

# Effects of biochar and fertilizer application on soil properties and nutrient status of lettuce

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## ABSTRACT

Different ways of benefiting from plant wastes in agricultural production are developed. One of the methods is to convert wastes into biochar and use it as a soil regulator. This study was conducted to determine the effects of biochar produced from tomato (*Solanum lycopersicum* L.) plant waste on soil fertility and nutritional status of the lettuce (*Lactuca sativa* L.) plant. For this purpose, the combined effect of five different doses of biochar (0, 10, 20, 30, and 40 t ha<sup>-1</sup>) and three chemical fertilizers (control, half-dose NPK and full-dose NPK) were investigated. The research was conducted in two cultivation periods. Biochar was applied to the soil just in the first period. In the first period, applications increased electrical conductivity, organic matter content, total N, and concentration of available P, Zn, and Mn, and the exchangeable K and Mg in the soil. Biochar and chemical fertilizer applications positively affected the lettuce plant's N, P, and K concentrations. In the second period, concentrations of the available P, Fe, Zn, Mn, Cu and exchangeable Ca, Mg in soil, as well as the N, P, Ca, Mg, Zn, and Cu concentrations of the plant are higher compared to the first period. It was determined that biochar application alone was not sufficient for the nutrition of the lettuce plant, chemical fertilizers should be used additionally. In lettuce cultivation, half-dose NPK was recommended in addition to 30 t ha<sup>-1</sup> biochar. As a result, it was determined that biochar produced from tomato plant waste was an effective soil improver material and might be an alternative source of K.

**Key words:** Biochar, *Lactuca sativa*, nutrient availability, organic matter, potassium, tomato plant waste.

## INTRODUCTION

In Turkey, active in many branches of plant production, it is estimated that 50-65 million tons of plant waste are generated annually (Başçetinçelik et al., 2005). As it is known, with a cultivation area of 187 070 ha and a production amount of 12.75 million tons, Turkey is the 5<sup>th</sup> largest tomato-producing country in the world (FAO, 2017). In addition to the branches and leaves that are pruned during the tomato growing process, with the plants that are removed at the end of the harvest period, root, stem, leaf, and fruit wastes emerge. However, due to reasons such as organizational and financial difficulties encountered in the collection and transportation of these plant wastes, poor public awareness about their recycling, and lack of state policies and regulations determined and put into practice in this regard, organic waste is either burned or deposited on roadsides, stream beds, in forests and empty lands (Fernández-Gómez et al., 2013). These disposal methods cause environmental pollution as well as the loss of nutrients found in plant organs. Sonmez et al. (2008) reported that 584 745 t ha<sup>-1</sup> plant waste was formed as fresh weight at the end of the tomato growing period in the Antalya region and 7043 t ha<sup>-1</sup> nutrient was wasted with these wastes. Similarly, Sonmez et al. (2002) found that tomato cultivation was carried out in about 8214.2 ha of area in Antalya province and that with the plants removed from the total area at the end of the cultivation period, 762.28 t N, 48.22 t P, 572.53 t K, 467.39 t Ca and 174.96 t Mg were lost. Reintroducing these plant nutrients to agricultural production by recycling is very important economically in Turkey, which is completely dependent on abroad for the supply of basic raw material sources of fertilizer production such as natural gas, phosphate rock, and potassium salt. Indeed, to meet the nutrient needs of the plants in Turkey in 2017, 1.765 million tons N (urea,

ammonium sulfate, and 20.20.0), 775 t P (triple superphosphate, di-ammonium phosphate and 20.20.0) and more than 125 t K fertilizer (potassium nitrate and potassium sulfate) were used (Anonymous, 2019). Whereas chemical fertilizers positively affect crop yield, they can threaten environmental health. This dilemma has made it obligatory that alternative farming practices, which improve soil fertility by maintaining ecological balance or help reduce chemical inputs, are preferred instead of traditional farming practices.

The importance given to the recovery of organic waste in the world has increased rapidly and numerous techniques for the conversion of biomass have been developed. Through providing thermal decomposition of organic wastes under low temperature and oxygen-free conditions by using pyrolysis, which is one of these techniques, biochar material that is rich in C and minerals is produced. Since biochar has high cation exchange capacity, large surface area, and porosity, it can improve the physical and chemical properties of the soil (Lehmann and Joseph, 2009). Since biochar is composed of decomposition-resistant aromatic and heterocyclic C, it is seen as an important material for preserving soil organic matter and maintaining soil fertility (Schulz and Glaser, 2012). The amount of organic matter of Turkey's soils is low due to semi-arid and arid climatic conditions (Kacar and Inal, 2008). By using compost and livestock manure, the amount of organic matter in the soil is attempted to be increased; however, the rapid decomposition of these organic materials has led the biochar-based soil management strategies to attract more attention.

In 2019, 499 766 t of lettuce (*Lactuca sativa* L.) were produced in Turkey (TUIK, 2019). Since the lettuce plant, whose green leaves are consumed raw, is able to store anions and cations extensively within its structure, it is required that chemical fertilizers should not be used extensively during its cultivation.

For these reasons, this study was conducted to determine the effects of direct use of tomato (*Solanum lycopersicum* L.) plant wastes, which are the active organic waste source of the region, through converting to biochar and the residual effect of it in the subsequent cultivation period on the productivity parameters of the soil and on the yield and nutritional status of the lettuce plant in soils in the Mediterranean region that has low amount of organic matter, calcareous, and neutral and alkaline reaction.

## MATERIALS AND METHODS

### Soil sampling and biochar production

Pot experiments were laid out greenhouse in Western Mediterranean Agricultural Research Institute. Table 1 gives the initial soil properties. Since tomato (*Solanum lycopersicum* L.) cultivation is widespread in our country and creates a significant amount of plant waste, tomato plant wastes were used as the raw material of biochar. For the production of biochar, branches, stems, and leaves removed from the soil at the end of tomato cultivation were dried until the humidity was between 5%-7% under direct sunlight and they were divided into small pieces of 7-10 cm. The pyrolysis process was carried out by keeping the branches, leaves, and body of the tomato plant under oxygen-free conditions at a temperature of 300 °C for 3 h in a 250 cm<sup>3</sup> volume aluminum container. The obtained biochar was ground and passed through a 2 mm sieve for use in analyses and crop production. Some chemical properties of the biochar and the tomato plant wastes from which it was produced are given in Table 2.

### Experimental design and plant growth

Plastic pots were filled with 2 kg air-dry soil. The soil in the pots was mixed with five different doses of biochar: 0 (B0), 10 (B10), 20 (B20), 30 (B30), 40 t ha<sup>-1</sup> (B40), it was irrigated at 70% of the field capacity, and left for incubation for 2 wk. At the end of the 2 wk period, four lettuce seedlings (*Lactuca sativa* L. 'Yedikule') were planted in each pot on 1 November 2016. Three different doses of chemical fertilizer were applied during the cultivation period: F0: control; F1: half dose NPK (1/2NPK: 65 kg ha<sup>-1</sup> N, 30 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub>, 100 kg ha<sup>-1</sup> K<sub>2</sub>O); and F2: full dose NPK (1/1NPK: 130 kg ha<sup>-1</sup> N, 60 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub>, 200 kg ha<sup>-1</sup> K<sub>2</sub>O). Application amounts were determined according to local recommendations. Ammonium nitrate, mono ammonium phosphate, and potassium nitrate were used as sources of fertilizer. The study was established as factorial and four replicates according to the design of the randomized plot. The first cultivation period was terminated on 20 December 2016, with the cutting of lettuce plants from the root collars. Since biochar is a material whose effects are long-lasting, its residual effects were intended to detect. Therefore, after the plants were cut from the root collars, four lettuce seedlings were planted in the same pots on 11 January 2017. As in the first trial, chemical fertilizers were applied in the same doses. The second cultivation period was completed with the cutting of lettuce plants from the root collars on 1 March 2017. At the end of the trial, wet and dry weights (dried at 65 °C for 3 d) of the plants cut from the root collars were determined.

### Chemical analysis method

Leaf samples taken from plants harvested at the end of the first and second cultivation periods were washed, they were dried in drying cabinets set to 65 °C until the last two weighing values become constant and then they were made ready for analysis by milling at the grinding mill. The total concentration of P, K, Ca, Mg, Fe, Zn, Mn, and Cu of the solution obtained by wet combustion of the plant samples in the nitric-perchloric acid mixture was determined by inductively coupled plasma optical emission spectroscopy (ICP-OES) (Varian 720-ES; Agilent Technologies, Santa Clara, California USA). The total N concentration of plant samples was determined based on the modified Kjeldahl method (Kacar and Inal, 2010). Soil samples taken at the end of cultivation periods were analyzed after the dried in air and after they were passed through a 2 mm sieve. Total carbonates were determined using the Scheibler calcimeter. Soil pH and electrical conductivity (EC) were determined in a portable EC and pH-meter in 1:2.5(v:v). Soil texture was determined based on the hydrometer method and the organic matter in the modified Walkley-Black method. Total N was determined based on the modified Kjeldahl method. Available P was extracted with NaHCO<sub>3</sub> and determined based on the molybdate colorimetric method (UV 1800; Shimadzu Corporation, Kyoto, Japan). Exchangeable K, Ca, and Mg were extracted with ammonium acetate (NH<sub>4</sub>OAc), available Fe, Zn, Mn, and Cu in the soil were extracted with diethylene triamine penta-acetic acid (DTPA) and determined with ICP-OES (Varian 720-ES) device (Kacar, 2016).

### Statistical methods

Statistical analysis was carried out using the JMP Statistical software developed by SAS (SAS Institute, Cary, North Carolina, USA). Means were compared by ANOVA and the LSD test at  $P \leq 0.05$ . A factorial analysis was used to determine the interaction effects of biochar and inorganic fertilization on soil properties, nutritional status, and fresh and dry weights of lettuce.

**Table 1. Some physical and chemical parameters of experimental soil.**

Measured parameters	0-30 cm
Total N, %	0.08
Available P, mg kg <sup>-1</sup>	15.00
Extractable K, mg kg <sup>-1</sup>	68.00
Extractable Ca, mg kg <sup>-1</sup>	2775.00
Extractable Mg, mg kg <sup>-1</sup>	248.00
DTPA-Extractable Fe, mg kg <sup>-1</sup>	8.10
DTPA-Extractable Cu, mg kg <sup>-1</sup>	1.40
DTPA-Extractable Mn, mg kg <sup>-1</sup>	11.60
DTPA-Extractable Zn, mg kg <sup>-1</sup>	3.50
pH (1:2.5 distilled water)	7.90
EC, dS m <sup>-1</sup> (1:2.5 distilled water)	0.16
Lime, %	26.50
Organic matter, %	1.20
Texture	Sandy loam (SL)

DTPA: Diethylene triamine penta-acetic acid; EC: electrical conductivity.

**Table 2. Some properties of tomato plant wastes and biochar used in experiment.**

Measured parameters	Tomato plant wastes	Biochar
Total N, %	4.20	1.44
Total P, %	0.52	0.60
Total K, %	3.02	6.20
Total Ca, %	4.39	3.55
Total Mg, %	0.56	0.95
Total Fe, mg kg <sup>-1</sup>	88.00	145.00
Total Cu, mg kg <sup>-1</sup>	13.20	30.00
Total Mn, mg kg <sup>-1</sup>	27.00	54.00
Total Zn, mg kg <sup>-1</sup>	14.50	167.00
TOC, %	-	56.00
pH (1:5 distilled water)	-	11.00
EC, dS m <sup>-1</sup> (1:5 distilled water)	-	10.74

TOC: Total organic C; EC: electrical conductivity.

## RESULTS AND DISCUSSION

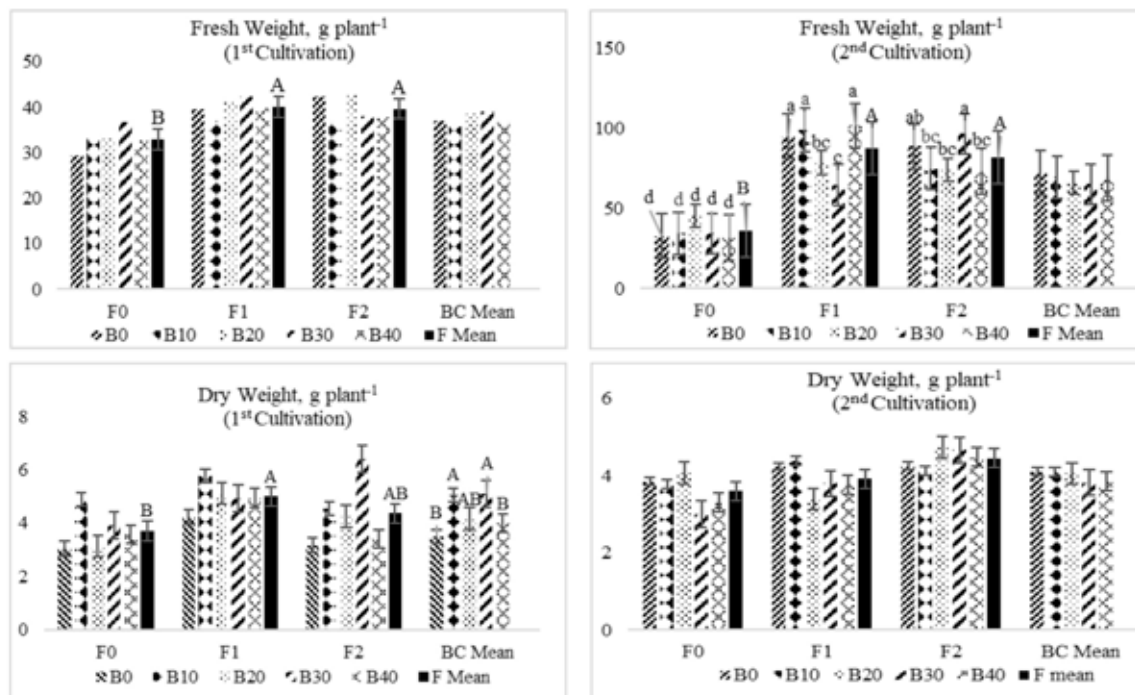
### Effects of applications on wet and dry weights of lettuce plant

During the first cultivation period, the wet and dry weights of the lettuce plant increased with chemical fertilization (Figure 1). Increased biochar doses did not affect plant wet weight while causing an increase in dry weight (Table 3). In the second cultivation period, the combined effects of residual biochar and fertilizer applications on the wet weight of the lettuce plant were significant. Plant wet weights ranged from 31.94-96.50 g plant<sup>-1</sup> and this was obtained by B40F0 and B30F2 applications. Akça and Namli (2015) reported that the wet and dry weights of tomato and pepper plants increased with chemical fertilizer applications in addition to chicken manure biochar.

### Effects of applications on nutritional element concentration of lettuce plant

The effects of biochar and fertilizer applications applied at different doses in the first cultivation period and the effects of fertilizer doses and residual biochar applied in the second cultivation period on the macro and micro nutritional element concentration of the lettuce plant are given in Figure 2. It was determined that biochar applied at different doses had no effect on the N concentration of the lettuce plant in the first cultivation (Table 3). Plant N concentration increased by 72% with full dose NPK (F2) application and by 68% with half-dose NPK (F1) application compared to the control. In the second cultivation period, the effects of fertilizer doses and residual Biochar×Fertilizer interaction on plant N concentration were significant. The N concentration of the lettuce plant changed between 1.54% and 4.27% and it was obtained by B10F0 and B0F2 applications in the 2<sup>nd</sup> period. Results were shown that the activity of biochar in the soil during the 2<sup>nd</sup> cultivation period continues and increases the plant N uptake with the residual effect. When chemical fertilizer applications are evaluated among themselves, in both cultivation periods, the N concentration of plants to which half-dose NPK (F1) was applied was higher than plants to which full-dose NPK (F2) was applied. This may be due to the fact that organisms that break down biochar increase their effectiveness in the presence of insufficient N (F1). According

**Figure 1.** Effects of biochar and chemical fertilizer in the first cultivation period and fertilizer and residual biochar in the second cultivation period in wet and dry weights of lettuce plants.



Chemical fertilization: F0: Control; F1: half dose NPK (1/2NPK: 65 kg ha<sup>-1</sup> N, 30 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub>, 100 kg ha<sup>-1</sup> K<sub>2</sub>O); F2: full dose NPK (1/1NPK: 130 kg ha<sup>-1</sup> N, 60 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub>, 200 kg ha<sup>-1</sup> K<sub>2</sub>O).  
Doses of biochar: B0: 0 t ha<sup>-1</sup>; B10: 10 t ha<sup>-1</sup>; B20: 20 t ha<sup>-1</sup>; B30: 30 t ha<sup>-1</sup>; B40: 40 t ha<sup>-1</sup>.

**Table 3. Results of ANOVA (P values) for N, P, K, Ca, Mg, Fe, Zn, Mn, and Cu concentrations of lettuce plants treated with biochar under different fertilization levels.**

Parameters	Biochar (BC)	Fertilization (F)	BC × F
Fresh weight <sup>1</sup>	0.273	< 0.0001	0.304
Fresh weight <sup>2</sup>	0.0021	< 0.0001	0.124
Dry weight <sup>1</sup>	0.016	0.036	0.589
Dry weight <sup>2</sup>	0.485	0.392	0.255
N <sup>1</sup>	0.222	< 0.0001	0.138
N <sup>2</sup>	0.366	< 0.0001	0.009
P <sup>1</sup>	0.059	< 0.0001	0.587
P <sup>2</sup>	0.597	0.011	0.0009
K <sup>1</sup>	< 0.001	< 0.0001	0.040
K <sup>2</sup>	< 0.001	< 0.0001	0.039
Ca <sup>1</sup>	0.016	0.007	0.080
Ca <sup>2</sup>	< 0.001	< 0.0001	0.720
Mg <sup>1</sup>	0.014	0.007	0.305
Mg <sup>2</sup>	< 0.001	< 0.0001	0.0006
Fe <sup>1</sup>	0.249	0.048	0.085
Fe <sup>2</sup>	0.313	0.211	0.097
Zn <sup>1</sup>	0.054	0.007	0.068
Zn <sup>2</sup>	0.463	< 0.0001	0.336
Mn <sup>1</sup>	0.0015	0.0002	0.356
Mn <sup>2</sup>	0.031	< 0.0001	0.078
Cu <sup>1</sup>	0.001	0.001	0.014
Cu <sup>2</sup>	0.147	< 0.0001	0.0057

P values: P < 0.05, P < 0.01 and P < 0.0001 were significant; P > 0.05 was nonsignificant.

<sup>1</sup>: 1<sup>st</sup> Cultivation, <sup>2</sup>: 2<sup>nd</sup> cultivation.

to the sufficiency limit values (sufficient level 2.5%-4.0%) reported by Hochmuth et al. (2012), the N content of plants grown by biochar application without chemical fertilizer (F0) is generally inadequate. Rajkovich et al. (2012) determined that the application of biochar together with fertilizer increases N uptake of the corn plant by 15%.

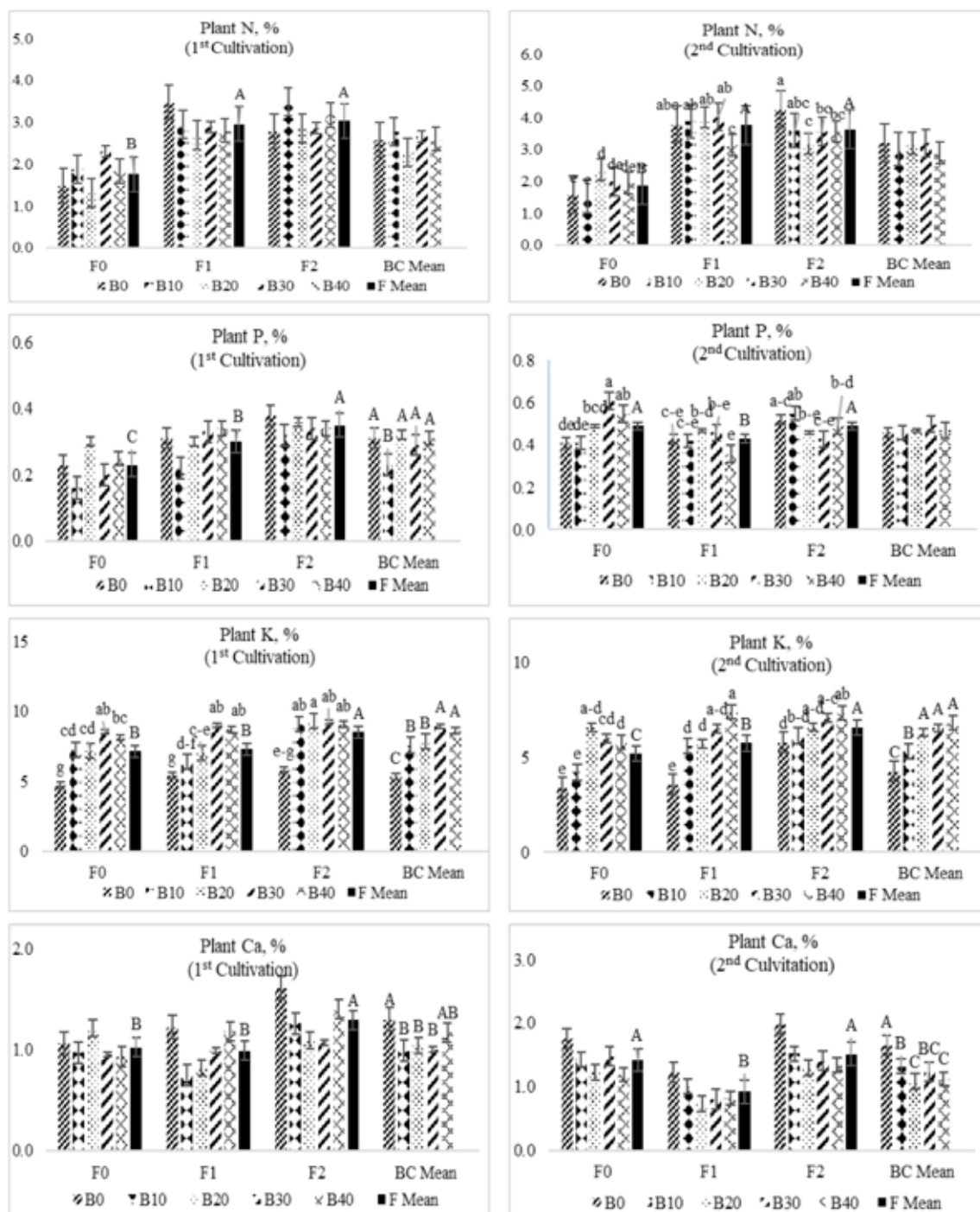
During the first cultivation period, the effect of biochar on the P concentration of the plant was not evident, but plant P concentration was increased with fertilizer application. The P concentrations of the lettuce plant changed between 0.36% and 0.61%, and were obtained by B40F1 and B30F0 applications in the 2<sup>nd</sup> period. P concentration was higher in the second period than in the first period and it was sufficient according to the limit values reported by Hochmuth et al. (2012) (sufficient level 0.4%-0.6%). Indeed, Dai et al. (2015) stated that the fractions of P in organic raw material had become stable through the process of pyrolysis, so biochar could be used as a source of long-lasting P in plant production.

In both cultivation periods, the effects of biochar and fertilizer doses and the interaction effect between these factors on the K concentration of the lettuce plant were significant (Table 3). The K concentration of the lettuce plant changed between 4.69% and 9.35% during the first cultivation period and this was obtained by B0F0 and B20F2 applications. In the second period, it changed between 3.41% and 7.39% and was obtained with B0F0 and B40F1 applications. Applications increased the K concentration of the lettuce plant at rates ranging from 14.7% to 99.3% in the first period and 4.7% to 116.7% in the second period. When effects of biochar applications at the F0 level increased plant K concentration compared with F1 and F2 fertilizer doses, it appears that the main responsible for the increase in K concentration is biochar applications. The biochar used in the study increased the exchangeable K concentration of the soil and hence the K uptake of the plant due to its high K content (6.20 %).

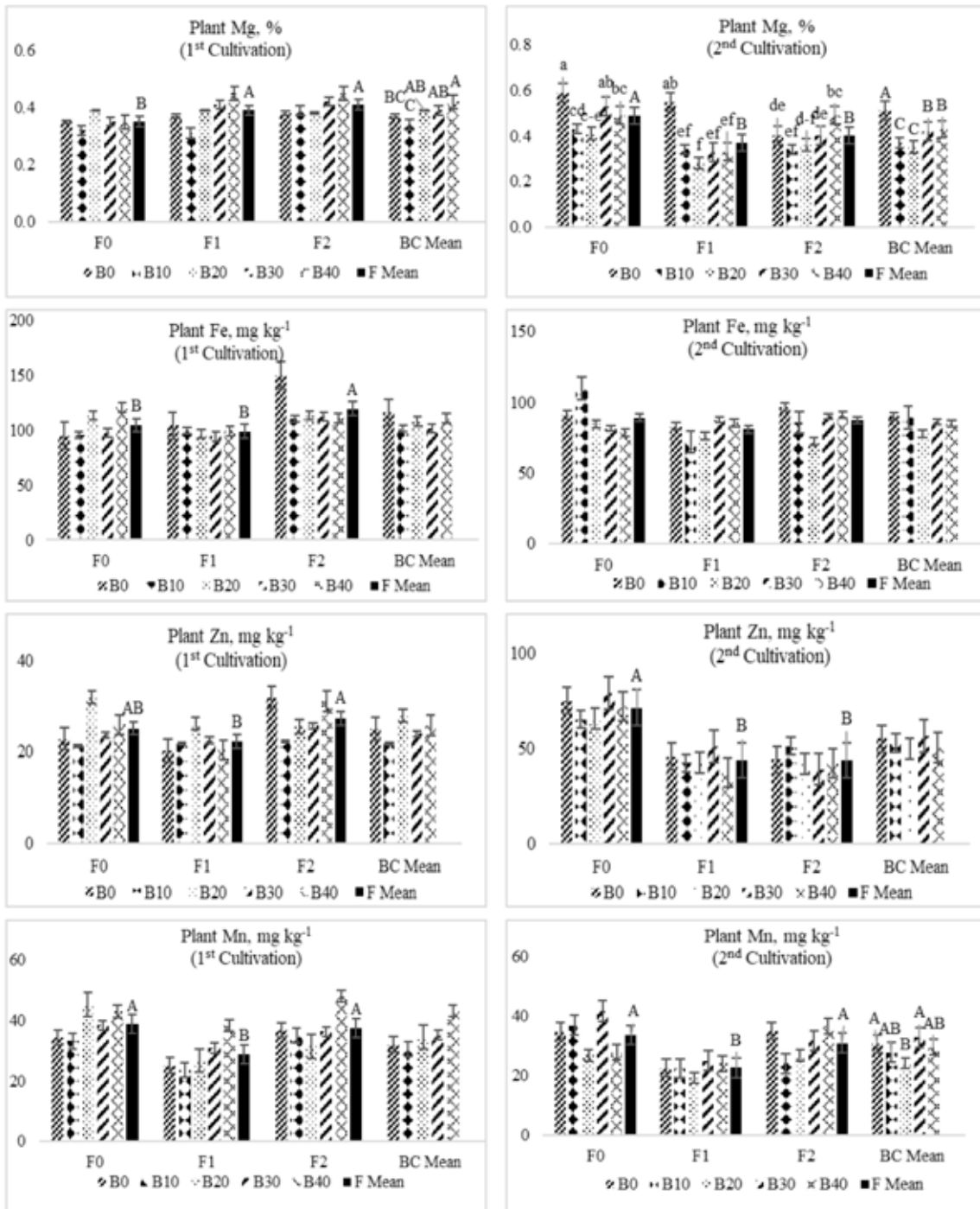
Ca concentration of the lettuce plant decreased by 11%-31% in the first cultivation period and by 25%-53% in the second period with increased biochar. This situation may have resulted from biochar K concentration. Zemanová et al. (2017) reported that with biochar applications, the Ca concentration of the spinach plant decreased by 45% in the spring period and by 30% in the autumn period.

The Mg concentration of lettuce plant increased by biochar applications and the highest value was obtained from B40 in the 1<sup>st</sup> period. Meanwhile, plant Mg concentration increased with the chemical fertilizer applications compared to F0. Mg concentrations ranged between 0.28% and 0.59%, and they were obtained by B20F1 and B0F0 applications in the 2<sup>nd</sup> cultivation period.

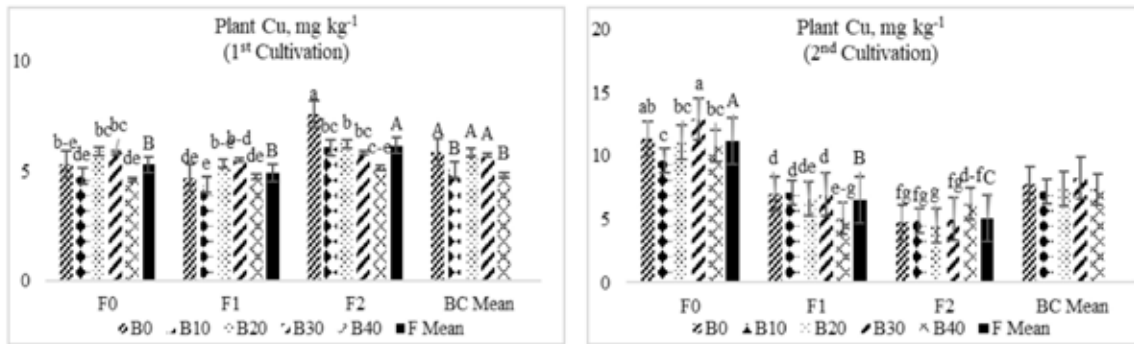
Figure 2. Effects of biochar and chemical fertilizer in the first cultivation period and fertilizer and residual biochar in the second cultivation period on the macro and micro nutritional element concentration of lettuce plants.



Continuation Figure 2.



Continuation Figure 2.



Chemical fertilization: F0: Control; F1: half dose NPK (1/2NPK: 65 kg ha<sup>-1</sup> N, 30 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub>, 100 kg ha<sup>-1</sup> K<sub>2</sub>O); F2: full dose NPK (1/1NPK: 130 kg ha<sup>-1</sup> N, 60 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub>, 200 kg ha<sup>-1</sup> K<sub>2</sub>O).  
Doses of biochar: B0: 0 t ha<sup>-1</sup>; B10: 10 t ha<sup>-1</sup>; B20: 20 t ha<sup>-1</sup>; B30: 30 t ha<sup>-1</sup>; B40: 40 t ha<sup>-1</sup>.

In both cultivation periods, biochar doses did not significantly affect the Fe concentration of the lettuce plant (Table 3). In the first cultivation period, the highest plant Fe concentration (119.32 mg kg<sup>-1</sup>) was obtained by the full-dose NPK (F2) (Figure 2). Küçükyumuk et al. (2017) determined that the Fe concentration of the pepper was more increased by biochar combined with fertilizer compared to the alone biochar.

The effect of biochar applications on the Zn concentration of the lettuce was nonsignificant. Although plant Zn concentration was not sufficient according to Hochmuth et al. (2012), deficiency symptoms were not observed. Plant Zn concentration was decreased with fertilization in the 2<sup>nd</sup> period. During the first cultivation period, the Mn concentration of the lettuce plant increased based on ascending biochar doses, but the effect of residual biochar was not clear. In both periods, the lowest concentrations were obtained with F1 and the highest concentrations were achieved with the F0. Plant Cu concentrations changed from 4.35 to 7.58 mg kg<sup>-1</sup> and were obtained by B10F1 and B0F2 applications in 1<sup>st</sup> period. Cu concentrations of the plant changed between 4.49 and 12.91 mg kg<sup>-1</sup> and were determined by B20F2 and B30F0 in the 2<sup>nd</sup> period.

### Effects of applications on some physical and chemical properties of the soil

The effects of biochar and fertilizer applications and the interaction effect between these factors on soil pH were significant (Table 4). In the first cultivation period in which biochar and fertilizer doses were applied, the lowest soil pH value (7.43) was obtained by the B0F2 application and the highest value (7.97) was obtained by the B0F0 application. In the 2<sup>nd</sup> period where chemical fertilizers were applied in addition to residual biochar, the lowest soil pH value (7.25) was determined by the B30F2 application and the highest value (8.32) was determined by the B40F1 application (Figure 3). The biochar used in the study was of alkaline (pH: 11) character and therefore increased biochar doses led to an increase in soil pH. Gul et al. (2015) reported that thanks to the phenol, carboxyl, and hydroxyl charges available on its surface, biochar leads to increased soil pH by holding active hydrogen ions in the soil.

The effects of biochar and fertilizer applications and the interaction effect between these factors on soil EC were significant (Table 4). At the end of the first cultivation period, the lowest soil EC value (0.13 dS m<sup>-1</sup>) was obtained by the B0F0 and the highest value (0.77 dS m<sup>-1</sup>) was obtained by the B40F1 application. At the end of the second cultivation period, the lowest soil EC value (0.21 dS m<sup>-1</sup>) was determined by the B0F0 application and the highest value (1.66 dS m<sup>-1</sup>) was determined by the B40F2 application. It is seen that in both cultivation periods, direct and residual biochar doses increased soil EC at F0 (no fertilizer) levels (Figure 3). This can be accepted as an indication that biochar was maintaining the breakdown and the releasing of metals during the 2<sup>nd</sup> period when it was not applied. Since chemical fertilizer was continued to be applied to meet the nutrient requirement of the lettuce plant when the residual effect of biochar was being determined in the second period, the EC of the soil in pots, where F1 and F2 doses were applied, increased significantly compared to the first period. Shah et al. (2017) reported that biochar doses increased the EC value of the soil and the highest value was achieved with a dose of 20 t ha<sup>-1</sup>.



**Table 4. Results of ANOVA (P values) for soil properties treated with biochar and different fertilization levels.**

Parameters	Biochar (BC)	Fertilization (F)	BC × F
pH <sup>1</sup>	< 0.0001	< 0.0001	< 0.0001
pH <sup>2</sup>	0.0002	< 0.0001	< 0.0001
EC <sup>1</sup>	< 0.0001	< 0.0001	< 0.0001
EC <sup>2</sup>	< 0.0001	< 0.0001	0.0001
OM <sup>1</sup>	< 0.0001	< 0.0001	0.0023
OM <sup>2</sup>	0.0003	< 0.0001	0.131
N <sup>1</sup>	0.0059	0.0412	0.268
N <sup>2</sup>	< 0.0001	0.0692	0.345
P <sup>1</sup>	< 0.0001	< 0.0001	0.016
P <sup>2</sup>	< 0.0001	< 0.0001	0.057
K <sup>1</sup>	< 0.0001	< 0.0001	0.127
K <sup>2</sup>	< 0.0001	< 0.0001	0.745
Ca <sup>1</sup>	< 0.0001	0.0048	0.0227
Ca <sup>2</sup>	< 0.0001	< 0.0001	0.0034
Mg <sup>1</sup>	< 0.0001	< 0.0001	< 0.0001
Mg <sup>2</sup>	< 0.0001	< 0.0001	< 0.0001
Fe <sup>1</sup>	0.0303	0.0017	0.1063
Fe <sup>2</sup>	0.0204	0.899	0.0055
Zn <sup>1</sup>	< 0.0001	< 0.0001	< 0.0001
Zn <sup>2</sup>	0.0074	0.0337	0.203
Mn <sup>1</sup>	< 0.0001	< 0.0001	0.0001
Mn <sup>2</sup>	0.0081	< 0.0001	0.0058
Cu <sup>1</sup>	< 0.0001	< 0.0001	0.0026
Cu <sup>2</sup>	0.048	0.240	0.042

P values: P < 0.05, P < 0.01 and P < 0.0001 were significant; P > 0.05 was nonsignificant.

<sup>1</sup>: 1<sup>st</sup> Cultivation, <sup>2</sup>: 2<sup>nd</sup> cultivation.

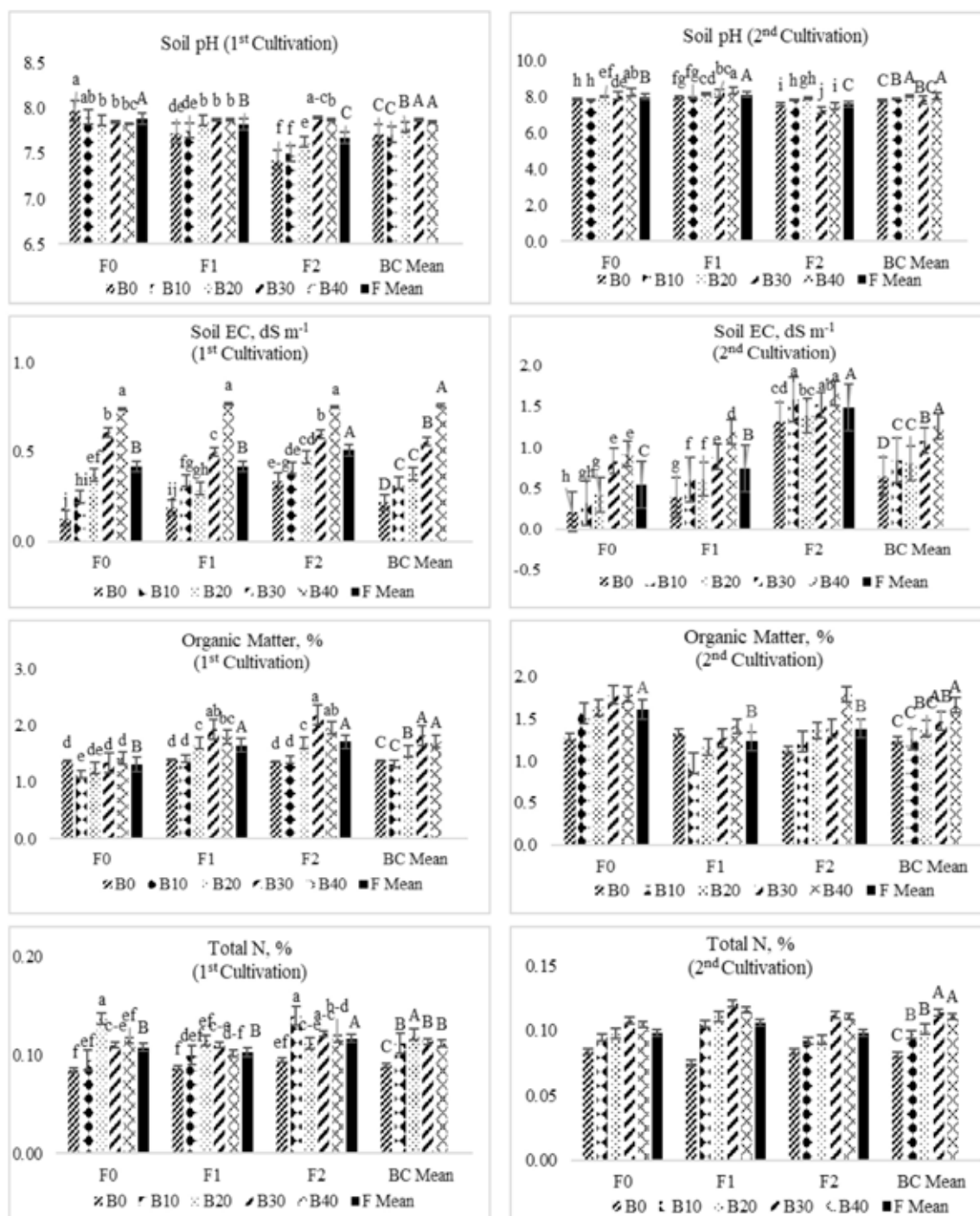
In the first cultivation period, the lowest amount of soil organic matter (1.14%) was determined with the B10F0 and the highest value (2.18%) was determined with the B30F2 application. Whereas the amount of soil organic matter was not significantly changed with biochar application without no fertilization (F0), the application of biochar together with fertilizer doses of F1 (half-dose NPK) and F2 (full-dose NPK) increased the amount of soil organic matter.

Tian et al. (2016) reported that the combination of biochar and NPK fertilizers increased the microbial population and activity in the soil, thus ascending the amount of soil organic matter. In the second cultivation period, soil organic matter increased due to the residual effect of biochar and the highest value was obtained with a dose of B40 (40 t ha<sup>-1</sup>).

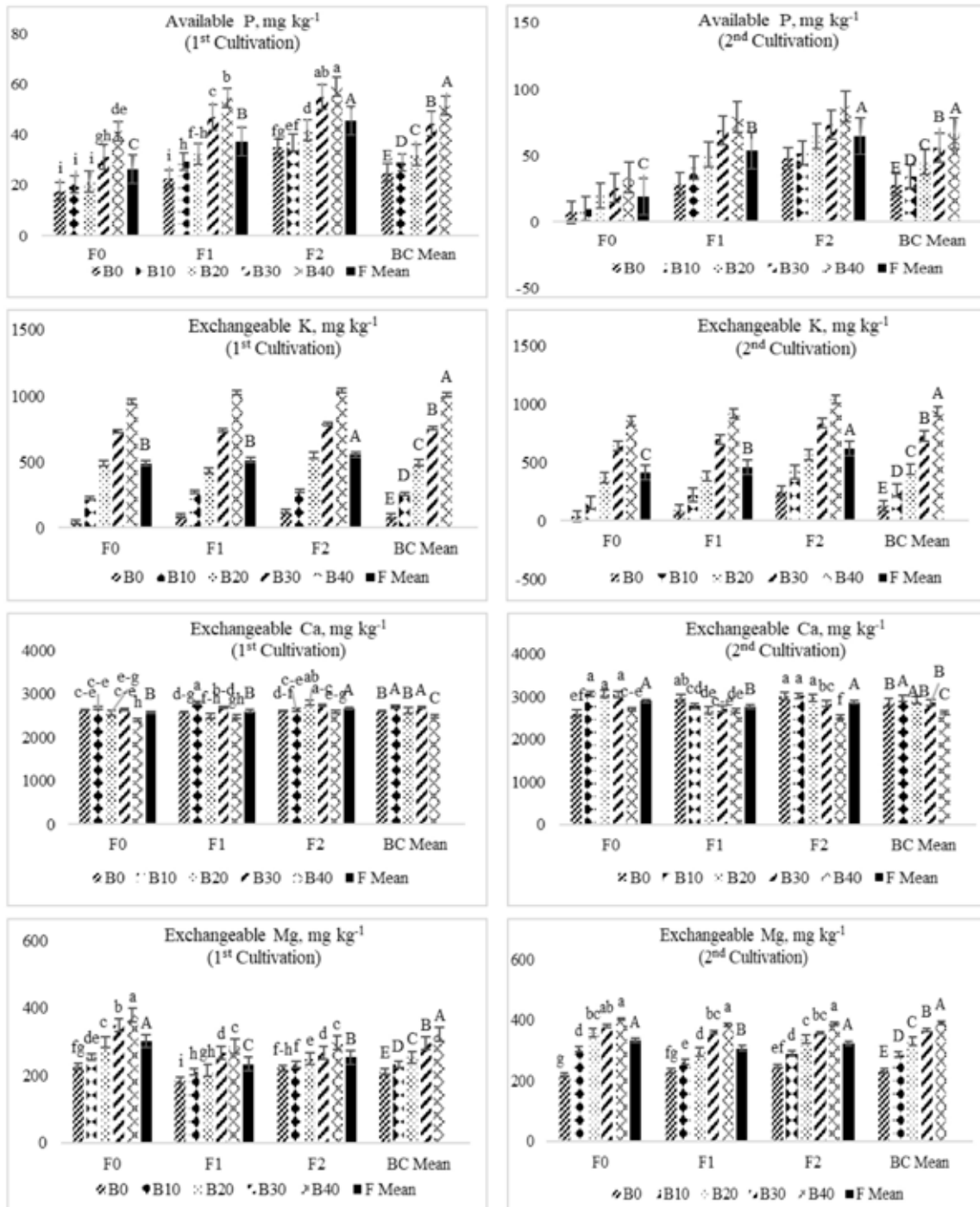
The effects of biochar, fertilizer doses and interaction between these factors on the soil's total N concentration were significant (Table 4). In the first cultivation period, the total N concentration of the soil changed between 0.085% and 0.140% and it was obtained by B0F0 and B10F2 applications. Due to the residual effect of biochar, the total N concentration of the soil increased and the highest value was obtained with 30 and 40 t ha<sup>-1</sup> biochar (compared to the control, 41% and 37% increase, respectively). In the study, since a significant portion of the N contained in the organic material to which the pyrolysis process was applied lost by evaporation (Sikder and Joardar, 2019), the C/N ratio of the resulting biochar (C: 56% and N: 1.44%) increased and therefore N mineralization slowed down (Asai et al., 2009).

The effects of biochar, fertilizer doses, and the interaction between these factors on the available P concentration of the soil were significant (Table 4). During the first cultivation period, the P concentration of the soil changed between 17.7 and 59.2 mg kg<sup>-1</sup> and it was obtained by B0F0 and B40F2 applications. At the F0 level, increased doses of biochar increased the P concentration of the soil. The residual biochar affected the available P concentration of the soil, and the highest value was obtained with 40 t ha<sup>-1</sup> (139% increase compared to the control). Based on the increase in P concentration in the nutrient solution, soil P concentration increased by 178% (F1) and 236% (F2) compared to the control. When cultivation was performed biochar without chemical fertilizer (F0), the available P concentration of the soil decreased due to plant consumption and that the residual effect of biochar did not continue. Therefore, P fertilization should also be applied in addition to the residual biochar. Silva et al. (2017) reported that biochar has a high P content caused to increase in the concentration of P in the soil depending on levels. Ma and Matsunaka (2013) stated that biochar might be an alternative source of fertilizer because of the available P content.

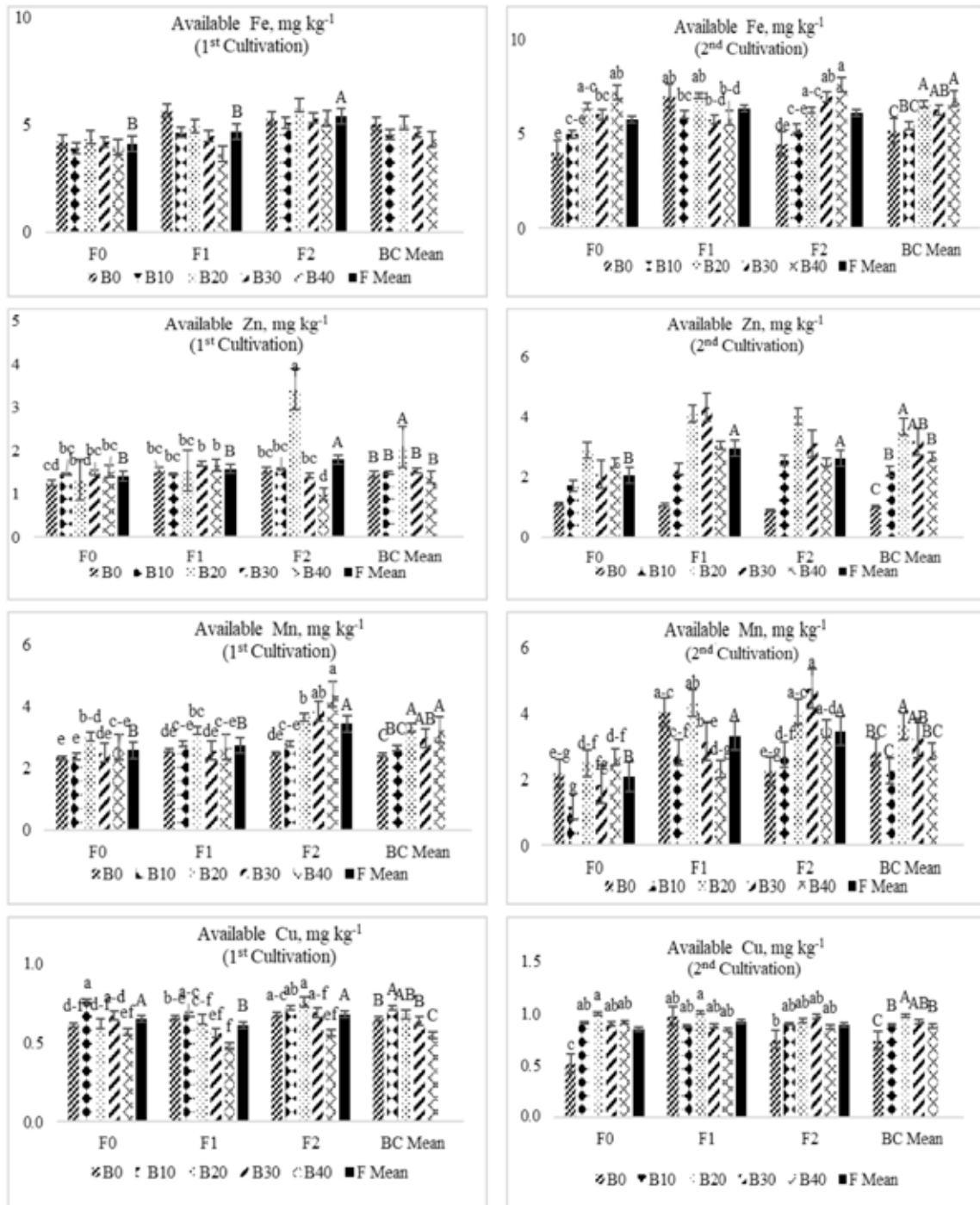
Figure 3. Effects of biochar and chemical fertilizer in the first cultivation period and fertilizer and residual biochar in the second cultivation period on some physical and chemical properties of the soil.



Continuation Figure 3.



Continuation Figure 3.



Chemical fertilization: F0: Control; F1: half dose NPK (1/2NPK: 65 kg ha<sup>-1</sup> N, 30 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub>, 100 kg ha<sup>-1</sup> K<sub>2</sub>O); F2: full dose NPK (1/1NPK: 130 kg ha<sup>-1</sup> N, 60 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub>, 200 kg ha<sup>-1</sup> K<sub>2</sub>O).  
 Doses of biochar: B0: 0 t ha<sup>-1</sup>; B10: 10 t ha<sup>-1</sup>; B20: 20 t ha<sup>-1</sup>; B30: 30 t ha<sup>-1</sup>; B40: 40 t ha<sup>-1</sup>.

Increased biochar doses increased the soil's exchangeable K concentration (Figure 3). The highest exchangeable K concentration was obtained from 40 t ha<sup>-1</sup> biochar an increase of 1044% was achieved compared to the control. The exchangeable K concentration of the soil increased due to the residual effect of biochar, and the highest concentration (940.5 mg kg<sup>-1</sup>; 644% increase compared to the control) was achieved with a dose of 40 t ha<sup>-1</sup>. Although the effect mechanism of biochar on the effectiveness of K in soil is unknown, there are many studies in which positive effects of soil on exchangeable K concentration have been reported (Singh et al., 2018; Wang et al., 2018). Based on the results of this research, it is thought that high K-containing biochar (6.2% K) produced from tomato plant waste may be an effective method of reducing the use of chemical K.

In both cultivation periods, the effects of biochar, fertilization, and interaction between these factors on the exchangeable Ca concentration of the soil were significant (Table 4). The exchangeable Ca concentration of the soil changed between 2395.5 and 2804.5 mg kg<sup>-1</sup> and this was achieved by B40F0 and B10F1 applications in 1<sup>st</sup> cultivation. In the second period, it changed between 2527.2 and 3078.8 mg kg<sup>-1</sup> and was obtained with B40F2 and B20F0 applications. Compared to B0, 40 t ha<sup>-1</sup> biochar led to a decrease in the soil exchangeable Ca by 5.0% and 8.7% over periods. Similarly, Hailegnaw et al. (2019) found that biochar applied to the soil at a rate of 8% caused the soil's exchangeable Ca concentration to decrease.

The exchangeable Mg concentration of the soil changed between 186.0 and 379.5 mg kg<sup>-1</sup> and it was obtained by B0F1 and B40F0 applications in the 1<sup>st</sup> cultivation. In the second cultivation period it changed between 219.0 and 402.7 mg kg<sup>-1</sup> and was determined by B0F0 and B40F0 applications. Compared to the control, the direct effect of 40 t ha<sup>-1</sup> biochar increased the exchangeable Mg concentration of the soil by 52% and the residual effect increased this concentration by 54%. Uzoma et al. (2011) reported that the application of biochar increased the exchangeable Mg concentration of the soil.

Since the K (6.20%) content of the biochar used in the study was higher than Mg (0.95%) and Ca (3.55%), its effect on the exchangeable K concentration of the soil became more pronounced. During the first cultivation period, the available Fe concentration of the soil increased with the chemical fertilization and the F2 dose ensured an increase by 30% compared to F0 (Figure 3). The lowest available Fe concentration of the soil (4.00 mg kg<sup>-1</sup>) was obtained with the B0F0 application and the highest value (7.59 mg kg<sup>-1</sup>) was obtained with the B40F2 application in 2<sup>nd</sup> cultivation. In the first cultivation period, the lowest available Zn value (1.0 mg kg<sup>-1</sup>) was obtained with the B40F2 application, while the highest concentration (3.42 mg kg<sup>-1</sup>) was obtained with the B20F2 application. The residual effect of biochar increased the available Zn concentration of the soil compared to the control, and the highest value was obtained with 20 t ha<sup>-1</sup>. Chemical fertilization increased the available Zn concentration of the soil. Similarly, Namgay et al. (2010) reported that the available Zn concentration of the soil increased with biochar applications.

In the two cultivation periods, biochar, fertilizer doses, and interaction between these two factors were found to be effective on the available Mn concentration of the soil (Table 4). The lowest value (2.35 mg kg<sup>-1</sup>) was obtained by the B0F0 application while the highest value (4.41 mg kg<sup>-1</sup>) was attained at the B40F2 application in 1<sup>st</sup> cultivation. In the second period the lowest available Mn concentration (1.18 mg kg<sup>-1</sup>) was determined by the B10F0 application, while the highest value (4.76 mg kg<sup>-1</sup>) was determined by the B30F2. In the first cultivation period, the available Cu concentration of the soil changed between 0.48 and 0.76 mg kg<sup>-1</sup> and it was obtained by B40F1 and B20F2 applications. On the other hand, Cu concentrations ranging from 0.52 to 1.01 mg kg<sup>-1</sup> in the second period were determined by B0F0-B20F1 applications. Due to chemical fertilization not using and plant consumption, soil microelement concentration decreased compared to before cultivation.

## CONCLUSIONS

In this study, the effects of direct and residual biochar and its chemical fertilizer combinations on soil fertility and nutritional status of lettuce plants were investigated. The amount of organic matter in the soil was positively affected by biochar and the use of chemical fertilizers together increased this positive effect. Although the total N and available P concentration of the soil increased with the use of biochar alone, it was not enough for the nutrition of the lettuce plant. In biochar applications, the incubation period should be kept long by taking into account the C/N ratio of the material. During the process of pyrolysis, tomato plant waste N was lost by changing form and evaporating. Despite this, the N concentration of the soil increased significantly with biochar. The concentration of K (3.02%) in the structure of the

tomato plant waste increased as a result of the pyrolysis (6.20% K). High K concentration of biochar caused to increase in soil and plant K concentrations. This shows that the biochar produced from tomato plant waste may be an alternative source to chemical fertilizers with K. Since antagonistic relationships between the increase in K in the plant structure and the uptake of the Ca have been determined, Ca fertilization should be applied in addition to biochar. As a result, it was determined that biochar applications without chemical fertilizer were not sufficient for the nutrition of the lettuce plant, but the application of 30 t ha<sup>-1</sup> biochar with half-dose NPK could be recommended in terms of the yield and nutritional status of the lettuce plant.

## REFERENCES

- Akça, M.O., and Namli, A. 2015. Effects of poultry litter biochar on soil enzyme activities and tomato, pepper and lettuce plants growth. *Eurasian Journal of Soil Science* 4(3):161-168.
- Anonymous. 2019. Plant nutrition statistics. Ministry of Agriculture and Forestry, Ankara, Turkey. <https://www.tarimorman.gov.tr/Konular/Bitkisel-Uretim/Bitki-Besleme-ve-Tarimsal-Teknolojiler/Bitki-Besleme-Istatistikleri>.
- Asai, H., Samson, B.K., Stephan, H.M., Songyikhangsuthor, K., Homma, K., Kiyono, Y., et al. 2009. Biochar amendment techniques for upland rice production in northern Laos: 1. Soil physical properties, leaf SPAD and grain yield. *Field Crops Research* 111(1-2):81-84.
- Başçetinçelik, A., Karaca, C., Öztürk, H.H., Kacira, M., and Ekinçi, K. 2005. Agricultural biomass potential in Turkey. Proceedings of the 9<sup>th</sup> International Congress on Mechanization and Energy in Agriculture & 27<sup>th</sup> International Conference of CIGR Section IV: (The Efficient Use of Electricity and Renewable Energy Sources), Izmir, Turkey. September 27-29.
- Dai, L., Tan, F., Wu, B., He, M., Wang, W., Tang, X., et al. 2015. Immobilization of phosphorus in cow manure during hydrothermal carbonization. *Journal of Environmental Management* 157:49-53.
- FAO. 2017. FAOSTAT. Food and Agriculture Organization (FAO) of the United Nations, Italy, Rome. <http://faostat3.fao.org/download/Q/QC/E>.
- Fernández-Gómez, M.J., Díaz-Raviña, M., Romero, E., and Nogales, R. 2013. Recycling of environmentally problematic plant wastes generated from greenhouse tomato crops through vermicomposting. *International Journal of Environmental Science and Technology* 10(4):697-708.
- Gul, S., Whalen, J.K., Thomas, B.W., Sachdeva, V., and Deng, H. 2015. Physico-chemical properties and microbial responses in biochar-amended soils: Mechanisms and future directions. *Agriculture Ecosystems & Environment* 206:46-59.
- Hailegnaw, N.S., Merci, F., Pračke, K., Száková, J., and Tlustós, P. 2019. Mutual relationships of biochar and soil pH, CEC, and exchangeable base cations in a model laboratory experiment. *Journal of Soils and Sediments* 19:2405-2416.
- Hochmuth, G., Maynard, D., Vavrina, C., Hanlon, E., and Simonne, E. 2012. Plant tissue analysis and interpretation for vegetable crops in Florida. Horticultural Sciences Department, UF/IFAS Extension, University of Florida, Gainesville, Florida, USA. Available at <https://edis.ifas.ufl.edu/pdf/EP/EP081/EP081-1347171.pdf> (accessed 1 October 2019).
- Kacar, B., and Inal, A. 2010. Plant analysis. Nobel Publications and Distribution, Ankara, Turkey. (In Turkish).
- Kacar, B. 2016. Physical and chemical soil analysis. Nobel Publications and Distribution, Ankara, Turkey. (In Turkish).
- Küçükçumuk, Z., Erdal, İ., Coşkan, A., Göktaş, M., and Sirça, E. 2017. Influence of biochar on growth and mineral concentrations of pepper. *Infrastructure and Ecology of Rural Areas* 10:793-802.
- Lehmann, J., and Joseph, S. 2009. Biochar for environmental management: Science and technology. Earthscan, London, UK.
- Ma, Y.L., and Matsunaka, T. 2013. Biochar derived from dairy cattle carcasses as an alternative source of phosphorus and amendment for soil acidity. *Soil Science and Plant Nutrition* 59:628-641.
- Namgay, T., Singh, B., and Singh, B.P. 2010. Influence of biochar application to soil on the availability of As, Cd, Cu, Pb and Zn to maize (*Zea mays* L.) *Australian Journal of Soil Research* 48:638-647.
- Rajkovich, S., Enders, A., Hanley, K., and Hyland, C. 2012. Corn growth and nitrogen nutrition after additions of biochars with varying properties to a temperate soil. *Biology and Fertility of Soil* 48(3):271-284.
- Schulz, H., and Glaser, B. 2012. Effects of biochar compared to organic and inorganic fertilizers on soil quality and plant growth in a greenhouse experiment. *Journal of Plant Nutrition and Soil Science* 175(3):410-422.
- Shah, T., Shah, S., and Shah, Z. 2017. Soil respiration, pH and EC as influenced by biochar. *Soil and Environment* 36(1):77-83.
- Sikder, S., and Joardar, J.C. 2019. Biochar production from poultry litter as a management approach and effects on plant growth. *International Journal of Recycling of Organic Waste in Agriculture* 8:47-58.
- Silva, I.C.B., Basilio, J.J.N., Fernandes, L.A., Colen, F., Sampaio, R.A., and Frazao, L.A. 2017. Biochar from different residues on soil properties and common bean production. *Scientia Agricola* 74(5):378-382.
- Singh, A., Singh, A.P., and Purakayastha, T.J. 2018. Characterization of biochar and their influence on microbial activities and potassium availability in an acid soil. *Archives of Agronomy and Soil Science* 65(9):1302-1315.
- Sonmez, S., Kaplan, M., Orman, Ş., and Sönmez, İ. 2002. The amounts of nutrient elements uptake with plant wastes after harvest in tomato greenhouses and some suggestions concerning its evaluation in Kumluca Region of Antalya. *Akdeniz University Journal of Faculty of Agriculture* 15(1):19-25.

- Sonmez, S., Citak, S., Sonmez, I., and Kaplan, M. 2008. Evaluation of mineral contents of greenhouse plant wastes in Antalya Region. *Asian Journal of Chemistry* 20(6):4739-4748.
- Tian, J., Wang, J., Dippold, M., Gao, Y., Blagodatskaya, E., and Kuzyakov, Y. 2016. Biochar affects soil organic matter cycling and microbial functions but does not alter microbial community structure in a paddy soil. *Science of the Total Environment* 556:89-97.
- TUIK. 2019. Data portal for statistics. Agriculture. <https://data.tuik.gov.tr/Kategori/GetKategori?p=tarim-111&dil=2>.
- Uzoma, K.C., Inoue, M., Andry, H., Fujimaki, H., Zahoor, A., and Nishihara, E. 2011. Effect of cow manure biochar on maize productivity under sandy soil conditions. *Soil Use and Management* 27(2):205-212.
- Wang, L., Xue, C., Nie, X., Liu, Y., and Chen, F. 2018. Effects of biochar application on soil potassium dynamics and crop uptake. *Journal of Plant Nutrition and Soil Science* 181(5):635-643.
- Zemanová, V., Břendova, K., Pavliková, D., Kubátová, P., and Tlustoš, P. 2017. Effect of biochar application on the content of nutrients (Ca, Fe, K, Mg, Na, P) and amino acids in subsequently growing spinach and mustard. *Plant, Soil and Environment* 63(7):322-327.