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PERIODICAL CHANGES OF SOME SOIL PROPERTIES OF A CALCAREOUS SOIL UNDER FIELD CONDITIONS AS AFFECTED BY DIFFERENT BIOCHAR APPLICATIONS

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ABSTRACT

In this study, the effects of the application of biochars derived from tomato harvest residues on some properties and nutrient concentrations of calcareous soils were investigated. Biochars produced at different pyrolysis temperatures (300, 500, and 700°C) with the duration of 4 hours were applied to the depth of 15 cm at the rates of 30 t/ha to microplots established (50 cm x 50 cm) in field conditions. Soil samples were taken at four soil incubation periods and were analyzed for pH, cation exchange capacity (CEC), plant available and/or extractable K, Ca, Mg, P, Fe, Mn, Zn, and Cu. Mean values showed that soil pH significantly increased with the increasing incubation time and pyrolysis temperature. All other parameters examined in the study were significantly affected by the interaction of incubation time and pyrolysis temperature. Depending on the results, it can be concluded that the biochars produced at different temperatures and the soil incubation periods did not have a significant contribution on the exchangeable cations and the other nutrients of soil. Furthermore, it was observed that the biochar obtained at the pyrolysis temperature of 700°C generally had a negative effect.

Keywords: biochar, incubation time, nutrients, soil, tomato harvest residue.

INTRODUCTION

Awareness on soil fertility in terms of soil conservation and sustainability is increasing especially in lands where intensive agricultural activity is performed. Besides several well-known ways to achieve these goals, there are also some materials that have a positive impact on maintaining soil fertility. Among these materials, biochar is one of the well-known input material used for sustainable soil fertility. Improvement of soil properties by means of biochar can be classified under three groups as land reclamation, agronomic productivity and reduction of greenhouse gas emissions from soil (Stavi, 2012; Spokas et al., 2012; Augustenborg et al., 2012)

Biochar, produced by a process called as pyrolysis, is a carbon-rich and porous material. When used as a soil amendment, biochar can boost soil fertility and improve soil quality by increasing soil pH, increasing moisture-holding capacity, attracting more beneficial microorganisms and improving cation exchange capacity (Schmidt and Noack, 2000; Lehmann et al., 2006; Lehmann, 2007; Herath et al., 2013). Incorporating carbon to the soil, biochar can increase soil fertility by helping nutrients to be held for a longer period of time within the root zone (Prendergast Miller et al., 2014). This leads to increase in nutrient use efficiency by the plants. Depending on the properties of biomass, most of the biochars obtained by dry-pyrolysis is alkaline (Lehmann et al., 2011; Sun et al., 2014).

At the same time, the pH value of the biochars is related to the pyrolysis temperature and duration. It has been reported that substances exposed to longer pyrolysis duration at the same temperature

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are more alkaline (Mukherjee et al., 2011; Yuan et al., 2011a). Although numerous studies have focused on the effects of the biochar application on the pH of the acidic soils, it has been reported that the biochar increases pH in high pH alkaline soils (Blackwell et al., 2010a; Van Zwieten et al., 2010; Yuan and Xu, 2011).

Tomato production in the covered area in Turkey was estimated as 4,083,681 tons in 2019 (TURKSTAT, 2020). Residues of this production are generally eliminated by burning near the greenhouses, at sea sides and river beds, and this eventually leads to air, environmental and visual pollutions (Erdal et al., 2018). In order to prevent the mentioned problems and to provide a cleaner and healthier environment, these wastes can be converted into biochar by pyrolysis process. As a result, a reduction in the quantity of such agricultural wastes could be provided during biochar production.

This study aimed to investigate the effect of the application of biochar derived from tomato harvest residues at different pyrolysis temperature on the changes of some soil properties during different incubation periods.

MATERIAL AND METHODS

Biochar material

Tomato harvest residues were air dried and crushed to a particle size of <4 mm before pyrolysis procedure. Then, tomato harvest residues were converted to biochar by slow pyrolysis method. A cylindrical batch pyrolysis reactor was used for biochar production. The effective volume of chamber of the reactor was 50 liters. Biochar production was performed under the temperature of 300, 500 and 700°C during for 4 hours. After combustion, biochar materials obtained were ground and then passed through sieves with a mesh size of <2.0 mm using a rotational sieve. Some properties of tomato harvest residues were as follows pH: 6.94, Electrical conductivity (EC): 4.78 (dS m^{-1}), total C: 221 g/kg and total N: 20 g/kg (Memici, 2018).

Soil characteristic before treatments

Some parameters of the soil representing the experimental area are given in Table 1. The soil is slightly alkaline, high in $CaCO_3$, low in organic matter. Soil is sufficient for all measured nutrients (Alpaslan et al., 2005).

Table 1. Some important properties of the soil in the experimental area

Properties	
Texture	Clayey loamy
pH (1:2.5 H_2O)	8.0
Organic matter (%)	1.8
$CaCO_3$	18
Cation exchange capacity (mmol kg^{-1})	230
Plant available P (mg kg^{-1})	63
Exchangeable K (mg kg^{-1})	156
Exchangeable Ca (mg kg^{-1})	6000
Exchangeable Mg (mg kg^{-1})	379
DTPA extractable Fe	11
DTPA extractable Mn	31
DTPA extractable Zn	2.9
DTPA extractable Cu	5.2

Soil analysis

Soil samples were collected at the depth of 0-15 cm from each plot. After collection, the samples were cleaned from the plant residues and rough materials. Then, air dried and then sieved through 2 mm sieves. These procedures were repeated for each sampling period. Soil was extracted with $NaHCO_3$, and P was measured according to molybdophosphoric blue color method (Olsen, 1954). Exchangeable K, Ca and Mg were determined using atomic absorption spectroscopy (AAS) after NH_4AOC extraction (Jackson, 1967). For Fe, Mn, Zn and Cu analysis, the samples were treated with diethylenetriaminepentaacetic acid (DTPA) and concentrations in the supernatant were measured using AAS (Lindsay and Norvell, 1969). CEC, pH, $CaCO_3$, texture and organic matter were measured as described by Rhoades (1982), Peech (1965), Allison and Moodie (1965), Bouyoucos (1951), and Walkley and Black (1934).

Harvest residues and biochar analysis: the pH and electrical conductivity (EC) of harvest residue and biochars were measured using 1:10 solid: solution ratio after shaking for 20 min, 120 rpm in deionized water on orbital incubator (Memici, 2018). Total C and N contents were determined using an Elemental analyzer (vario MAX CN, Elementar, Germany). The samples were wet digested with nitric and perchloric acid mixture (4/1, V/V) in with a microwave digestion system and then filtered up to 50 mL with de-ionized water for P, K, Ca, Mg, Cu, Zn, and Mn measurement. Total P, K, Ca, Mg, Zn, Fe and Mn concentrations in biochar were determined after digestion. Phosphorus concentration was measured spectrophotometer by vanadate-molybdate method. Other nutrients were determined using atomic absorption spectrophotometer (Havlin and Soltanpur, 1980; Mills and Jones 1996). A modified ASTM method (D-1762-84) by measuring the mass loss after the burning of about 10 g of biochars and tomato harvest residues at 900°C for 6 min and at 750°C for 2 h was adopted to measure ash contents, respectively.

Experiment set up and data analysis

The biochars obtained were applied into bare microplots prepared in 50x50 cm dimensions at the depth of 15 cm at the rates of 30 t/ha in the field conditions. The trial started on June 2017 and ended on October 2018. The study was planned according to completely randomized design with three replications. Soil samples were taken every 4 months during the whole period of the field experiments. The soil incubation period (I) was classified as I1: October 2017, I2: February 2018, I3: June 2018, and I4: October 2018. Biochar applications were named based on the pyrolysis temperature (T) of T1: 300°C, T2: 500°C, and T3: 700°C. The parcel that was not included any biochar material (control) was marked as 'T0'. Variance analysis was performed by using Minitab 16 package program. The mean values were compared using the Tukey multiple comparison test.

RESULTS AND DISCUSSION

Changes in the pH values, ash content and total nutrient concentrations of biochars

Variations of some properties of biochars produced under tree different temperatures (300, 500 and 700°C) are presented in Table 2. Results showed that there was a significant effect of temperature on most of the biochar properties. Although, there is no a statistical evaluation on the measured parameters, it can be clearly seen that the values of all parameters except for C, increased with the pyrolysis temperatures. The highest increase rates were determined between 300 and 700°C. The pH of the biochars increased significantly with the pyrolysis temperature. Among the biochar products, the lowest value (6.31) was recorded at the pyrolysis temperature of 300°C. However, this value increased and reached to 9.1 (at 500°C) and 9.7 (at 700°C). Therefore, it was concluded that pH of biochar obtained from low temperature was acidic; however it was alkaline at 500 and 700°C. The main reason for the increases in pH values can be attributed to the formation of alkali salts from organic materials as a result of the increased pyrolysis temperature (Yuan et al., 2011a). Additionally, concentrated alkaline cations in biochar under higher temperature might have contributed to the increase in pH (Al-Wabel et al., 2013). Ash contents of biochar showed a linear increase with the pyrolysis temperature. While the ash content of the biochar obtained at 300°C was 123 g/kg, this value showed 2.3 and 2.5 folds increases with the increase of temperature from 300 to 500 and 700. The increase in ash content was reported by Yuan and Xu (2012) and Murray et al. (2015). This could be attributed to the concentrated mineral nutrients in the material with increased temperature (Peng et al., 2011; Naeem et al., 2014). Total C content (221 g/kg) of tomato harvest residues increased to 439, 444, 413 g/kg with the slow pyrolysis process with the increment of 49.65%, 50.18% and 45.06%, respectively, for the pyrolysis temperature 300, 500 and 700°C. However, total C content did not increase linearly with increasing temperature (Memici, 2008). In pine derived biochar, the content of carbon increased when the temperature increased from 300°C to 500°C (Kim et al., 2012). It has been determined that the prolonged residence time also increased the C content (Yuan et al., 2014).

Table 2. Variation of some basic properties of biochars produced under tree prolysis temperature

Pyrolysis temp. (°C)	pH	Ash	C	N	P	K	Ca	Mg	Fe	Zn	Mn	Cu
		(g/kg)							(mg/kg)			
300	6.3 a*	123 a	439	19.1 a	8 a	22 a	23 a	9 a	350 a	83 a	37 a	22 a
500	9.1 b	284 b	444	21.7 a	8 a	41 b	34 b	10 a	643 b	110 b	80 b	22 a
700	9.7 b	302 c	413	24.4 b	12 b	43 b	61 c	16 b	750 c	166 c	227 c	43 b

* Shows the differences between the pyrolysis temperatures. There is no difference between the values sharing the same letters ($p<0.05$).

Increasing pyrolysis temperature from 300 to 700°C increased N, P, K, Ca and Mg concentrations as 28, 50, 95, 165, and 78%, respectively. Furthermore, total micronutrient concentrations in the biochars increased with the increase in the pyrolysis temperatures. While the total Fe, Zn, Mn and Cu concentrations of the biochar produced at the temperature of 300°C were 350, 83, 37 and 22 mg/kg, these values increased to 750, 166, 227 and 43 mg/kg, respectively, for the biochar produced at the temperature of 700°C. These results showed that nutrients concentrations increased with the increasing pyrolysis temperature, mainly due to a concentration effect of these elements in biochar samples with temperatures without volatilization (Novak et al., 2009). Additionaly, increasing ash content with the pyrolysis temperature may be the other reason for the nutrient increase in the biochars (Smider and Singh, 2014; Murray et al., 2015).

When compared to the feedstock, N concentration of biochar obtained at low (300°C) temperature decreased from 20 the 19.1 mg/kg, but then increased to 21.7 and 24.4 mg/kg at 500°C and 700°C. Nitrogen is removed from the environment through NH_4-N and NO_3-N losses, as well as by volatile substance loss containing N groups at a temperature of 200-250°C. However, they slowly transform into pyridine-like structures with increasing temperature (>600°C) (Bagreev et al., 2001). Although nitrogen is often lost in gas form during thermal decay, it has been reported that some biochars are enriched in N through the formation of heterocyclic N compounds (Knicker, 2007). The reason for not occurring nutrient loss for other nutrients can be their high vaporization temperature (760-1240°C) (Knicker, 2007; Olsson et al., 1997).

Changes in soil pH, CEC, K, Ca, Mg and P

The results of variance analysis on pH, CEC, K, Ca, Mg and P and their values obtained from the treatments were presented in Table 3 and Table 4, respectively. It can be said that individual factors and/or their interactions significantly affected all parameters.

Table 3. F values of the soil pH, CEC, K, Ca, Mg and P values obtained from variance analysis

Sources of variation	DF	F values					
		pH	CEC	K	Ca	Mg	P
Incubation period (A)	3	7.95‡	4.11*	15.9‡	14.5‡	19.2‡	48.7‡
Pyrolysis temperature (B)	3	ns	19‡	81.4‡	20.3‡	10.4‡	21.4‡
A x B	9	ns	6.81‡	4.27†	12.3‡	3.73†	17.2‡
Error	32						

DF: degree of freedom; *: $p<0.05$; †: $p<0.01$; ‡: $p<0.001$; ns: non-significant.

The pH values measured in the soil depending on the treatments showed a change in the range from 7.93 (I1+T1) to 8.23 (I1+T1) (Table 4). Among these variations, only incubation period was found to be significant on soil pH. Small changes in soil pH were observed when the temperature increased from 300 to 700°C. In recent studies, it was reported that the pH of the calcareous soils was quite stable and there was no significant change in the pH of the soils with the use of biochars (Zhang et al., 2011; Liang et al., 2014). The non-significant change in pH value of soils examined in the present study may be attributed to the high buffering capacities of calcareous soils (Bache, 1984). The results showed that pH values of the biochars obtained at 500 and 700°C were 9.1 and 9.7, respectively. The level of alkalinity of these biochars consequently led to an increase in soil pH with time (Yuan and Xu, 2011; Van Zwieten et al., 2014). In this study, depending on the incubation period, the pH values of the soils increased from 8.03 (I1) to 8.19 (I4). These results are in the agreement with the previous studies and the findings can be explained with the release of alkali cations with the time (Fellet et al., 2011; Peng et al., 2011; Yuan et al., 2011b; Murray et al., 2015). Furthermore, it was stated that the amount of carbonate, which causes alkalinity in the biochars obtained at higher temperatures, increases, thus contributing more to the alkalinity of the soil (Yuan et al., 2011a).

Based on the mean values, the CEC values of the soils increased by 11-22% compared to the control due to the increase of the pyrolysis temperature (Table 4). It can be said that biochars obtained at higher temperatures having higher CEC are more effective in increasing CEC of soil. Likewise, Yuan et al. (2011a) reported that CEC values of biochars obtained at high temperatures (500-700°C) are generally higher than those of low temperature (300°C). This was due to the increased surface area and the negative charge density of biochars depending on the pyrolysis temperature. There was no significant change in the CEC values of the soil due to the incubation period. The interaction of pyrolysis temperature with incubation period on CEC values of the soil had a significant effect. While the lowest CEC values were obtained from the control treatments, the highest value was reached in I4+T2. Generally speaking, it can be said that biochar applications increased CEC values of soil. In various studies, it was reported that biochar increases CEC of the soil due to the increased surface area and charge of biochars (Oguntunde et al., 2004; Liang et al., 2006; Yuan and Xu, 2011; Peng et al., 2011; Machado et al., 2018). In addition, during the formation of the biochar, the aromatic C is oxidized and the carboxylic groups are formed. This may be another factor that leads to an increase in CEC (Mikutta et al., 2005; Liang et al., 2006).

As for soil K concentrations, it was seen that the K concentrations obtained from T1 were higher than the others and the highest K concentration was determined in I2+T1 (Table 4). This situation was also reflected in the mean values and the mean K value in T1 was 24% higher than the control. Although it was pointed out that biochar application increases the K concentration of soil (Van

Zwieten et al., 2010), it was observed that the K concentrations of soil decreased with biochar application where its pyrolysis temperature was above 300°C. Although K concentrations decreased with increasing pyrolysis temperature, incubation time at each pyrolysis temperature increased the amount of soil K slightly. With the increase in the pyrolysis temperature, the total and water-soluble K in biochar is exposed to more losses. Or their availability decreases by transforming them into insoluble silicate forms (Wornat et al., 1995; Shinogi, 2004; Yu et al., 2005; Lehmann and Joseph, 2015). In addition, due to the increased pyrolysis temperature, the negative charge due to the increased surface area may have caused the fixation of the existing K in the soil (Lehmann and Joseph, 2015). When the mean values of incubation periods were examined, the K concentrations of soils in I2, I3 and I4 periods showed an increase of 22, 9 and 16% compared to the initial soil (I1), respectively. The effects of all applications except for I1+T3 on soil Ca concentration were close to or below the control treatment. According to the mean values, the incubation periods and the biochar applications had no significant effect on the exchangeable Ca content of the soil. Soil Mg concentrations measured due to the biochar applications and incubation periods were generally similar to or lower than that of the control group. According to the mean values, the effect of the biochar applications on the Mg content of soil was negative. The highest Mg value was obtained from control (T0) while the lowest value was measured in T3 (Table 4).

Soils containing high amounts of Ca and Mg can be effective in the fact that the biochar does not contribute to soils in Ca and Mg. In addition, Chan and Xu (2009) stated that the change of exchangeable alkaline cations to slow release or acid-soluble fractions during pyrolysis may also have an effect on this situation. In the study conducted, it was highlighted that the biochars are more effective in low acidic soils (Yuan and Xu, 2011).

Phosphorus concentrations of soil were generally observed to be the highest in I2 and I3 incubation periods of each biochar application while it decreased, especially, in the last incubation period (I4). The lowest P concentrations were obtained from T3. The decrease in P concentrations of soils in I4 compared to the control group at the similar period were as follows: 40.5% in I4+T0 and I4+T1, 30.5% in I4+T2, and 32.7% in I4+T3. Similarly, it was reported that soil P concentrations showed decrement with biochar applications by approximately 40% under 25 and 67 - day incubation periods and these reduction have been explained with higher sorption capacity of biochar for selective nutrients including P (Novak et al., 2009). At the same time, increased Ca released from biochars to soils might be resulted in Ca-induced P sorption or precipitation especially in longer incubation period (Xu et al., 2014). It is also possible that the increase in pH caused by the application of biochar will transform the soil P into insoluble compounds (Marschner, 2011). In addition, phenomenon related to biochar-induced retention or binding to organic molecules can also lead to a reduction in the amount of available P (Preston and Smith, 2006; Bornermann et al., 2007; Lehmann and Joseph, 2015).

Table 4. Effect of the biochar application and incubation periods on soil pH, CEC, K, Ca, Mg and P values of soil

Treatments		pH	CEC (mmol/kg)	K (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	P (mg/kg)
I1 + T0		8.10	227c	156cd	6140b	375ab	62.0ab
I2 + T0		8.06	231c	155cd	6140b	379ab	65.9ab
I3 + T0		8.04	241c	151cd	6140b	388ab	65.0ab
I4 + T0		8.12	226c	161d	6141b	375ab	64.0ab
I1 + T1		7.93	233c	159cd	5860bc	358d	66.7ab
I2 + T1		8.07	266abc	228a	5560c	404a	72.0a
I3 + T1		8.12	265abc	201ab	5900bc	373ab	74.5a
I4 + T1		8.18	257bc	189abc	6340b	379ab	38.1d
I1 + T2		8.05	288ab	140de	6300b	306bc	56.1bc
I2 + T2		8.11	268abc	184bc	6140b	384ab	65.9ab
I3 + T2		8.18	271ab	142de	6140b	369ab	69.4a
I4 + T2		8.21	303a	167bcd	6280b	347ab	44.5cd
I1 + T3		8.06	261abc	111f	7820a	256bcd	49.8cd
I2 + T3		8.10	263abc	124ef	6080bc	260bcd	48.6cd
I3 + T3		8.15	262abc	120ef	6180b	296bc	38.8d
I4 + T3		8.23	274ab	137def	6180b	324bc	43.1cd
Means	I1	8.03C	252	141	6530	296	58.7
	I2	8.09BC	252	173	5980	356	69.6
	I3	8.14AB	260	154	6090	357	61.9
	I4	8.19A	265	163	6235	356	48.8
	T0	8.08	231C	156	6140	379	64.2
	T1	8.08	258B	194	5915	350	62.8
	T2	8.14	282A	158	6225	351	59.0
	T3	8.14	265AB	123	6565	284	51.5

Small letters indicates the interaction effects and capital letters indicate main factor effects.
There is no difference between the values sharing the same letters ($p<0.05$).

Soil Fe, Mn, Zn and Cu changes during incubation periods

The results of variance analysis on soil Fe, Mn, Zn and Cu and their values obtained from the treatments were presented in Table 5 and Table 6, respectively.

Table 5. F values of the Fe, Mn, Zn and Cu values obtained from variance analysis

Sources of variation	DF	F values			
		Fe	Mn	Zn	Cu
Incubation period (A)	3	20.9†	24.7†	8.4†	ns
Pyrolysis temperature (B)	3	11.4†	84.0†	34.5†	22.4†1
A x B	9	2.9*	6.5†	2.9*	2.31*
Error	32				

DF: degree of freedom; *: $p<0.05$; †: $p< 0.001$; ns: non-significant.

Individual effects of incubation period and pyrolysis temperature of biochars and their interactions significantly affected periodical variations of micronutrient concentrations in the soil generally (Table 6). The effect of biochars on soil available Fe concentration was found to be positive in the early period. As for soil Fe concentrations, it can be seen that the highest values were determined from I1 for all pyrolysis temperatures examined. However, the lowest Fe value was measured from I4+T3 treatment. Soil Mn concentrations showed decrement depending on the pyrolysis temperature and incubation periods. Biochars obtained from all pyrolysis temperatures for I1, I2 and I3 did not affect soil Mn concentrations. Soil Zn concentrations changed between 2.08 (I3+T1) and 3.97 mg/kg

(I1+T2) depending on the treatments. Except for both treatments, there was no significant difference among the rest in terms of soil Zn concentrations. Based on the mean values, it can be said that soil Zn concentration decreased with the increasing incubation periods. The highest soil Zn was measured from the biochar with the pyrolysis temperature of 500°C. Generally speaking, the effect of biochars produced at 300 and 500°C on soil available Cu concentrations was similar to that of the control group whereas the effect of biochar obtained at the highest temperature (700°C) was significantly negative compared to the others. Available Cu concentration in the soil significantly decreased with incubation periods, especially in 12 months (T3) when compared to the control group (T0).

According to the results of the change in the micronutrients concentrations of soils depending on biochar applications and incubation time, it can be concluded that the effect of biochar applications except for a few applications for each element was either not or negative. Similar results were found by Kloss et al. (2012). Incubation period of the biochar, especially obtained at higher temperature, adversely affected the available microelement concentration. These may be the results of longer chemical reaction between biochar colloids and nutrients and increased surface area and the negative charge density of biochars obtained at higher temperatures (Yuan et al., 2011a). The alkaline character and the increase in pH caused by the biochar could be the main reason of the decrease in the availability of the microelements by biochar applications (Masunaga and Fong, 2018).

Table 6. Effect of the biochar obtained at different temperatures and soil incubation periods on Fe, Mn, Zn and Cu values of soil

Treatments		Fe (mg/kg)	Mn (mg/kg)	Zn (mg/kg)	Cu (mg/kg)
I1 + T0		11.9de	30.9bc	2.93bcde	5.33ab
I2 + T0		11.7de	31.6bc	2.93bcde	4.99ab
I3 + T0		11.6de	32.4bc	3.10bcde	5.26ab
I4 + T0		10.9de	31.8bc	2.83bcde	5.30ab
I1 + T1		17.9a	35.8abc	2.52cdef	4.81abcd
I2 + T1		11.9cde	39.5a	2.66bcde	4.06abcd
I3 + T1		14.2abcd	40.4a	2.08ef	4.15abcd
I4 + T1		12.8bcde	31.5bc	2.86bcde	5.37a
I1 + T2		17.0ab	32.2bc	3.97a	4.10abcd
I2 + T2		12.2cde	33.3bc	3.15abcd	4.39abcd
I3 + T2		13.4abcde	30.6cd	3.57ab	5.41a
I4 + T2		11.0de	22.8e	3.39abc	5.09abc
I1 + T3		16.3abc	25.4de	3.18abcd	3.71cd
I2 + T3		11.7de	25.0de	2.37def	3.42d
I3 + T3		13.5abcde	24.7de	2.70bcde	3.67cd
I4 + T3		9.82e	19.9e	2.40def	3.59d
Means	I1	15.8	31.1	3.15	4.49
	I2	11.9	32.3	2.78	4.22
	I3	13.2	32.0	2.86	4.62
	I4	11.1	26.5	2.87	4.83
	T0	11.5	31.7	2.95	5.22
	T1	14.2	36.8	2.28	4.60
	T2	13.4	29.8	3.52	4.75
	T3	12.8	23.8	2.66	3.62

Small letters indicates the interaction effects and capital letters indicate main factor effects.
There is no difference between the values sharing the same letters ($p<0.05$).

CONCLUSIONS

Tomato harvest residue derived biochar applications and incubation time slightly increased soil pH and CEC. Although, the total nutrient concentrations of the biochar increased with the increasing pyrolysis temperature, this was not reflected to the available soil nutrient concentrations under soil conditions. Biochar applications and incubation time, in comparison with the control, generally did not have an effect on the availability of most nutrients, and in some cases, in particular biochar produced at 700°C adversely affected. Considering that the positive effects determined are generally in the biochars produced at 300 and 500°C, it can be concluded that the production of biochars at 700°C does not make any sense in terms of the examined criteria. As conclusion, in calcareous soils, it was observed that tomato harvest residue derived biochar did not make a significant contribution to fertility parameters such as pH and the existing nutrient elements in the conditions where no fertilization was done.

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