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CONTENTS AND BIOACCUMULATION OF NUTRIENTS FROM SOIL TO CORN ORGANS AFTER APPLICATION OF DIFFERENT BIOCHAR DOSES

Vladimír ŠIMANSKÝ[1], Jerzy JONCZAK[2], Agnieszka PARZYCH[3] & Ján HORÁK[4]

[1]*Department of Soil Science, Faculty of Agrobiology and Food Resources, Slovak University of Agriculture,Tr. A. Hlinku 2, 949 76 Nitra, Slovakia. E-mail: vladimir.simansky@uniag.sk*

[2]*Department of Soil Environment Sciences, Warsaw University of Life Sciences, Nowoursynowska St. 159, 02-776 Warsaw, Poland.*

[3]*Institute of Biology and Environmental Protection, Pomeranian University in Słupsk 22 Arciszewskiego, 76 200 Słupsk, Poland.*

[4]*Department of Biometeorology and Hydrology, Horticulture and Landscape Engineering Faculty Slovak University of Agriculture in Nitra, Hospodárska 7, 949 01 Nitra, Slovakia.*

Abstract: The application of biochar into soil could increase the immobilization of macronutrients and micronutrients and reduce their uptake to a plant therefore we studied the transmission of nutrients to the maize organs in relations to the addition of biochar at the different rates in loamy Haplic Luvisol in the locality of Dolná Malanta (Slovakia). Soil and plant samples were collected from the plots exposed to the following treatments: 1) B0 – no biochar as the control, 2) B10 – biochar at rate of 10 t ha^{-1}, 3) B20 – biochar at rate of 20 t ha^{-1}. The results showed that in B10 and B20 treatments, the values of soil pH were higher by 8% and by 10% in comparison with B0. A higher content of the total organic carbon in B10 (12.1 ± 0.81 g kg^{-1}) and B20 (13.6 ± 1.59 g kg^{-1}) than in B0 (10.9 ± 1.69 g kg^{-1}) was also determined. Our results showed no significant trends on the changes of total nitrogen due to biochar application. The addition of 20 t ha^{-1} of biochar increased significantly total Mn content in the soil by 5% as compared to B0 plot. The contents of HCl-extractable Mn, Zn and Ni were influenced significantly by the biochar application. Mg content in stalks was increased significantly only after the application of biochar at rate of 20 t ha^{-1}. Biochar affected significantly Ni contents in stalks (in case of B20) and leaves (in case of B10) of maize. The application of biochar increased significantly bioaccumulation of Mg in stalks of maize and their values in B10 and in B20 treatments were higher by 25% and 40% in comparison to B0. In comparison to B0, bioaccumulation of Ni in stalks was lower by 32% and 44% in B10 and B20, respectively. The application of 10 and 20 t ha^{-1} of biochar decreased bioaccumulation of Ni in leaves by 37%.

Keywords: Bioaccumulation, biochar, nutrients, heavy metals, maize.

1. INTRODUCTION

Biochar is a charcoal that is produced by exposing the organic waste matter (such as wood chips, crop residue or manure) to heat in an oxygen-poor environment and it is used especially as a soil amendment. The inspiration for biochar addition to soils comes from mid Amazonian where is recorded up to 350 hectares of artificially formed "black" soils originating from the pre-Columbian period known as „Terra Preta soils". These soils are characterised by high levels of fertility as compared to the adjacent soils where no organic C addition occurs (Renner, 2007). Over the past decade, biochar have been particularly desirable due to their positive effects. Its positive effect mainly on crop yield was known already by the ancient cultures (Glaser, 2007). Despite the fact that information about the beneficial effects of biochar has been mentioned since the ancient cultures, the application of biochar is a relatively new concept. For this reason, the national and supranational legislation in the EU is not yet adequately prepared to regulate both the production and the application of biochar. Driven by this "regulatory gap", voluntary biochar quality standards have been formed in Europe with the European

Biochar Certificate, in the UK with the Biochar Quality Mandate and in the USA with the IBI Standard which is intended to be used internationally. In parallel to this, biochar producers and biochar users in a number of EU countries were partly successful in fitting the new biochar product into the existing national legislation for fertilisers, soil improvers and composts. The intended revision of the EC Regulation 2003/2003 on fertilisers offers the opportunity to regulate the use of biochar at the EU level. In publication (Meyer et al., 2017) is summarized the efforts on biochar standardization which have been carried out by voluntary products standards and illustrates existing legislation in EU member states, which apply to the production and use of biochar. It describes existing and planned EU regulations; which impact biochar applications and it develops recommendations on the harmonization of biochar legislation in the EU.

The results of many studies conducted during the recent years are not entirely clear, however the positive opinions predominate. Biochar incorporated to soil can be an effective tool for improving the soil fertility and sustainable agriculture productivity. Several studies (Laghari et al., 2015; Šimanský et al., 2016) supported the fact about the positive effects of the biochar application on increase of soil organic carbon and carbon sequestration capacity of soil. The studies of Nelissen et al., (2012) show that biochar can accelerate soil nitrogen dynamics. Biochar can also improve soil chemical (Lehmann et al., 2011; Park et al., 2011; Horák, 2015), physical (Sohi et al., 2010; Obia et al., 2016), and biological properties (Steinbeiss et al., 2009; Lehmann et al., 2011). In terms of the soil quality improvement, several researchers have evaluated the role of biochar as a stable source of carbon and shown the positive affect of soil properties and increasing crop yields (Lehman et al., 2006; Jones at al., 2012). However, the results of some studies reported also the negative effect of biochar on crop yield (Huang et al., 2013)

Among the key physical properties are the large surface area and presence of micropores (Mukherjee et al., 2011; Chintala et al., 2014), which alter potentially the surface area, pore size distribution, bulk density, water-holding capacity and soil penetration resistance. The incorporation of biochar may enhance specific surface area up to 4.8 times that of the adjacent soils (Liang et al., 2006). As presented by Cornelissen et al., (2005) the sorption ability of biochar in some cases exceeds that of the natural soil organic matter. This indicates the potential of biochar for pollutants immobilisation, including heavy metals and pesticides (Beesley et al., 2010; Zheng et al., 2010; Beesley & Marmiroli, 2011), but also other nutrients important for plant growth (P, Ca, N), (Rees et al., 2015).

Over the last two decades there has been a decline in livestock population in the Slovak Republic, which has led to a decline in organic fertilizer production, with the consequent disturbance of the balance of organic matter on agricultural soils. At present, a 30-50% deficit is estimated from the point of view of the need for organic substances, as the annual production of organic fertilizers is around 10 mil. t y^{-1}, which is less than 5 t ha^{-1} of agricultural soil (Green Report, 2014). From the point of view of sustainable land management, the balanced balance of organic substances is essential and so new resources must be sought. One of the possible and innovative solutions can be the application of biochar. Applied biochar to the soil increases the content of soil organic carbon (Šimanský et al., 2016). With a higher carbon content is observed improving of physical properties, especially the soil structure (Šimanský & Jonczak, 2016), nutrition regimes in the soils.

We hypothesised that the application of biochar to soil could increase the immobilization of macro- and micronutrients and decrease their uptake by plants and these effects might be more intensive due to the application of higher biochar doses. Biochar can also influence the translocation of nutrients in plants.

However, farmers are not interested in a low uptake of nutrients from the soil into the crop in relation to the healthy and sufficient crop production. Their aim is to secure the optimum available amount of nutrients for crop growing. Under above-mentioned circumstances, the application of biochar might be a problem. Therefore, the objective of this study was (1) to quantify the impacts of two doses of biochar on the soil macro- and micronutrients contents in the soil, and (2) to quantify the transmission of nutrients to the individual parts of maize and its bioaccumulation in relations to biochar addition at the different rates.

2. MATERIAL AND METHODS

2.1. Stand characteristics

Nitra-Malanta (lat. 48°19′00″; lon. 18°09′00″) is situated in the lower part of Selenec Creek basin with its tributaries and it belongs to the central part of Nitra River basin. It is located east of Nitra, on the Žitavská upland. The geological substratum consisted of little previous rocks with high quantities of fine materials. The Young Neogene deposits were composed of various clays, loams, sand gravels on which loess was deposited in the Pleistocene Epoch. The soil is classified as Haplic Luvisol (WRB, 2014). The locality has a temperate climate. The average annual air temperature was 9.6°C and annual precipitation was 531.8 mm during the studied year (2015). In 2014, before setting up the experiment with biochar, the soil samples from 10 random locations (experimental field trial) were taken from the depth of 0–20 cm. The soil carbon content was 9.13 g kg^{-1}, while the average soil pH (KCl) was 5.71 and soil was silt loam with content of clay 24.2–26.1%.

2.2. Experiment characteristics

The experiment was established in March 2014. The field was ploughed, harrowed and biochar was spread evenly onto the soil surface and immediately incorporated into the soil (10 cm). Biochar used in the experiment was produced from the paper fiber sludge and grain husks (1:1 w/w) (company Sonnenerde, Austria) by pyrolysis at 550°C for 30 minutes in a Pyreg reactor (Pyreg GmbH, Dörth, Germany). The detailed information concerning the chemical composition of biochar is included in the Table 1.

Table 1. Total content of macro- and micronutrients in biochar

Component	Content
ash (g kg^{-1})	327.5
TOC (g kg^{-1})	361.5
Nt (g kg^{-1})	10.4
P (g kg^{-1})	3.5
K (g kg^{-1})	5.3
Ca (g kg^{-1})	15.0
Mg (g kg^{-1})	3.4
Mn (mg kg^{-1})	359.8
Cu (mg kg^{-1})	32.5
Ni (mg kg^{-1})	24.1
Zn (mg kg^{-1})	60.6

TOC – total organic carbon

The experiment consisted of the following treatments: 1) B0 – no biochar as control, 2) B10 – biochar at rate of 10 t ha^{-1}, 3) B20 – biochar at rate of 20 t ha^{-1}. The replicated (n=3) trial plots were laid out in a randomized block design. The spring barley (*Hordeum vulgare* L.) and maize (*Zea mays* L.) were sown in 2014 and 2015, respectively. The yields of spring barley and maize in B0, B10 and B20 treatments were 3.6±0.8, 5.1±0.9, 3.2±0.5 and 13.6±2.6, 13.9±1.5, 12.7±4.9, respectively.

2.3. Soils sampling and analysis

Three soil subsamples from A-horizons (to the depth of 20 cm) were collected from each treatment plot and mixed into one average sample. The plant residues and visible particles of biochar were removed from the samples and then dried in the oven and sieved through 2.0 mm mesh sieve to remove the skeleton fraction. Soil pH was analysed potentiometrically (Elmetron CPC 401) in suspension with water and 1 M KCl solution, the content of total organic carbon (TOC) by Tyurin method, the content of total nitrogen (Nt) with Kjeldahl method (distillation unit Velp UDK 127), the total content of P, K, Ca and Mg after samples digestion in a mixture of 40% HF and 60% $HClO_4$, the content of Cu, Mn, Ni and Zn after the digestion of ashed samples in aqua regia and the content of P, K, Ca, Mg, Cu, Mn, Ni and Zn after soils extraction in 1 M HCl. The content of P in solutions was determined by using molybdenum-blue method (Raileigh UV-1800), whereas the remaining elements by microwave plasma atomic emission spectrometry (Agilent 4100 MP-AES).

2.4. Plant sampling and analysis

Three subsamples of leaves, stalks, seeds and roots were collected from each plot and mixed into one representative treatment sample. The samples were dried at 65°C, milled into powder using IKA A11 laboratory mill and analysed. The following properties were determined: the content of total nitrogen (Nt) with Kjeldahl method (distillation unit Velp UDK 127) 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 molybdenum-blue method (Raileigh UV-1800) and the remaining elements by microwave plasma atomic emission spectrometry (Agilent 4100 MP-AES).

2.5. Data treatment

The statistical evaluation of the data was performed by using the software Statgraphics Centurion XV.I (Statpoint Technologies, Inc., USA). The treatment differences in soil properties, in nutrients contents of soil and individual parts of maize (one-way ANOVA) were considered significant at P values <0.05 by the LSD test. The relationship between the content of nutrients in maize organs and in soil was determined by bioconcentration factors (BF) and translocation factors (TF). The BF was calculated as the ratio:

concentration of element in leaves (stalks, seeds, roots) and concentration of element in soil (Zang et al., 2009). TF was calculated as the ratio: concentration of nutrients in leaves/concentration of nutrients in stalks (seeds/stalks, stalks/roots) according to Bose et al., (2008). The changes of the value of bioconcentration factors of nutrients were evaluated by using a Kruskal-Wallis test.

3. RESULTS

3.1. General characteristics of the soil

Soil pH ranged from 5.1 to 6.1 and it was the lowest at B0 treatment and slightly higher at B10 and B20 treatments. In B10 and in B20 treatments, the values of soil pH were higher by 8% and by 10% in comparison to B0 (Table 2). The observed differences in soil pH were influenced by the application of biochar. The soils contained 9.66–14.50 g kg^{-1} of TOC and 1.04–1.29 g kg^{-1} of Nt at TOC:Nt ratios from 8.8 to 12.3. There is clearly visible the positive effect of biochar application on TOC content in the studied soil. We determined a higher content of TOC in B10 (12.1±0.81 g kg^{-1}) and B20 (13.6±1.59 g kg^{-1}) than in B0 (10.9±1.69 g kg^{-1}). Such effect was not observed in case of nitrogen. Nt content was higher in B20 (1.22±0.06 g kg^{-1}) and lower in B10 (1.12±0.09 g kg^{-1}) than in B0 (1.16±0.11 g kg^{-1}).

Table 2. Selected chemical properties of soil

Treatments	pH	TOC g kg^{-1}	Nt g kg^{-1}	TOC/Nt
B0	5.31a	10.9a	1.16a	9.3a
B10	5.71ab	12.1ab	1.12a	10.7ab
B20	5.85b	13.6b	1.22a	11.2b

B0 – no biochar as the control variant, B10 – biochar at rate of 10 t ha^{-1}, B20 – biochar at rate of 20 t ha^{-1}; TOC – total organic carbon; different letters between lines (a, b) indicate that treatment means are significantly different at $p < 0.05$ according to LSD test.

3.2. The content of macro- and micronutrients in the soil

The applied biochar did not influence significantly the total contents of macro- and micronutrient in the soil, except Mn (Table 3). The addition of 20 t ha^{-1} of biochar increased significantly the total Mn content in the soil by 5% as compared to control (B0). There was also found a slight increase by 3% ($P > 0.05$) in B10 treatment. The contents of HCl-extractable Mn, Zn and Ni were significantly influenced by the biochar application at the rate of 20 t ha^{-1}. The highest contents of HCl-extractable Mn, Zn and Ni in the soil were observed when 20 t ha^{-1} of biochar were applied. In B10 treatments HCl-extractable Mn, Zn and Ni in the soil were higher than in B0 by 22, 13 and 6 %, respectively with the significant treatment effect found only in case of Mn.

Table 3. Mean ± SD contents of total and HCl-extractable forms of macro- and micronutrients in soils

	B0		B10		B20	
	mean	SD	mean	SD	mean	SD
Total						
P (g kg^{-1})	0.98a	0.08	0.92a	0.07	0.94a	0.04
K (g kg^{-1})	21.28a	0.24	20.95a	0.34	20.74a	0.32
Ca (g kg^{-1})	5.51a	0.27	5.58a	0.28	5.64a	0.20
Mg (g kg^{-1})	5.23a	0.18	5.17a	0.07	5.03a	0.11
Mn (mg kg^{-1})	1125.6a	11.98	1157.7ab	39.21	1184.5b	8.13
Cu (mg kg^{-1})	15.15a	0.55	14.65a	0.07	12.86a	2.30
Ni (mg kg^{-1})	28.37a	0.91	28.48a	0.42	28.46a	0.96
Zn (mg kg^{-1})	46.59a	1.57	46.67a	1.14	47.49a	2.17
HCl-extractable						
P (g kg^{-1})	0.14a	0.03	0.14a	0.04	0.18a	0.03
K (g kg^{-1})	0.32a	0.05	0.30a	0.03	0.36a	0.02
Ca (g kg^{-1})	2.39a	0.28	2.67a	0.41	2.89a	0.18
Mg (g kg^{-1})	0.36a	0.03	0.41a	0.04	0.42a	0.02
Mn (mg kg^{-1})	180.9a	18.29	220.7b	35.82	297.8b	54.04
Cu (mg kg^{-1})	5.85a	0.43	5.75a	0.35	6.01a	0.55
Ni (mg kg^{-1})	4.81a	0.21	5.11ab	0.29	5.65b	0.46
Zn (mg kg^{-1})	6.62a	0.74	7.48ab	0.99	8.21b	0.56

B0 – no biochar as the control variant, B10 – biochar at rate of 10 t ha^{-1}, B20 – biochar at rate of 20 t ha^{-1}; different letters between lines (a, b) indicate that treatment means are significantly different at $p < 0.05$ according to LSD test.

Table 4. Mean ± SD contents of macro- and micronutrients in corn roots, stalks, leaves and seeds

Treatments		P ($g\ kg^{-1}$)	K ($g\ kg^{-1}$)	Ca ($g\ kg^{-1}$)	Mg ($g\ kg^{-1}$)	Mn ($mg\ kg^{-1}$)	Cu ($mg\ kg^{-1}$)	Ni ($mg\ kg^{-1}$)	Zn ($mg\ kg^{-1}$)
roots									
B0	mean	1.09a	8.68a	7.40a	1.74a	290.4a	20.97a	23.43a	32.03a
	SD	0.35	2.92	0.53	0.31	104.39	3.88	3.18	9.71
B10	mean	1.54a	9.78a	8.16a	1.67a	230.3a	16.78a	24.51a	37.23a
	SD	0.13	4.20	2.06	0.08	40.73	4.73	2.36	4.02
B20	mean	1.56a	8.81a	7.65a	1.51a	186.1a	13.60a	23.61a	36.04a
	SD	0.25	5.23	0.33	0.39	44.29	3.74	1.08	1.92
stalks									
B0	mean	1.31a	17.55a	2.00a	1.05a	15.5a	4.00a	14.23b	32.10a
	SD	0.32	3.68	0.38	0.12	5.09	1.08	2.90	15.16
B10	mean	1.41a	14.45a	2.58a	1.30ab	12.9a	4.25a	9.63ab	21.40a
	SD	0.11	1.92	0.86	0.23	2.58	0.74	2.27	5.75
B20	mean	1.64a	17.80a	2.63a	1.42b	15.1a	4.15a	8.08a	25.63a
	SD	0.18	4.54	0.20	0.10	3.29	0.30	2.38	8.73
leaves									
B0	mean	1.51a	5.95a	9.85a	2.92a	127.9a	4.70a	9.83b	36.29a
	SD	0.47	1.48	1.25	0.55	33.87	0.76	1.07	5.31
B10	mean	1.81a	6.51a	10.81a	3.41a	114.7a	4.34a	6.38a	35.18a
	SD	0.93	2.31	2.13	0.97	19.02	0.78	0.97	9.45
B20	mean	1.38a	5.64a	9.51a	2.78a	98.3a	4.52a	6.32a	29.11a
	SD	0.43	1.07	0.95	0.38	13.23	0.57	0.64	7.57
seeds									
B0	mean	3.43a	4.15a	0.24a	1.29a	8.11a	3.35a	2.01a	27.27a
	SD	0.29	0.29	0.02	0.10	0.67	0.31	1.11	0.27
B10	mean	3.29a	4.01a	0.25a	1.26a	7.71a	2.89a	1.06a	24.83a
	SD	0.13	0.23	0.03	0.04	1.23	0.04	0.31	0.93
B20	mean	3.31a	4.15a	0.25a	1.24a	7.67a	2.98a	0.72a	24.44a
	SD	0.19	0.20	0.02	0.04	1.45	0.40	0.22	2.43

B0 – no biochar as the control variant, B10 – biochar at rate of 10 t ha^{-1}, B20 – biochar at rate of 20 t ha^{-1}; different letters between lines (a, b) indicate that treatment means are significantly different at $p < 0.05$ according to LSD test.

3.3. The content of macro- and micronutrients in maize

The contents of macro- and micronutrients in the different maize vegetative organs are shown in the Table 4. The applied biochar to the soil did not change the contents of macronutrients in the maize organs. However, the highest contents of P, K, Ca and Mg were determined in seeds, stalks and leaves, respectively. The higher dose of biochar resulted in the higher contents of P in roots and in stalks, but on the other hand, a higher biochar dose resulted in a lower P content in leaves. The treatment with biochar showed decrease of P content in seeds, but without the statistical significance. The contents of K in the different parts of maize fluctuated from 4.01 to 17.8 g kg^{-1} with biochar having not significant influence on K (Table 4). In comparison to B0, contents of K in roots were higher by 13% and 2% in B10 and B20, respectively. On the other hand, the contents of K in stalks were lower by 18% after the application of 10 t ha^{-1} of biochar as compared to B0 treatment. The biochar at rate of 10 t ha^{-1} increased the contents of Ca in the maize parts more intensively but with no statistical significance. Mg content in stalks was increased significantly only after the application of biochar at rate of 20 t ha^{-1}. Generally, the highest contents of micronutrients were determined in roots and the lowest ones in seeds of maize. Biochar significantly decreased Ni contents in stalks (in case of B20) and leaves (in case of B10 and B20) of maize. In comparison to B0, Ni contents in stalks and leaves were decreased by 32%, 43% and 35%, 36% in B10 and B20 treatments, respectively.

3.4. Bioaccumulation and translocation factors of nutrients in maize

The application of biochar increased significantly the bioaccumulation of Mg in stalks of maize and their values in B10 and in B20 treatments were higher by 25% and by 40% in comparison with B0 (Fig. 1). There was not observed the significant increase of bioaccumulation factors of other macronutrients and Mn in relation to the biochar application. The decreasing trend was found out in case of Ni in stalks and leaves ($P < 0.05$). In comparison to B0, bioaccumulation of Ni in stalks was lower by 32% and by 44% in B10 and B20, respectively.

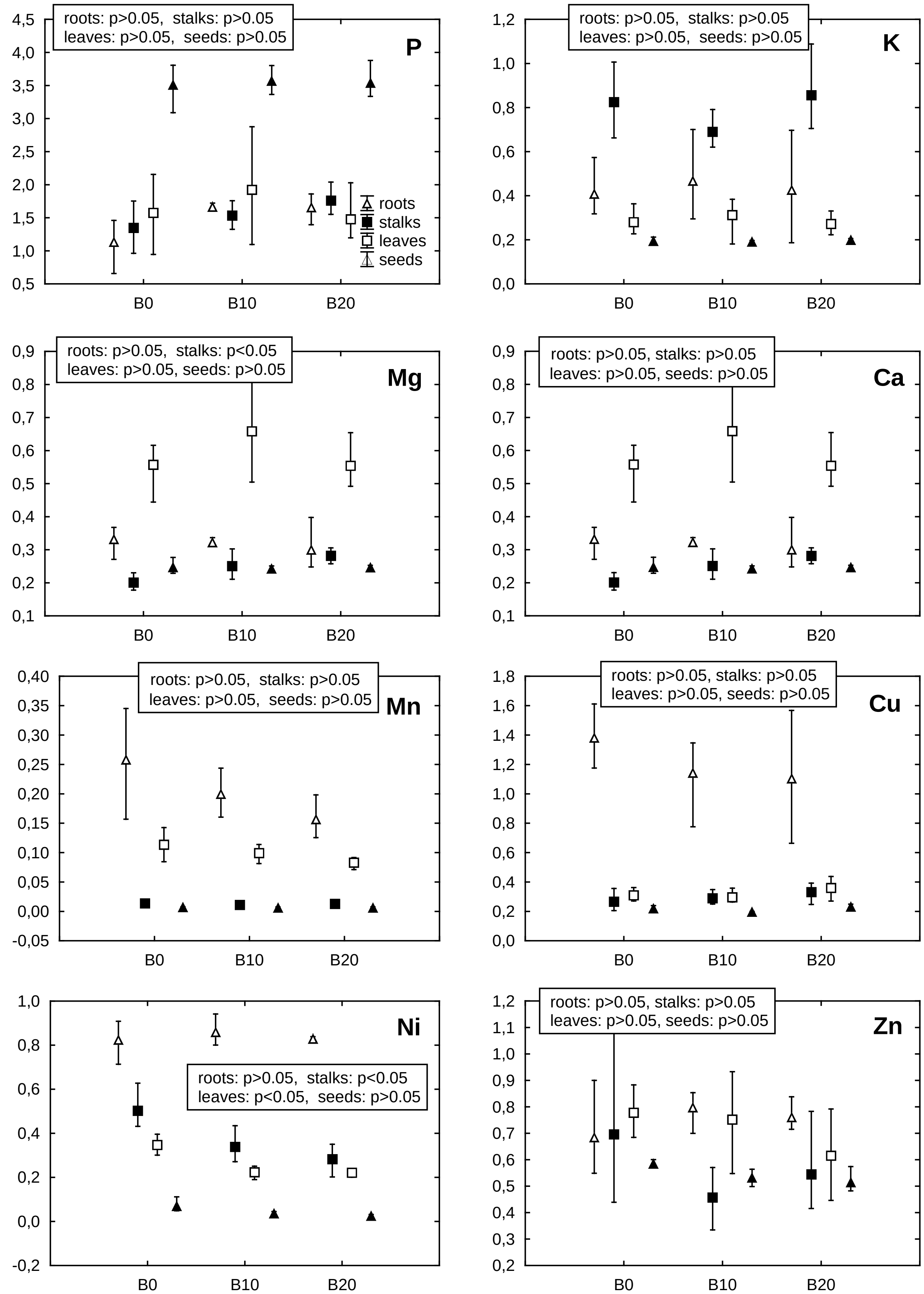

Figure 1. Mean and range of bioaccumulation factors of nutrients in corn with the results of Kruskal-Wallis test
B0 – no biochar as the control variant, B10 – biochar at rate of 10 t ha^{-1}, B20 – biochar at rate of 20 t ha^{-1}

The application of 10 and 20 t ha^{-1} of biochar decreased the bioaccumulation of Ni in leaves by 37%. There was not detected any significant difference in the bioaccumulation of Cu in seeds between B0 and B10, as well as between B0 and B20. The addition of biochar decreased movement of Ca, Mg and Cu from stalks to leaves; P, Mg and Cu from stalks to seeds and P, Ni and Zn from roots to stalks (Table 5). Among the studied elements the lowest mobility was noted for Mn. The highest values of BF for P, Mg and Ca were noted in leaves, whereas Cu and Mn in roots. The least accumulation of the above-mentioned elements was observed in seeds. The relations between the values of BF in the experiment were changing as follows: B0: (roots) Cu>Ca>P>Ni>Zn>K>Mg>Mn; B10: (roots) P>Ca>Cu>Ni>Zn>K>Mg>Mn; B20 (roots) P>Ca>Cu>Ni>Zn>K>Mg>Mn; B0: (stalks) P>K>Zn>Ni>Ca>Cu>Mg>Mn; B10: (stalks) P>K>Zn=Ca>Ni>Cu>Mg>Mn; B20: (stalks) P>K>Zn>Ca>Cu>Mg=Ni>Mn; B0: (leaves) Ca>P>Zn>Mg>Ni>Cu>K>Mn; B10: (leaves) Ca>P>Zn>Mg>K>Cu>Ni>Mn; B20: (leaves) Ca>P>Zn>Mg>Cu>K>Ni>Mn; B0: (seeds) P>Zn>Mg>Cu>K>Ni>Ca>Mn; B10: (seeds) P>Zn>Mg>Cu>K>Ni=Ca>Mn; B20: (seeds) P>Zn>Mg>Cu>K>Ca>Ni >Mn.

4. DISCUSSION

The biochar application to soils may have the agronomic benefits such as neutralizing soil pH (Jeffery et al., 2011; Yuan et al., 2011; Kim et al., 2015). Horák (2015) stated that biochar could be suggested as a valuable tool for the management of agroecosystems and a plausible way to ameliorate soils and may be effective in increasing soil pH in acid soils. This knowledge has been confirmed by our findings (Table 2). Several studies (Agegnehu et al., 2016; Xu et al., 2016) supported the fact about the positive effects of biochar application on increase of the soil organic carbon. We determined a higher content of TOC in treatments with added biochar, as well. Generally, the biochar application influences the nitrogen cycling in the soil (Lone et al., 2015). Purakayastha et al., (2015) recorded that the nitrogen content was increased significantly due to the biochar application. The extent of increase in N in the soil ranged between 25 and 40%. Our results showed no significant trends in the changes of Nt due to the biochar application.

The biochar contains ash, which is a valuable source of macronutrients for plants such as: K, Ca and Mg (Rajkovich et al., 2012). In our case the applied biochar did not have statistically significant influence on the total contents of the studied macronutrient in the soil, which is in contrast with the published results of several authors (Haefelea et al., 2011; Parvage et al., 2013) which in our case might be an effect due to a short time of the experiment. The concentrations of macronutrient are affected significantly by the type and rate of biochar in the soil (Butnan et al., 2015), but also their contents in the soils (Musielok & Drewnik, 2016). As reported by Borchard et al., (2014), the availability of P and K was increased when the biochar was added to the rich soils and less when it was added to the acidic soils. These findings did not correspond completely with our results because the investigated soil had acidic pH, but contained a high content of available P and K. In general, the higher concentrations of HCl-extractable macronutrients were observed in the soils amended with biochar, which could be explained by the retention of elements by biochar particles (Beesley & Marmiroli, 2011; Chintala et al., 2014; Rees et al., 2015). In addition, the added biochar to the acid soils can reduce substantially P precipitation with Al^{3+} and Fe^{3+} (DeLuca et al., 2009).

The nutrients uptake by plants is strongly influenced by the requirements of the individual species, growth phase, and season of the year and by a complex of physical and chemical properties of the soils determining bioavailability (Kabata-Pendias & Pendias, 1999).

Table 5. Translocations factors (mean ± standard deviation) of nutrients in maize organs

		P	K	Ca	Mg	Mn	Cu	Ni	Zn
Leaves/ Stalks	B0	1.2±0.5	0.3±0.1	4.9±1.5	2.8±0.8	8.3±4.0	1.2±0.5	0.7±0.2	1.1±0.7
	B10	1.3±0.8	0.5±0.2	4.2±1.5	2.6±0.9	8.9±2.9	1.1±0.3	0.7±0.3	1.6±0.0
	B20	0.8±0.3	0.3±0.1	3.6±0.6	1.9±0.2	6.5±1.5	1.1±0.1	0.8±0.2	1.1±0.2
Seeds/ Stalks	B0	2.6±1.0	0.2±0.1	0.1±0.0	1.2±0.2	0.5±0.2	0.8±0.3	0.1±0.1	0.8±0.4
	B10	2.3±0.2	0.3±0.0	0.1±0.0	0.9±0.1	0.6±0.0	0.7±0.1	0.1±0.0	1.2±0.4
	B20	2.0±0.1	0.2±0.1	0.1±0.0	0.9±0.0	0.5±0.0	0.7±0.2	0.1±0.0	0.9±0.4
Stalks/ Roots	B0	1.2±0.7	2.0±0.9	0.3±0.0	0.6±0.1	0.1±0.0	0.2±0.1	0.6±0.1	1.0±0.6
	B10	0.9±0.1	1.5±0.9	0.3±0.1	0.8±0.2	0.1±0.0	0.3±0.1	0.4±0.1	0.6±0.2
	B20	1.1±0.3	2.0±2.5	0.3±0.0	0.9±0.2	0.1±0.0	0.3±0.1	0.3±0.1	0.71±0.2

B0 – no biochar as the control variant, B10 – biochar at rate of 10 t ha^{-1}, B20 – biochar at rate of 20 t ha^{-1}

The phosphorus compounds are the most available to plants at pH from 6.0 to 10.0, whereas calcium and magnesium at pH 6.5–8.5. The solubility of heavy metals is low as to neutral and alkaline pH, and it increases along with lowering of reaction (Smal & Salomons, 1995). The increase of Zn and Mn mobility is most effective with pH = 6.0, and copper and nickel at pH = 5.5. The manganese components are characterized by the increased solubility also in alkaline environment (pH ~ 8.0) (Kabata-Pendias & Pendias, 1999).

Maize is a variety having high nutritional requirements due to the high production of biomass (Sądej & Mazur, 2003). The contents of macronutrients in the individual parts of maize are affected by a number of factors such as: soil and climatic conditions, variety of maize, fertilization, and growth stage, etc. (Fecenko & Ložek, 2000). In our experiment, the addition of biochar resulted in the increase of soil pH (Table 2), which might lead to the reduction in bioavailability of the studied nutrients, mainly in neutral and alkaline soils. Their bioavailability was also reduced by the sorption on biochar particles (Beesley & Marmiroli, 2011). However, through this mechanism the essential plant nutrients may also be immobilized, leading to the plant deficiencies in calcium and phosphorus, or even the decreased competition with cations for metal uptake (Rees et al., 2015). Specifically, the effects of biochar application depend on the various factors such as soil type, metal type, type of feedstocks used for charring, pyrolysis conditions and the amount of biochar applied to the soil (Park et al., 2011; Debela et al., 2012). A higher dose of biochar resulted in a lower content of Ni in stalks and leaves of maize (Table 4). Nickel is accumulated easily by the plants and transported to their aboveground organs (Kabata-Pendias & Pendias, 1999). However, the reduced mobility of this element in soils supplied with biochar contributed significantly to reducing in its concentration in leaves and stalks. Parzych et al., (2015) observed that Ni, Zn, Cu were accumulated mainly in the underground shoots and the highest accumulation of Mn was observed in the leaves of investigated plants.

The values of bioconcentration factors suggest a stronger bioaccumulation of P (1.14-3.57) and Ca (0.04-1.94) as compared to the remaining elements. This confirms also high requirements of maize for these elements (Fecenko & Ložek, 2000). The biochar application resulted also in reducing of translocation factors (TF), which confirms the results obtained by Rees et al., (2015). TF is a parameter for evaluating the direction of movement of nutrients between plant organs.

5. CONCLUSION

The results of our study indicate a positive response of soil pH and total organic carbon in the Haplic Luvisol to biochar application. The most favourable effects on soil pH and total organic carbon were observed when 20 t ha^{-1} of biochar were applied. Despite the fact that biochar had a high content of nutrients, there was found out the significant increase of total Mn and in HCl extractable Mn, Ni and Zn in the soil after the application of 20 t ha^{-1} of biochar. This higher dose of biochar (20 t ha^{-1}) had a positive effect on the increase of Mg content only in stalks, and on the reduction of Ni in stalks and leaves of maize. The values of bioaccumulation factor suggest a stronger bioaccumulation of P and Ca as compared to the remaining elements. The highest values of bioaccumulation factor for P, Mg and Ca were observed in leaves, whereas Cu and Mn in roots. The least accumulation of the above-mentioned elements we found in seeds. Generally, a higher bioaccumulation macro- and micronutrients was observed after the application rate of biochar 20 t ha^{-1}. The results of our study confirm that biochar as a soil amendment has neutralizing effect in acid soil as well as increased total organic carbon content in soil and has influence on the immobilization of soil nutrients. A higher the dose is, the higher the effect is observed. Therefore, biochar can be used as an effective tool for the improving of soil reaction, especially acidic soils, organic matter increase and sequestration of carbon in soils, and nutrients management and shaping of chemical composition in crops.

Based on the obtained results, we suggest applying biochar to the soil together with other nutrients. However, the doses of these individual nutrients combined with biochar require further studies in relation to the sufficient production of healthy crops. The application of biochar alone in terms of supplying the adequate nutrition for plants is not an optimal alternative for other organic or mineral fertilizers.

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