: organic carbon, S.C.L: sandy clay loam

Table 3. Basic properties fresh chicken manure and three level chicken manure tea compost (chicken manure-to-water ratio by w/v) were extracted 6 days before apply in the greenhouse

	NO_3 (%)	NH_4 (%)	P_2O_5 (%)	K_2O (%)	O.C (%)	pH	EC (ds/m)
Fresh chicken manure	2.65	–	4.34	2.12	29.77	6.81	10.74
Chicken manure compost tea (1/4)	–	0.48	380	0.59	1.9	7.53	0.53
Chicken manure compost tea (1/8)	–	0.28	20	0.25	0.67	6.88	0.3
Chicken manure compost tea (1/12)	–	0.15	100	0.17	0.38	7.12	0.18

O.C: organic carbon, EC: electrical conductivity

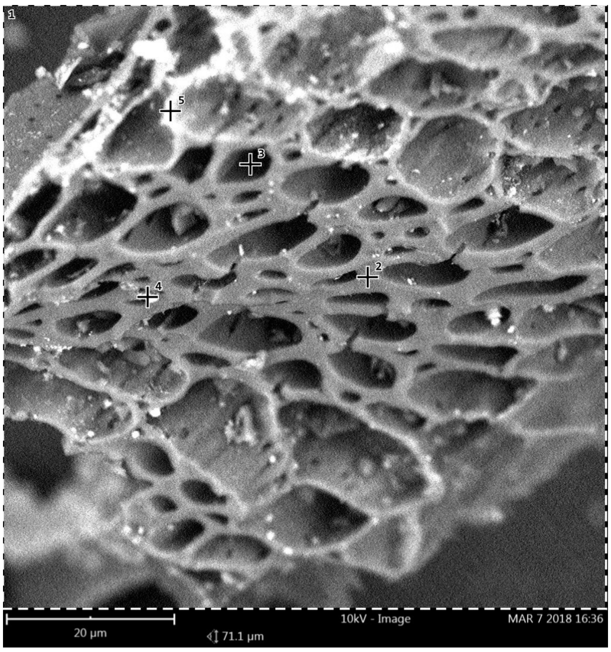

Fig. 1. Scanning electron micrograph of wood biochar with a magnification of 10,000 X

compared to the control soil. The highest values of EC and pH (1.81 dS m^{-1} and 7.46, respectively) were detected in the biochar together with chemical fertilizer (T_1B_1) treatment. The addition of 10 t ha^{-1} wood biochar plus fertilizer did not significantly change the pH of the soil (data not shown). The EC values were generally enhanced with increasing application rates of chicken manure compost tea, fresh chicken manure, and chemical fertilizer under biochar; the enhancement was significant in all cases. As shown in Table 4, the highest values of total soil N (0.39%), available P (156.92 ppm), and available K (442.22 ppm) in the soil were detected in the treatment of biochar and chemical fertilizer.

Effects of biochar and fertilizer amendment on plant growth and crop yield. Results showed that biochar and organic and chemical fertilizer had a significant effect on growth indices, including stem length and shoot dry weight, but it did not significantly influence stem diameter or leaf SPAD compared with control conditions (data not shown) (Tab. 5).The dry matter weight of plant shoots changed significantly

Table 4. Mean values chemical properties of the soil measured after harvesting tomato plants was collected at 0–0.3 m depth

Treatment	EC (ds/m)	TN (%)	Available P (mg/kg)	Available K (mg/kg)
Biochar + chemical fertilizers	1.81^{a}	0.39^{a}	156.92^{a}	442.22^{a}
Chemical fertilizer only	1.57^{b}	0.28^{b}	150.98^{b}	366.36^{b}
Biochar + fresh chicken manure	1.44^{c}	0.24^{c}	144.23^{e}	317.21^{c}
Fresh chicken manure only	1.22^{f}	0.14^{e}	140.54^{f}	278.91^{d}
Biochar + compost tea (1/4)	1.53^{b}	0.27^{b}	148.81^{c}	361.91^{b}
Compost tea only ((1/4)	1.32^{de}	0.16^{e}	145.25^{d}	320.28^{c}
Biochar + compost tea (1/8)	1.37^{d}	0.22^{d}	137.86^{g}	273.87^{d}
Compost tea only (1/8)	1.16^{g}	0.11^{f}	134.23^{h}	254.23^{e}
Biochar + compost tea (1/12)	1.31^{e}	0.20^{d}	133.93^{h}	242.99^{f}
Compost tea only (1/12)	1.08^{h}	0.10^{f}	129.95^{i}	221.19^{g}
Biochar only	0.92^{i}	0.06^{g}	127.61^{j}	198.29^{h}
Control soil	0.86^{j}	0.04^{g}	124.67^{k}	181.90^{i}

EC: electrical conductivity, TN: total nitrogen
Mean values means with different letters are significantly different (alpha 0.05) by the Duncan's multiple range test

Table 5. Mean values the growth, yield components, leaf N and K of tomato

Treatment	Yield/Plant (kg)	Fruit / Plant	Shoot dry weight (g)	Stem length (cm)	Leaf N (%)	Leaf K (%)
Biochar + chemical fertilizers	13.8^{a}	81.9^{a}	463^{a}	403.3^{a}	3.54^{a}	6.73^{a}
Chemical fertilizer only	12.6^{b}	74.1^{b}	401.6^{b}	341.3^{b}	3.34^{b}	5.22^{b}
Biochar + fresh chicken manure	7.8^{h}	48.6^{h}	240^{h}	174.7^{h}	2.73^{i}	4.30^{e}
Fresh chicken manure only	7.1^{i}	43.8^{i}	209.6^{i}	155.7^{i}	2.51^{j}	3.11^{i}
Biochar + compost tea (1/4)	9.3^{f}	57.5^{f}	302.6^{f}	227.9^{f}	2.98^{g}	4.58^{d}
Compost tea only ((1/4)	8.5^{g}	51.2^{g}	260.6^{g}	192.7^{g}	2.79^{h}	3.43^{h}
Biochar + compost tea (1/8)	11.5^{c}	68.5^{c}	378.3^{c}	309.1^{c}	3.31^{c}	$5.06b^{c}$
Compost tea only (1/8)	10.5^{d}	60.7^{e}	328.6^{e}	258.4^{e}	3.10^{e}	3.94^{f}
Biochar + compost tea (1/12)	10.8^{d}	64.7^{d}	341.6^{d}	278.8^{d}	3.26^{d}	4.89^{c}
Compost tea only (1/12)	9.9^{e}	58.1^{f}	299^{f}	217.8^{f}	3.03^{f}	3.72^{g}
Biochar only	2.9^{j}	19.9^{j}	146.3^{j}	109.5^{j}	2.46^{k}	2.72^{j}
Control soil	2.8^{j}	17.6^{j}	119.3^{k}	94.9^{k}	2.28^{l}	2.18^{k}

Mean values means with different letters are significantly different (alpha 0.05) by the Duncan's multiple range test

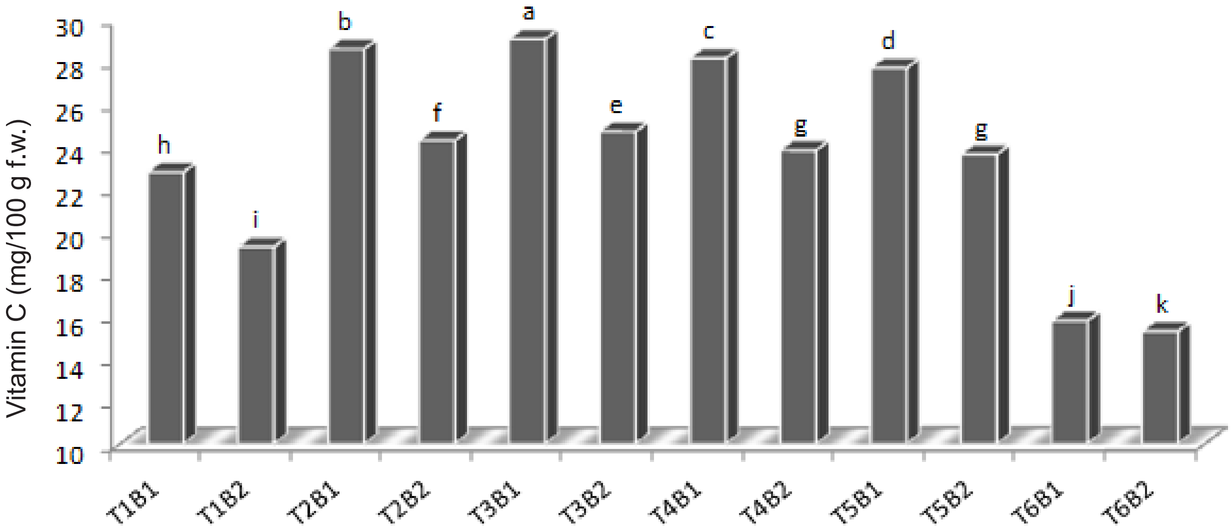

Fig 2. Interaction effect of biochar and fertilizer (organic and chemical) on tomato fruit vitamin C

Biochar amounts applied were 0 (B_2) and 10 (B_1) ton ha^{-1}, fertilizer treatments biochar and chemical fertilizers (T_1B_1), chemical fertilizer only (T_1B_2), biochar and fresh chicken manure (T_2B_1), fresh chicken manure only (T_2B_2), biochar and compost tea 1/4 (T_3B_1), compost tea only 1/4 (T_3B_2), biochar and compost tea 1/8 (T_4B_1), compost tea only 1/8 (T_4B_2), biochar and compost tea 1/12 (T_5B_1), compost tea only 1/12 (T_5B_2), biochar only (T_6B_1) and control soil (T_6B_2). Treatment means with different letters are significantly different (alpha 0.05) by the Duncan's multiple range test

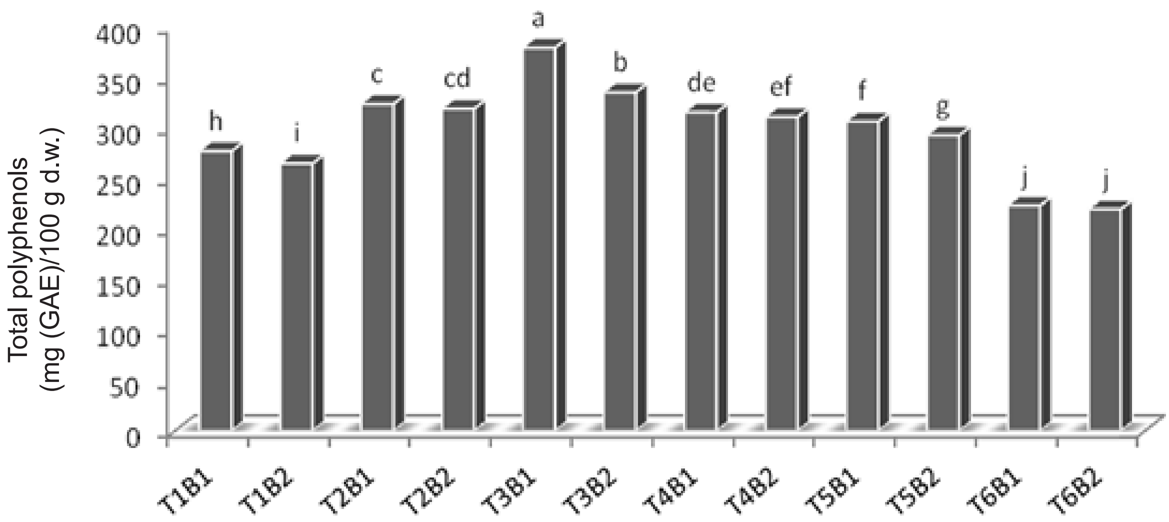

Fig. 3. Interaction effect of biochar and fertilizer (organic and chemical) on tomato fruit total polyphenols

Biochar amounts applied were 0 (B_2) and 10 (B_1) ton ha^{-1}, fertilizer treatments biochar and chemical fertilizers (T_1B_1), chemical fertilizer only (T_1B_2), biochar and fresh chicken manure (T_2B_1), fresh chicken manure only (T_2B_2), biochar and compost tea 1/4 (T_3B_1), compost tea only 1/4 (T_3B_2), biochar and compost tea 1/8 (T_4B_1), compost tea only 1/8 (T_4B_2), biochar and compost tea 1/12 (T_5B_1), compost tea only 1/12 (T_5B_2), biochar only (T_6B_1) and control soil (T_6B_2). Treatment means with different letters are significantly different (alpha 0.05) by the Duncan's multiple range test among the different treatments, as shown in Table 5. The average shoot dry weight and stem length ranged from (146 g plant^{-1}) and (109.5 cm), respectively, for the soil with biochar only treatment (T_6B_1) to (463 g plant^{-1}) and (403.3 cm), respectively, for the soil with biochar and chemical fertilizers treatment (T_1B_1). The application of biochar and organic and chemical fertilizer to the soil resulted in increased total leaf N (p = 0.0046) and plant tissue K concentration (p<0.0001), but it did not significantly affect leaf P-values on average, compared with control conditions. At harvest, the root dry weight was not significant in the plants grown on the biochar together with fertilizer plots (data not shown). Nutrients balance of the greenhouse plots showed that the overall amounts of nutrients in the plants at the end of the experiment in conventional and organic treatments were larger in the biochar plus chemical fertilizers T_1B_1 and biochar and chicken manure compost tea 1 : 8 (T_4B_1) treated plots than in the controls, respectively (Tabs 4 and 5). The interactive effect of biochar × organic and inorganic fertilizer was significant for measured leaf nutrient concentrations (except for P-values). Biochar + chemical fertilizer led to the highest values of leaf N (3.54%) and K (6.73 ppm) of greenhouse tomato.

The results of analysis of variance demonstrated that the effect of biochar on tomato fruit yield was significant (p < 0.0001); however, the effects of organic and chemical fertilizer (p < 0.0001) and interaction between biochar, organic and chemical fertilizer were significantly different (p = 0.0229). Biochar amendment in combination with fertilizer increased total fruit yield and number of fruits per plant in all treatments, but it did not significantly affect fruit length, fruit diameter, or fruit size compared with the control (Tab. 5). Plants grown with biochar and chemical fertilizers (T_1B_1) had the significantly highest average number of fruits per plant and total fruit yields, which were 19.50% and 19.94% greater, respectively, than in the treatment of soil with biochar and compost tea (1 : 8) (T_4B_1) and 365.51% and 393.9% greater, respectively, than the control soil (T_6B_2), respectively. The application of organic fertilizers did not give higher yields compared with chemical fertilizers, but for the treatment with chicken manure compost tea (1 : 8) (T_4B_1), the productivity stimulus was much greater with organic fertilizer.

Effects of biochar and fertilizer amendment on nutritional traits. Total polyphenols and vitamin C values were generally enhanced with increases in application rates of organic manure under biochar; this enhancement was significant compared to the treatment with chemical fertilizer (Figs. 2 and 3). The effect of biochar × organic and chemical fertilizers on total polyphenols (TP) and vitamin C were significant (p < 0.0001). The largest total polyphenols (378.83 mg) and vitamin C (29.03) values were detected in the treatment of biochar plus compost tea (1 : 4) (T_3B_1). Total soluble solid (TSS) and titratable acidity (TA) contents were affected non-significantly by treatment with biochar plus organic and chemical treatments (data not shown).

DISCUSSION

The use of biochar, chemical fertilizers, fresh chicken manure and chicken manure tea compost improved soil chemical properties significantly compared with the control (Tab. 4). Soil EC, total nitrogen, available phosphorus, and available potassium were increased, while wood biochar (10 t ha^{-1}) × organic and inorganic fertilizer caused no significant difference on soil pH. It is noteworthy that the treated soil proved a high buffering capacity and, therefore, no additional liming effect on the soil. Similar findings were achieved by Paneque et al. [2016] under greenhouse conditions. The increase in EC values following the addition of biochar plus organic and inorganic fertilizer was consistent with the analysis presented for organic matter (Tab. 4). In this study, the application of biochar together with fertilizer resulted in relatively large increases in soil nutrient concentrations. Additionally, the enhancement in soil EC due to the addition of biochar could generally be attributed to the accretion of ash containing soluble salts, the release of fused-ring aromatic structures, and the high aromaticity and abundance of polycyclic aromatic hydrocarbons of wood biochar samples [Paneque et al. 2016]. Vaccari et al. [2015] showed that CEC was enhanced in biochar, likely due to the presence of cation exchange sites on the biochar surface. This encouraged the improved N nutrition and enhanced P and K contents in the biochar-amended plots. The reaction of leaf nutrient concentrations of tomato to the application of biochar and organic and chemical fertilizer was consistent with the values of the soil chemical properties obtained for these treatments. There was enhanced nutrient availability in the soil as a result of using biochar and organic and inorganic fertilizer, which led to increased uptake by tomato plants [Adekiya et al. 2018]. Chemical, physical, and possibly microbiological actions may explain the observed responses [Vaccari et al. 2015]. Encouragement of dry mass accumulation in plant parts likely received by higher N, K and P availability in the soil and significant increases in the leaf levels of N and K (but not for P), resulted in taller plants and increased total plant dry matter, proving a direct role for biochar in the nutrient supply to plants as well as organic manure [Walker and Bernal 2008, Vaccari et al. 2015]. The insignificant phosphorus content likely contributed to the increase in cations that interact with phosphate (e.g., Ca^{2+}), by adsorbing them on the biochar surface and, therefore, delaying phosphate adsorption and/or precipitation in the soil [Vaccari et al. 2015]. The application of biochar together with fertilizer did not influence the root dry weight significantly. (The data was not shown). On the other hand, may indicate improved resource supply that requires fewer roots to sustain the same above-ground biomass production [Lehmann et al. 2011].

The present results indicate that the application of biochar to sandy clay loam soil significantly increased fruit yield probably because of the increased plant water status [Akhtar et al. 2014], ash and nutrients [Paneque et al. 2016], and the ability of biochar to retain nutrients in the soil [Lehmann et al. 2011]. The results are in agreement with findings that biochar decreased leaching of applied mineral N fertilizer and encouraged better utilization of applied nutrients [Lehmann et al. 2011]. An adequate supply of potassium increases ammonium utilization, thereby improving crop yield [Dibb and Welch 1976]. The organic fertilizers applied did not result in higher yields compared with the applied chemical fertilizers, and biochar and compost tea (1 : 8) T_4B_1 led to the highest total tomato yield from the organically fertilized plants (Tab. 5). Organic fertilizers release nutrients more slowly than chemical ones, resulting in reduced ion concentrations in the leaves, which limits growth and yield in organic manures [Ghorbani et al. 2008]. Because the nutrients added through fertilizer were optimal for tomato growth and production, the improved yield observed in the combined wood biochar and fertilizer treatment, when compared to fertilizer only, suggests additional beneficial effects of biochar inclusion, which are beyond the exclusive nutrient effect. Jeffrey et al. [2011] stated that statistically significant increases in crop productivity, with a mean increase of 10%, were seen when wood and other feedstock biochar was used concomitantly with inorganic fertilizer, considering different crops, soils, and climates. However, the application of wood biochar at 10 t ha^{-1} cannot fully substitute for fertilizers. Therefore, nutrition management can be achieved by biochar plus fertilizer and can increase tomato productivity.

The current results clearly demonstrate that adding biochar to soil under organic fertilizer better improved total polyphenols and vitamin C of tomato fruits, which might be due to the enhanced water uptake and improved plant physiology achieved with the addition of biochar [Akhtar et al. 2014] and the changes in the nutritive composition of plants with the application of fertilizer [Mitchell et al. 2007, Vallverdú-Queralt et al. 2012]. Fruit quality, in terms of TSS and TA, was not affected by biochar treatments. The current findings are in agreement with the results of Petroccelli et al. [2015], who reported that the primary metabolites of tomato fruits (TSS and TA) showed no significant changes in tomato plants grown in substrates amended with biochar (straw and olive residues biochar). Phenolic compounds result from secondary metabolism and play a critical role in the development and regulation of plant growth, the adaptation of plants to the environment, and in overcoming stress conditions.

In general, even though the application of chemical N fertilizer increases yield, N fertilizers decrease vitamin C concentrations and secondary plant metabolites which lack N in their structure, such as phenolics and flavonols that are favored under N-limiting conditions [Dorais et al. 2008]. However, tomato shoot biomass production and fruit yields were lower in the organic-N (a mixture based on chicken manure) treatment than in the inorganic-N treatments, but fruit quality was good [Heeb et al. 2005].

CONCLUSIONS

This study showed that plant tissue N and K concentrations and soil N, P, and K concentrations increased following the addition of biochar. Although biochar affected the soil nutrients and supported plant growth and yield, its effects were not equivalent to those of fertilizer; wood biochar together chemical fertilizer and chicken manure compost tea were more effective for improving plant productivity and tomato fruit quality, respectively. This provides an enormous economic advantage in terms of production and the addition of biochar and fertilizers.

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