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ORIGINAL PAPER

WILL THE NUTRIENT CONTENT IN BIOCHAR BE REFLECTED BY THEIR HIGHER CONTENT OF CORN ORGANS?*

Vladimír Šimanský[1], Ján Horák[2], Nora Polláková[1], Martin Juriga[1], Jerzy Jonczak[3]

[1]Department of Soil Science
[2]Department of Biometeorology and Hydrology
Slovak University of Agriculture, Nitra, Slovakia
[3]Department of Soil Environment Sciences
Warsaw University of Life Sciences, Poland

Abstract

The objective of this study was to investigate the effects of biochar (B) at different application doses (0, 10 and 20 t ha^{-1}) on the content of macro- and micronutrients in soil (silt loam Haplic Luvisol at a field site of Dolná Malanta, Slovakia) as well as in the organs of corn. Application of 20 t ha^{-1} of biochar had significant effects by increasing the soil pH, total content of P, Ca and available K. The content of available Mn, Ni and Zn in the soil significantly increased in B20 treatment by 45, 17 and 32%, respectively, as compared to B0. The total content of Cu in the soil was significantly decreased by 9% in B20 compared to B0. In comparison to B0, the statistically significantly lower Ca content was found in corn seeds grown on the plots where biochar in both doses was applied. Biochar applied to the soil did not change the content of other macro- and micronutrients in the corn organs. Negative correlations between P in seeds of corn and total (r = 0.543, $P \le 0.05$) and available (r = 0.564, $P \le 0.05$) content of P were observed. Higher total content of K in the soil resulted in higher content of K in leaves (r = 0.561, $P \le 0.05$) and corn seeds (r = 0.905, $P \le 0.001$). Higher total content of Mn in the soil increased the content of Mn in stalks (r = 0.830, $P \le 0.001$) and in seeds of corn (r = 0.874, $P \le 0.001$). There was a positive correlation (r = 0.756, $P \le 0.001$) observed between the total content of Zn in the soil and Zn in corn roots and, conversely, a negative correlation was determined between available Zn in the soil and Zn in corn roots (r = -0.506, $P \le 0.05$).

Keywords: biochar, corn parts, nutrients, luvisol.

Vladimír Šimanský, PhD, Assoc. prof., Department of Soil Science, Faculty of Agrobiology and Food Resources, FAFR – SUA Nitra, 949 76 Nitra, Tr. A. Hlinku 2, e-mail: Vladimir.Simansky@uniag.sk
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INTRODUCTION

Biochar, known as new black gold, is a novel, stable, carbonaceous by-product which is synthesized through pyrolysis of biological materials in the absence of O_2. Recently, an emerging interest in the application of biochar as a robust soil amendment has given rise to a broad research area in science and technology (Lahori et al. 2017). Numerous studies have been conducted worldwide to determine consequences of biochar amendments on soil properties and on agronomical production (Tammeorg et al. 2015, Lima et al. 2018). Biochar has shown a promise as a sustainable amendment able to enhance soil chemical properties (Lehmann et al. 2011). Biochar increases soil pH, mainly in acid soils (Horák et al. 2017). Some biochars contain high quantities of ash, which is enriched with a number of plant nutrients, especially cationic elements, such as K, Ca and Mg (Yuan et al. 2011). Biochar can also improve nutrient absorption, cation exchange capacity (Van Zwieten et al. 2010) sorption parameters, mainly soil organic matter sorption (Šimanský et al. 2017), as well as reduce the leaching of pesticides and nutrients to surface and ground water (Novak et al. 2009, Oleszczuk et al. 2014). Biochar is considered as a promising remediation option for heavy metal contaminated soils to reduce heavy metal bioavailability to plants (Evangelou et al. 2014, Lahori et al. 2017). Another positive effect of biochar that has been shown is the ability to change soil biological community composition and abundance (Lehmann et al. 2011) as well as physical properties. Biochar applied to soil has had positive effects on the soil water holding capacity, bulk density, porosity (Kammann et al. 2011) large inner surface area (Chintala et al. 2014) and soil structure (Obia et al. 2016, Šimanský et al. 2016). The effects of biochar on soil properties largely depend on biochar properties, which vary widely between different biochars, mainly due to variations in feedstock materials (Butnan et al. 2015, Purakayastha et al. 2015) and pyrolysis conditions (Wang et al. 2013). The different effects might be a result of differences in the biochar reactivity (i.e. the amount of reactive functional groups) that strongly depends on production conditions and feedstock (Keluweit et al. 2010) but also on the length of time (duration of contact between biochar and soil particles).

Up to 35% of corn yield depends on fertilization, which is therefore considered to be a significant intensification factor (Kováčik 2014). It is obvious that in order to achieve high production with the required quality there must be enough nutrients in the soil. If nutrients are missing, they can be delivered through fertilization. Corn is a plant that has high nutrient requirements (Fecenko, Ložek 2000, Vaněk et al. 2013). To produce 1 tonne of grains corn needs the following nutrient supply: 22-26, 4.4-6.6, 21-33, 4.3-7.1 and 4-6 kg N, P, K, Ca and Mg, respectively (Vaněk et al. 2013). Since biochar is considered to be a significant source of nutrients, it could be applied to soil to increase yields (Jones et al. 2012, Vítková et al. 2017). However, there have been cases where biochar had no effect on yields or even had an opposite effect (Huang et al. 2013, Horák et al. 2017). Sometimes the application of biochar into soil can increase the immobilization of macronutrients and micronutrients, and reduce their uptake to a plant. Information on the total content of nutrients in biochar is important, but even more important is to have information on how much of them is in the available form because they are the source for the future yield of crops (Kováčik 2014). It is impossible to achieve higher yield with poor nutrition. The uptake of nutrients from soil is affected by different factors and often the uptake of one nutrient is blocked by the absorbtion of another one (Zlámalová et al. 2015). Also, the release of nutrients from the soil stock or fertilizers is influenced by a number of factors. Therefore, the results obtained from various soil climatic conditions on the translocation of nutrients into plants are of utmost value, and this is also true about studies into the impact of biochar. Based on the data mentioned above farmers are able to decide about the application of fertilizers, including biochars.

We have assumed that if soil has an acidic soil pH, applied biochar with a higher pH value containing a valuable source of nutrients will improve the soil environment and increase the nutrients' availability in the soil and their subsequent uptake by corn. We also assume that the percentage of macro- and micronutrients in corn parts might be higher owing to the application of higher biochar doses. Therefore, the objective of this study was (1) to quantify the impacts of two doses of biochar application on the soil's macro- and micronutrient content, (2) to quantify the translocation of nutrients to individual parts of corn in relation to biochar addition, and (3) to determine the relationships between nutrients in the soil and their content in the individual corn parts.

MATERIAL AND METHODS

A field experiment was conducted in Nitra-Malanta (lat. 48°19′00″; lon. 18°09′00″) during 2015 and 2017. The area has a temperate climate with an annual rainfall of 539 mm and the average annual temperature is 9.8°C. The studied soil had been used for at least 100 years before the experiment started for the production of classical crops, typical of this area (winter wheat, spring barley, oil rape and corn). The soil contains 25.2% of clay, 9.13 g kg^{-1} of soil organic carbon while the average soil pH (KCl) is 5.71 in A horizon (to the 0.25 m) and it is classified as Haplic Luvisol (WRB 2014).

The experiment was established in March 2014. Three treatments were applied: (1) B0 – no biochar as a control, (2) B10 – biochar at the dose of 10 t ha^{-1}, (3) B20 – biochar at the dose of 20 t ha^{-1}. Each treatment was performed in triplicate over an area of 24 m^2 in a randomized block design. The biochar used in the trials was obtained from pyrolysis at 550°C for

Table 1
Total content of macro- and micronutrients in biochar

Component	Content
Biochar size (mm)	1-5
Ash (g kg^{-1})	383
Specific surface area (m^2 g^{-1})	21.7
TOC (g kg^{-1})	531
Nt (g kg^{-1})	14
pH	8.8
P (g kg^{-1})	6.20
K (g kg^{-1})	15
Na (g kg^{-1})	0.77
Ca (g kg^{-1})	57
Mg (g kg^{-1})	3.9
Mn (mg kg^{-1})	150
Cu (mg kg^{-1})	25
Ni (mg kg^{-1})	7
Zn (mg kg^{-1})	110

30 minutes. Biochar was produced from paper fiber sludge and grain husks (1:1 w/w) in a Pyreg reactor (Pyreg GmbH, Dörth, Germany). Biochar properties are shown in Table 1. Spring barley (*Hordeum vulgare* L.), corn (*Zea mays* L.), spring wheat (*Triticum aestivum* L.) and once again corn were sown in 2014, 2015, 2016 and 2017, respectively.

Three soil subsamples from A-horizons (to the depth of 20 cm) were collected from each treatment plot and mixed into one representative sample in 2015 and 2017. The plant residues and visible particles of biochar were removed from the samples, which were then dried in an oven and sieved through a 2.0 mm mesh sieve to remove the skeleton fraction. Soil pH was analyzed potentiometrically (Elmetron CPC 401) in suspension with water and 1 M KCl solution, the content of total nitrogen (Nt) was determined with the Kjeldahl method (distillation unit Velp UDK 127), total content of P, K, Ca, Mg, Cu, Mn, Ni and Zn was assayed after digestion of ashed samples in aqua regia. The content of P in solution was analyzed by the molybdeanum-blue method, whereas the remaining elements were determined by AAS (Perkin Elmer AA 2100). The content of bioavailable forms of P, K, Ca, Mg, Cu, Mn, Ni and Zn was determined after extraction of samples in 1 mol/l solution of HCl and the content of P in extracts was also analyzed by the molybdeanum-blue method, whereas the remaining elements were determined by AAS (Perkin Elmer AA 2100).

Three subsamples of leaves, stalks, seeds and roots were collected from each plot and mixed into the one representative treatment sample. The samples were dried at 65°C, milled into powder using an IKA A11 laboratory mill and finally analyzed. The following properties were determined: the content of total nitrogen (Nt) with the Kjeldahl method (distillation unit Velp UDK 127) and total content of P, K, Ca, Mg, Cu, Mn, Ni and Zn after the digestion of ashed samples in aqua regia. The content of P in solutions was determined by using the molybdenum-blue method (Raileigh UV-1800) and the remaining elements were submitted to microwave plasma atomic emission spectrometry (Agilent 4100 MP-AES).

The statistical evaluation of the data was performed by using the software Statgraphics Centurion XV.I (Statpoint Technologies, Inc., USA). The treatment differences in the soil properties, in the content of nutrients in soil and in the individual parts of corn (one-way ANOVA) were considered significant at P values <0.05 by the LSD test. The relationship between the content of nutrients in the soil and in individual parts of corn was determined using a correlation matrix.

RESULTS AND DISCUSSION

The soil pH and content of macro- and micronutrients in the soil

Biochar pH and also its mineral composition are important regarding its effect on soil pH. As presented in the study of Ruysschaert et al. (2016), biochar is usually alkaline and therefore it has a capacity to neutralize acid soils and thus it is expected to increase the soil pH. The results from the quoted study support our findings (Figure 1). In our case, biochar pH was 8.8 and on average it contained 57 g kg^{-1} of Ca, 3.9 g kg^{-1} of Mg, 15 g kg^{-1} of K and 0.77 g kg^{-1} of Na. Soil pH was weakly acidic (5.7) and only the application of 20 t ha^{-1} of biochar significantly increased soil pH in H_2O and in KCl by 0.36 and 0.45 unit, respectively. Optimal soil pH is in a range from weak acid to neutral because the best uptake of nutrients from the soil into the plants is secured in this range (Fecenko, Ložek 2000, Vaněk et al. 2013). Nurhidayati, Mariati (2014) reported that a large increase in soil alkalinity can reduce the availability of some plant nutrients such as Ca, Mg, P and micronutrients, resulting in reduced plant yields. In our study, the applied biochar increased soil pH (Table 2), but the pH of the soil has remained weakly acidic, which means that soil conditions have been optimal for the soil nutrient uptake by plants. Generally, some nutrients are present in the ash fraction of biochar and could be available for plants, as well. The content of total N in the soil ranged from 1.21 to 1.31 g kg^{-1} and it was the lowest at B10 treatment and slightly higher at B0 and B20 treatments.

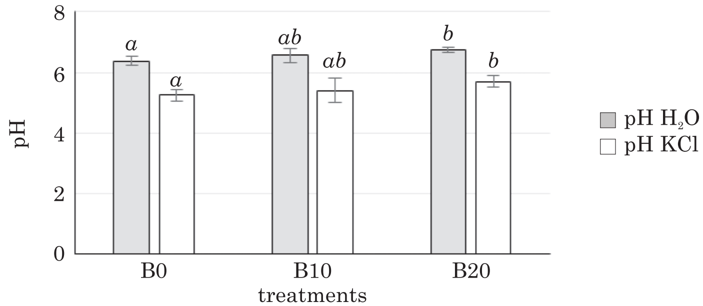

Fig. 1. Statistical evaluation of soil pH.
Different letters (*a*, *b*) between columns in the same colour indicate that treatment means are significantly different at $P \leq 0.05$ according to LSD multiple-range test

Table 2

Content of total and available macronutrients in soils

Doses (t ha^{-1})	Nt (g kg^{-1})	P (g kg^{-1})		K (g kg^{-1})		Ca (g kg^{-1})		Mg (g kg^{-1})	
		total	available	total	available	total	available	total	available
B0	1.23±0.12^a	0.41±0.10^a	0.18±0.05^a	7.96±1.10^a	0.35±0.06^a	3.29±0.18^a	3.03±0.74^a	3.02±1.61^a	0.31±0.07^a
B10	1.21±0.11^a	0.47±0.02^{ab}	0.17±0.07^a	8.07±1.05^a	0.33±0.04^a	3.42±0.27^a	3.15±0.62^a	3.15±1.61^a	0.33±0.09^a
B20	1.31±0.11^a	0.50±0.06^b	0.23±0.07^a	8.25±0.87^a	0.41±0.06^b	3.75±0.16^b	3.51±0.70^a	3.15±1.65^a	0.35±0.08^a

Differences between treatments were not influenced by the biochar application. As it was mentioned above, the biochar used in this study had relatively good nutrient supply (Table 1). The content of total P in the soil was 0.41 g kg^{-1} and after the application of 20 t ha^{-1} of biochar its content significantly ($P < 0.05$) increased to the value 0.50 g kg^{-1}. It was surprising that this effect was not reflected by a higher concentration of P in its available form. The content of P and also of other nutrients is influenced by the mineralogical characteristics and clay content (Casson et al. 2006), soil organic matter, soil pH and exchangeable and soluble Al, Fe and Ca (Xu et al. 2014). We expected that the biochar application to weakly acidic soil will increase the total P and thus the concentration of available P would be increased as well. P fixation in acid soil could be inhibited because organic amendments have high affinity to Al and Fe. On the other hand, increasing an application dose of high pH biochar may increase soil alkalinity and precipitate P ions with Ca as calcium phosphate (Nelson et al. 2011). The effects of biochar on the availability of P were found to be inconsistent (Sandeep et al. 2013). Each biochar and soil type combination requires further characterization in order to better predict the nutrients' retention and release. The applied biochar contained also 15 g kg^{-1} of K, which means that with the application of 10 and 20 t ha^{-1} of biochar there was also applied K in amounts of 150 and 300 kg ha^{-1}, respectively. We observed an increase in total K in the soil after its application but this effect was not statistically significant. On the other hand, our results showed a significant effect of biochar on available K in the case of B20 treatment, where the concentration of available K significantly increased by 17% in B20 treatments compared to control (B0) treatments. Ruysschaert et al. (2016) also found some statistical effects of potassium availability due to biochar amendment in the North Sea region and across Europe. Purakayastha et al. (2015) also recorded positive effects of biochar application to soil, which increased available nutrients, including potassium. The improved nutrient status is in line with the amount of biochar applied (Laird et al. 2010). As in the case of P, the same effects were observed for calcium, which means that the application of the higher dose of biochar (20 t ha^{-1}) had significant ($P < 0.05$) influence on the increase of total Ca supply. No significant effect due to biochar amendment was observed in the case of available Ca (Table 2). This can be explained by the dissolution of carbonates and oxides and successive leaching of base cations (Joseph et al. 2010) during the studied period of biochar application. The effectiveness of biochar amendment decreases with time after its application (Šimanský et al. 2018*a*) and this regularity is observed in our study when we compare the previously published results after one-year biochar application (Šimanský et al. 2018) with the current ones (as average of years 2015 and 2017). All data in 2017 were lower compared to the data in 2015. The content of both total and available Mg was unchanged in treatments with biochar. We determined a lower content of total Cu in B20 (13.6±1.69 g kg^{-1}) and B10 (14.6±0.11 g kg^{-1}) than in B0 (15.0±0.52 g kg^{-1}). No such effect was observed for the total Mn, Ni and Zn. The content of available Zn and Cu in all treatments corresponds to a high content, and that of available Mn is very high (Ložek 2010) mainly in the B20 treatment. The higher dose of biochar significantly ($P < 0.05$) increased the content of available Mn, Ni and Zn in the soil. These effects have not been found in B10 treatments compared to B0 treatments (Table 3).

The content of macro- and micronutrients in corn organs

The content of macro- and micronutrients in the different corn organs is shown in Table 4. Generally, the highest content of N and P was determined in corn grain. The highest content of K, Mn, Cu and Zn was determined in corn roots and the highest content of Ca, Mg and Ni was observed in leaves.

Table 3

Content of total and available micronutrients in soils

Doses (t ha^{-1})	Cu (mg kg^{-1})		Mn (mg kg^{-1})		Ni (mg kg^{-1})		Zn (mg kg^{-1})	
	total	available	total	available	total	available	total	available
B0	15.0±0.52^{b}	5.67±0.40^{a}	949±193^{a}	214±42.2^{a}	28.9±0.94^{a}	4.68±0.22^{a}	50.0±4.25^{a}	5.75±1.08^{a}
B10	14.6±0.11^{ab}	5.58±0.31^{a}	971±206^{a}	242±39.2^{a}	28.4±0.61^{a}	4.97±0.29^{a}	50.0±3.75^{a}	6.50±1.48^{ab}
B20	13.6±1.69^{a}	5.85±0.49^{a}	976±228^{a}	309±39.5^{b}	28.2±0.77^{a}	5.47±0.37^{b}	51.1±4.30^{a}	7.57±0.92^{b}

Table 4

Content of macro- and micronutrients in corn organs

Nutrient	Treatments	Corn organs			
		roots	stalks	leaves	seeds
N (g kg^{-1})	B0	5.48±1.48^{a}	5.01±1.00^{a}	6.12±1.12^{a}	14.8±1.77^{a}
	B10	5.41±1.58^{a}	5.31±1.14^{a}	6.35±1.53^{a}	14.0±1.15^{a}
	B20	5.38±0.66^{a}	4.84±1.87^{a}	5.68±1.58^{a}	13.1±1.62^{a}
P (g kg^{-1})	B0	0.75±0.44^{a}	0.99±0.44^{a}	1.01±0.64^{a}	2.69±0.84^{a}
	B10	1.05±0.57^{a}	1.05±0.47^{a}	1.18±0.94^{a}	2.55±0.82^{a}
	B20	1.10±0.56^{a}	1.11±0.63^{a}	0.87±0.63^{a}	2.54±0.86^{a}
K (g kg^{-1})	B0	6.33±3.28^{a}	17.6±2.50^{a}	4.71±1.72^{a}	3.68±0.58^{a}
	B10	8.44±3.56^{a}	15.5±2.18^{a}	5.14±2.19^{a}	3.62±0.46^{a}
	B20	6.66±2.23^{a}	16.9±3.04^{a}	4.05±1.88^{a}	3.78±0.43^{a}
Ca (g kg^{-1})	B0	8.52±2.27^{a}	2.00±0.26^{a}	9.97±1.16^{ab}	1.13±1.08^{b}
	B10	8.12±1.46^{a}	2.52±0.61^{a}	12.0±2.34^{b}	0.21±0.07^{a}
	B20	9.65±2.39^{a}	2.50±0.38^{a}	9.25±1.12^{a}	0.19±0.08^{a}
Mg (g kg^{-1})	B0	1.88±0.27^{a}	1.02±0.18^{a}	2.57±0.52^{a}	1.14±0.19^{a}
	B10	1.90±0.27^{a}	1.20±0.28^{a}	3.02±0.79^{a}	1.11±0.16^{a}
	B20	1.71±0.36^{a}	1.28±0.20^{a}	2.68±0.38^{a}	1.10±0.17^{a}
Mn (mg kg^{-1})	B0	240±88.4^{a}	10.7±1.30^{a}	114±30.4^{a}	6.07±2.45^{a}
	B10	257±68.4^{a}	10.4±3.33^{a}	118±21.2^{a}	5.57±2.69^{a}
	B20	223±109^{a}	10.6±4.53^{a}	99±17.1^{a}	6.03±2.02^{a}
Cu (mg kg^{-1})	B0	15.1±3.99^{a}	3.80±0.80^{a}	7.17±2.94^{a}	2.87±0.59^{a}
	B10	14.4±4.26^{a}	4.08±0.92^{a}	7.00±1.05^{a}	2.57±0.42^{a}
	B20	11.5±3.45^{a}	3.17±1.11^{a}	6.18±2.44^{a}	2.77±0.39^{a}
Ni (mg kg^{-1})	B0	16.8±5.56^{a}	7.93±0.13^{a}	12.5±4.12^{a}	1.53±0.09^{a}
	B10	19.2±6.07^{a}	5.77±2.48^{a}	11.7±3.48^{a}	0.95±0.23^{a}
	B20	18.2±3.22^{a}	4.83±1.85^{a}	11.2±2.15^{a}	0.85±0.29^{a}
Zn (mg kg^{-1})	B0	43.3±16.1^{a}	23.7±6.64^{a}	27.9±10.5^{a}	25.3±2.82^{a}
	B10	43.9±8.51^{a}	19.9±5.93^{a}	26.4±11.8^{a}	23.9±1.28^{a}
	B20	40.6±5.62^{a}	21.9±7.94^{a}	24.3±10.4^{a}	23.7±1.84^{a}

The biochar amendment did not change the content of macro- and micronutrients in the corn parts except the Ca and Mn content. Several authors (MARSCHNER 1995, FECENKO, LOŽEK 2000, VANĚK et al. 2013) stated that the uptake of Ca from soil into plants is in antagonism with the uptake of K. In our case, the biochar was a significant source of Ca, which was confirmed with its higher total content after its application to the soil, although its available form was not significantly changed. The applied biochar (at the dose of 20 t ha^{-1}) increased available K in the soil (Table 2). The high K content in the biochar contributed to the higher K consumption, adversely influencing Ca and Mg nutrition of the corn. This was shown by deficient levels of Ca and Mg in the corn stalks and seeds, which were considerably lower than the critical levels of 5 and 1.5 g kg^{-1} for Ca and Mg, respectively (Reuter, Robinson 1997). The biochar amendment significantly decreased the Ca concentration in corn seeds and a more intensive effect was found in the case of the higher biochar dose. This B20 treatment had a significant effect on the increase of the Ca concentration in corn leaves. Our study showed that the higher available Mn content in the soil did not translate into higher Mn uptake by the corn plants as indicated by no significant changes in the concentration of Mn in corn organs. The same results have been published by Butnan et al. (2015). Porter et al. (2004) stated that the critical toxic level of Mn concentrations in plant organs is 200 mg kg^{-1} and biochar could be an effective tool to achieve a significant reduction of this element below the toxic level. In our case, the content of Mn in corn organs were deeply below the mentioned level (Table 4). The highest content of Mn was determined in roots > leaves > stalks > seeds but once again we did not find any significant differences in corn organs in the Mn content due to the biochar application. The study of Marschner (1995) stated that as one of the possible mechanisms responsible for a low Mn concentration in corn despite the increased soil Mn could be related to biochar-derived tannin derivatives, such as gallic and tannic acids, which are known to inhibit the activity of H^+-ATPase, an enzyme required for active uptake of Mn.

Correlations between macro- and micronutrients in the soil and their content in corn organs

Correlation coefficients between the content of macro- and micronutrients in the soil and corn organs are summarized in Table 5. The content of total P negatively correlated with the P content in the corn seeds. At the same time, we determined a significant correlation between available P in the soil and the P content in seeds (r = -0.564, $P \leq 0.05$) as well as in leaves (r = -0.484, $P \leq 0.05$) of corn. The highest content of P is usually observed in seeds of plants (Vaněk et al. 2013), which agrees with our results (Table 4). In the case of P, according to our knowledge, the negative correlation could be connected with an increase of both the total and available P in the soil due to biochar amendment. The uptake of P takes place against a concentration gradient, which means that the soil solution is less concentrated to the P content than the cytoplasmic solution in the plant to the P content. The increase of P in the soil resulted in a decrease in the P content in the seeds and leaves in the case of available P. The higher content of the total K in the soil resulted in a higher content of K in leaves and seeds of corn. This points to the luxury uptake of K from the soil to the corn. There is antagonism between the uptake of K and Ca (Zlámalová et al. 2015), which was also confirmed in our study. The content of total Ca was increased after bio-

Table 5

Correlation coefficients between content of macro- and micronutrients in the soil and corn organs

Nutrients	Content of macro- and micronutrient in corn organs			
	roots	stalks	leaves	seeds
	N			
N_t	n.s.	n.s.	n.s.	n.s.
	P			
P_t	n.s.	n.s.	n.s.	-0.543*
P_{av}	n.s.	n.s.	-0.484*	-0.564*
	K			
K_t	n.s.	n.s.	0.561*	0.905***
K_{av}	n.s.	n.s.	n.s.	n.s.
	Ca			
Ca_t	n.s.	n.s.	n.s.	n.s.
Ca_{av}	0.581*	n.s.	n.s.	n.s.
	Mg			
Mg_t	-0.679**	n.s.	0.482*	0.949***
Mg_{av}	-0.627**	0.474*	0.545*	0.806***
	Cu			
Cu_t	n.s.	n.s.	n.s.	n.s.
Cu_{av}	n.s.	n.s.	n.s.	n.s.
	Mn			
Mn_t	n.s.	0.829***	n.s.	0.874***
Mn_{av}	n.s.	n.s.	n.s.	n.s.
	Ni			
Ni_t	n.s.	n.s.	n.s.	n.s.
Ni_{av}	n.s.	n.s.	n.s.	n.s.
	Zn			
Zn_t	0.756***	n.s.	-0.670**	n.s.
Zn_{av}	-0.506*	n.s.	0.503*	n.s.

char application at the dose of 20 t ha^{-1} (Table 2), although its available form was not changed. The higher content of available Ca in the soil resulted in higher content of Ca in corn roots. The content of Mg (both total and available form) was unchanged by biochar application. On the other hand, we found that the higher the content of total Mg in the soil, the higher the increase in the content of Mg in seeds and leaves of corn. And again, we found that the higher content of available Mg is in the soil, the higher the increase of Mg in stalks, leaves and seeds of corn. A negative correlation between both forms of Mg in the soil and Mg in the roots of corn was determined (Table 5). An optimal content of Mn in the plant tissues ranges from 15 to 200 mg kg^{-1} (Fecenko, Ložek 2000, Kováčik 2014). The highest content of Mn was determined in corn roots (Table 4) and its available content depended on biochar application doses (Table 3). The higher content of total Mn in the soil increased the content of Mn in the stalks and in corn seeds. There was a positive correlation observed between total Zn in the soil and Zn in the corn roots. On the other hand, a negative correlation was determined between available Zn in the soil and Zn in corn roots. The negative correlation in the case of available Zn might be explained by the intensive uptake of Ca from the soil to the plant as well as by the positive relationships between available Ca in the soil and the content of Ca in corn roots (Table 5). The uptake of Zn from the soil to the plant is weakened due to more intensive uptake of Ca, Mg and sometimes P (Vaněk et al. 2013).

CONCLUSION

Our results showed that biochar amendment at a dose of 20 t ha^{-1} had significant effects on the increase of soil pH, total content of P, Ca and available K, Mn, Ni and Zn, as well as on the decrease of the no increase of macro- and micronutrients was found in the individual corn organs. Even the corn seeds in both biochar treatments showed a significantly lower Ca content.

Biochar might be used for improvement of soil reaction, especially in acidic soils, as well as improvement of nutrient regimes in the soils. It is very important to know the demand of plants for nutrients and to apply nutrients so as to obtain sufficient production of healthy crops. It is extremely important to pay special attention to the content of macro- and micronutrients in biochar, as their concentrations may be unbalanced. Based on the results, we suggest applying biochar to soil together with other nutrients. The doses of other nutrients added to the soil should respond to demands of individual plants, although the nutrients released from the biochar in subsequent years should also be taken into account. How much of the nutrients is released from biochar in subsequent years after its application to the soil is a question that needs to be carefully addressed in future research.

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