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Can a single dose of biochar affect selected soil physical and chemical characteristics?

Dušan Igaz[1*], Vladimír Šimanský[2], Ján Horák[1], Elena Kondrlová[1], Jana Domanová[1], Marek Rodný[3], Natalya P. Buchkina[4]

[1] Department of Biometeorology and Hydrology, Faculty of Horticulture and Landscape Engineering, Slovak University of Agriculture, Tr. A. Hlinku 2, 94 901 Nitra, Slovakia.
[2] Department of Soil Science, Faculty of Agrobiology and Food Resources, Slovak University of Agriculture, Tr. A. Hlinku 2, 949 76 Nitra, Slovakia.
[3] Institute of Hydrology, Slovak Academy of Sciences, Dúbravská cesta 9, 841 04 Bratislava, Slovakia.
[4] Agrophysical Research Institute, 14 Grazhdansky prospect, 195220 St. Petersburg, Russian Federation.
[*] Corresponding author. Tel.: +421 37641 5245. E-mail: dusan.igaz@uniag.sk

Abstract: During the last decade, biochar has captured the attention of agriculturalists worldwide due to its positive effect on the environment. To verify the biochar effects on organic carbon content, soil sorption, and soil physical properties under the mild climate of Central Europe, we established a field experiment. This was carried out on a silty loam Haplic Luvisol at the Malanta experimental site of the Slovak Agricultural University in Nitra with five treatments: Control (biochar 0 t ha^{-1}, nitrogen 0 kg ha^{-1}); B10 (biochar 10 t ha^{-1}, nitrogen 0 kg ha^{-1}); B20 (biochar 20 t ha^{-1}, nitrogen 0 kg ha^{-1}); B10+N (biochar 10 t ha^{-1}, nitrogen 160 kg ha^{-1}) and B20+N (biochar 20 t ha^{-1}, nitrogen 160 kg ha^{-1}). Applied biochar increased total and available soil water content in all fertilized treatments. Based on the results from the spring soil sampling (porosity and water retention curves), we found a statistically significant increase in the soil water content for all fertilized treatments. Furthermore, biochar (with or without N fertilization) significantly decreased hydrolytic acidity and increased total organic carbon. After biochar amendment, the soil sorption complex became fully saturated mainly by the basic cations. Statistically significant linear relationships were observed between the porosity and (A) sum of base cations, (B) cation exchange capacity, (C) base saturation.

Keywords: Biochar; Soil physical characteristics; Soil sorption characteristics; Soil organic carbon; *Zea mays*.

INTRODUCTION

The potential benefits of biochar application to agricultural soils have been extensively analyzed in several environmental studies. Biochar was primarily discussed from the point of view of carbon sequestration, and its potential to reduce greenhouse gas emissions to the atmosphere (Lehmann et al., 2011). Biochar, as a product of thermal modification of organic matter by pyrolysis, is a solid porous material with a high carbon content.

The scientific community is interested in biochar application to soil in the terms of its impact on the agro-environmental parameters such as soil chemistry, pH, and soil organic carbon (Jien and Wang, 2013; Peng et al., 2011), as well as absorption, movement of nutrients in the plant root zone and their leaching. Also of interest is the impact on soil organic matter content (Brodowski et al., 2007), soil aggregate stability and soil crust formation (Ajayi and Horn, 2016; Sun and Lu, 2014; Šimanský et al., 2016). Various studies have shown that biochar has the potential to influence the physical characteristics of soil (Buchkina et al., 2017; Castellini et al., 2015; Herath et al., 2013) and thus change the rootzone water balance of ecosystems. Observations have included soil properties such as bulk density (Ajayi and Horn, 2016) soil porosity (Obia et al., 2016), soil water content (Novak et al., 2012, Vitkova et al., 2017), the available water capacity of the soil (Abel et al., 2013; Brockhoff et al., 2010), the water holding capacity of the soil and field capacity (Busscher et al., 2010; Jones et al. 2010; Novak et al., 2012) and the soil-water retention curve (Liu et al., 2011).

Several studies have indicated that the addition of about 1–2% (w/w) of the biochar to soil influences the water holding capacity of the soil and increases the soil's water content. Depending on the amount applied, biochar can modify the soil structure (Ajayi and Horn, 2016). These physical properties can affect the various processes that impact the formation, structure, and stability of aggregates, as well as the, shapes and the size of soil pores (Lin et al., 2012). However, there are very few studies that have focused on the processes and mechanisms of the biochar's interactions with the soil environment. Despite the clear connection between biochar porosity and the soil porosity after its application, very few studies have reported a direct effect of biochar pore size on subsequent changes in the soil properties. Ajayi and Horn (2016) reported that after repeated wetting and draining of biochar-amended sandy soil, the formation of finer soil pores comprised of finer biochar particles in the vicinity of the coarser sandy particles. Similar results were also found in the study of Rizhiya et al. (2015).

Several authors have investigated with the impact of the biochar application on soil water content and more specifically on the available water content which is defined as the amount of plant available water in the root zone being the range from permanent wilting point up to field capacity. According to Jones et al. (2010), the field capacity of sandy soil increased from 0.11 (cm^3 cm^{-3}) up to 0.16 and 0.20 (cm^3 cm^{-3}) after biochar application at rates of 2.6 and 5.2% (g g^{-1}), respectively. Similar observations were reported by the other authors at different rates of biochar application (Karhu et al., 2011; Novak et al., 2012). In contrast, a study of Busscher et al. (2010) showed a decrease of the field capacity of a loam sandy soil after biochar application at 0.5; 1.0 and 2.0% (g g^{-1}).

As yet, the interaction between biochar and biochar with nitrogen fertilizer, in commercial field setting has not been explored in field conditions of Slovakia. Therefore, the aim of this study was to determine the impact of different rates of biochar application with, and without inorganic nitrogen, on selected soil chemical and physical characteristics. This was carried out via field experiments conducted in Malanta, Slovakia. We hypothesized that the application of biochar to the soil would (i) increase the soil's water content, (ii) increase the total organic carbon content, (iii) increase the saturation of the soil's sorption complexes.

MATERIAL AND METHODS

Field site

Field experiment was established in the spring of 2014 at the experimental site of the Slovak University of Agriculture located in Malanta municipality, in the Danubian Upland (48°19′00′′ N; 18°09′00′′ E). The altitude of the site is 175 m, the soil is classified as Haplic Luvisol and the topsoil contains 249 g kg^{-1} of clay, 599 g kg^{-1} of silt and 152 g kg^{-1} of sand, giving it a silt loam texture. The soil is slightly acidic (pH 5.71) and low in organic carbon content (9.13 g kg^{-1}). The locality is characterized by a warm lowland climate with long, warm and dry summers, and short dry winters and only a very short duration of snow cover (14–30 days). For the first year of the project in 2015, the average annual air temperature at the Malanta site was 9.6°C and the annual rainfall was 532 mm. The average annual temperature varied in the range of 9 to 10°C and the average annual precipitation varied from 500 up to 600 mm.

In March 2014, a single dose of biochar at 0, 10, and 20 t ha^{-1} was applied on trial plots by hand and incorporated into the soil to a depth of 0–0.1 m with a tractor cultivator. Subsequently, the influence of biochar on selected soil characteristics under corn crop *(Zea mays* L.) was analyzed in 2015.

Five treatments of the experiment were established in 3 replicates on plots of 4 m x 6 m with a protection zone of 0.5 m (Fig. 1).The treatments were as follows: Control (biochar 0 t ha^{-1}, nitrogen 0 kg ha^{-1}); B10 (biochar 10 t ha^{-1}, nitrogen 0 kg ha^{-1}); B20 (biochar 20 t ha^{-1}, nitrogen 0 kg ha^{-1}); B10+N (biochar 10 t ha^{-1}, nitrogen 160 kg ha^{-1}) and B20+N (biochar 20 t ha^{-1}, nitrogen 160 kg ha^{-1}). The N-fertilizer was manually applied at two times: 80 kg N ha^{-1} on 24 April, 2015 and 80 kg N ha^{-1} on 5 August, 2015, and was in the form of calcium-ammonium nitrate. The rate of N applied was calculated according a nutrient balance method, which reflects the crop's nitrogen requirements. The same form of N-fertilizer had been applied at rate of 40 kg ha^{-1} to the spring barley crop in the previous year on the same day as the biochar (10 March, 2014).

Properties of the used biochar

The biochar used for the experiment was made from the mixture of paper fiber sludge and cereal husks in a weight ratio 1:1 and was produced by Sonnenerde, in Austria using pyrolysis at 550°C for 30 min in a Pyreg reactor (Pyreg GmbH, Dörhe, Germany). On average the biochar 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 (DIN EN ISO 11 885). Total C content of biochar was 53.1%, while total N content was 1.4% (DIN 51732), so the C:N ratio was 37.9. The specific surface area (SSA) was 21.7 m^2 g^{-1} (DIN 66132/ISO 9277) and the ash content was 38.3% (DIN 51719). On average, the pH($CaCl_2$) of the biochar was 8.8 (DIN ISO 10390).

Soil sampling and subsequent analyzes

The soil moisture was determined from disturbed soil samples by the gravimetric method (g g^{-1}) every week during the growing season (March 2015–October 2015). The gravimetric water content (w/w) was determined according to the weight of soil sample before and after drying as the ratio of the weight of water (m_w) in the sample to the weight of the dried soil (m_s) after drying at 105°C in the oven until reaching a constant weight. Subsequently, the mass water content (w/w) was multiplied by the soil bulk density (ρ_d) to calculate the volumetric water content (θ, v/v).

To determine the selected physical and hydro-physical characteristics, two sampling events were conducted, one in the spring of 2015 and again in the autumn of 2015. Three undisturbed soil samples were taken from each plot (a total of 45 samples) of all treatments (n = 5) across the 3 replicates. This means that each soil property was determined from 9 representative undisturbed soil samples that were collected from a depth of 5–10 cm using stainless steel cylinders with a volume of 100 cm^3 and the height of 5.1 cm. The cylinders were gently pushed into the soil using the soil sampler. To maintain the soil water content close to field capacity, the soil sampling was conducted 2 days after intensive rainfall.

The relationship of the soil water potential and the water content (the water retention curve) was determined using a pressure-plate apparatus. The drainage retention curve was derived from pre-saturated soil samples placed on ceramic plates at the pressure potentials of 0, –1, –5.5, –20, –55, –100 and –300 kPa. Prior every increase of pressure potential, the undisturbed soil samples were weighed and the water content corresponding to each pressure potential was calculated. At the end, the soil samples were dried for 24 h at 105°C and weighed.

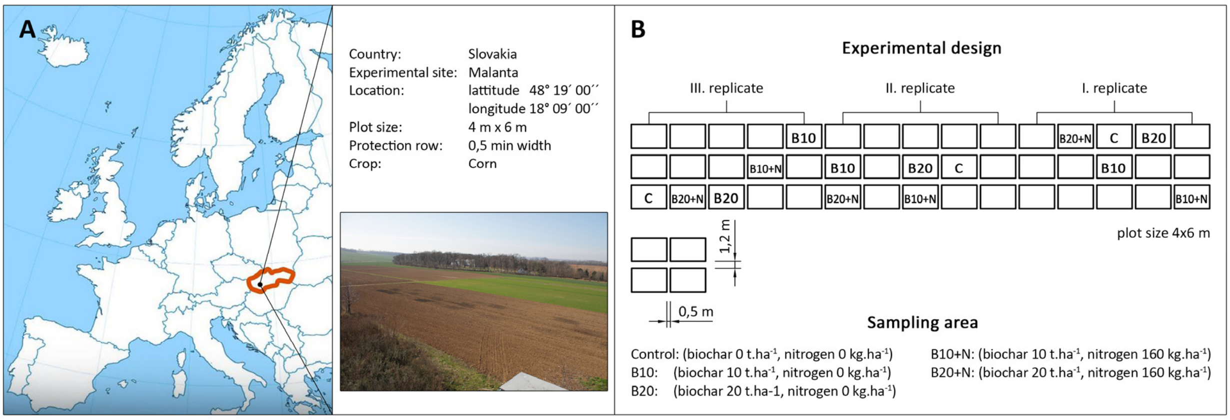

Fig. 1. The location (A) and experimental design of the field experiment (B).

The readily available water content (RAWC) is that water in the soil that is easily extracted by the plant. The RAWC was calculated as a difference between measured values of field capacity (FC, at a pressure potential of –20 kPa) and the refill point (RP, at pressure potential of –300 kPa). The refill point is the water content when the plant has used all readily available water. Beyond refill point, as the soil dries out, the plant needs to work harder to extract water via its roots and crop becomes under stress.

According to convention, the available water content (AWC) corresponds to the moisture interval between the limit of the field capacity (FC) and the wilting point (WP). The value of the FC was determined from the measured values. Wilting point (-1500 kPa) was calculated using the RETC software (Leij et al., 1992) with a van Genuchten soil-moisture retention model (VG) (van Genuchten, 1980). The unknown parameters of the VG model, namely the shape parameters (α, n), and the saturated water content (θ_s) were found via the optimization process and used to calculate the WP. The RETC code minimizes the sum of squared residuals (RMSE) between model-predicted and the observed water retention data by means of a weighted least-squares approach based on Marquardt's maximum likelihood method (Marquardt, 1963). Following Mualem (1976), the shape parameter m was set equal to $1 - 1/n$. To reduce the number of parameters being estimated, the residual soil water content θ_r was handled as a constant and its value was estimated with the means of a pedotransfer function to be $\theta_r = 0.040$ (Skalová et al., 2015).

The soil porosity was estimated as the volumetric water content found after saturating the undisturbed soil samples for 24 h at the free-water potential of 0 kPa, and was calculated as the volumetric proportion of water in the sample. The undisturbed soil samples were also used for calculating the bulk density as the ratio of dried soil mass (for 24 h at 105°C) to the total soil sample volume (100 cm^3).

Soil samples for determination of the soil organic carbon content (SOC) and sorption parameters were collected at the same time from the same depths and plots as the samples for the purposes of the physical characteristics. The SOC was determined by wet combustion method of Tyurin (Dziadowiec and Gonet, 1999), by oxidizing the organic matter using a mixture of 0.07 M H_2SO_4 and $K_2Cr_2O_7$ with titration using 0.01 M Mohr's salt ($(NH_4)_2SO_4 \cdot FeSO_4 \cdot 6H_2O$). The sorption parameters such as hydrolytic acidity (Ha) and the sum of exchangeable base cations (SBC) were determined by the Kappen method (Hanes, 1999). Cation exchange capacity (CEC) was calculated as the sum of Ha and SBC, while the base saturation (Bs) was calculated as the ratio of SBC to CEC (Hrivňáková et al., 2011).

Statistical analysis

The impact of biochar amendment on chemical and physical soil characteristics, organic carbon, and soil sorption parameters was assessed by a statistical one-way analysis of variance (ANOVA) using the Statgraphics Centurion software by LSD test ($p < 0.05$). The statistical analysis was performed on the treated value set excluding the highest and lowest values for all treatments of the experiment ($n = 7$). Further, regression analysis was used to determine the interrelationships between the soil organic matter, sorption complex parameters and physical characteristics.

RESULTS AND DISCUSSION

Effect of biochar on water content dynamics

The impact of the single application of biochar at 0, 10 and 20 t ha^{-1} in March 2014 on the water content dynamics in 2015 under the corn crop (*Zea mays* L.) is presented in Fig. 2. The water content trends are influenced by precipitation and the subsequent dry down due to transpiration, soil evaporation and drainage runoff. Prior to, and during the spring, the highest average soil water content was in B10+N and B20+N treatments and the lowest in the control treatment. From early May 2015, soil water contents started to diverge, with higher values across all treatments compared to control. This difference in this trend was subsequently observed throughout the whole growing season.

An interesting effect of biochar application on the water content was recorded in the relation to the crop (*Zea mays* L.) and its growth phases. Corn is a water demanding plant, particularly during crop emergence and then subsequently from silking until the beginning of kernel milk stage. During germination (15th May 2015) soil water contents were ranked in the following order: Control < B10 < B20+N < B10+N < B20 at 13.2 < 21.6 < 22.2 < 23.5 < 23.8 % vol., respectively. Next, at the beginning of silking stage (8th July 2015) the soil water contents increased in the order: Control < B10 < B10+N < B20 < B20+N and 5.1 < 6.7 < 7.2 < 9.6 < 10.1 % vol., respectively. At the beginning of the kernel milk stage (31st July 2015) the soil water contents increased as follows: Control < B20 < B10 < B20+N < B10+N and 5.8 < 9.0 < 9.1 < 9.7 < 9.9 % vol., respectively. At this growth stage, the corn root system had

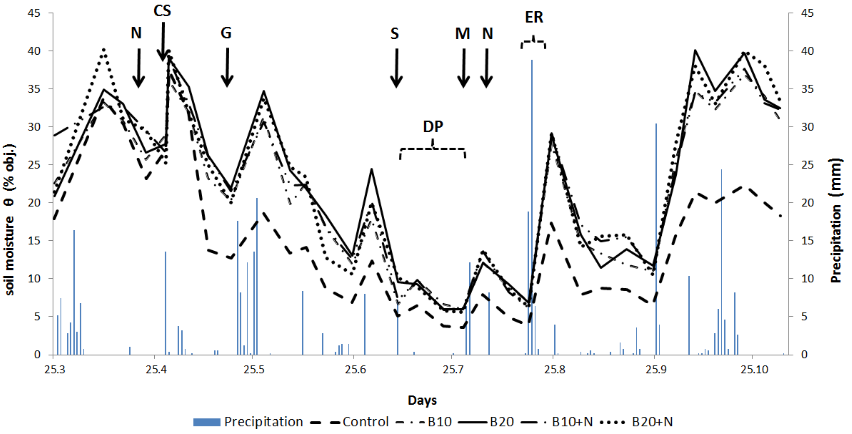

Fig. 2. The trend in the soil water content (% vol.) at the depth from 0.05–0.1 m under the corn crop in 2015 and the daily total precipitation (mm). N – nitrogen fertilizer application, CS – sowing of corn, G – corn germination, S – beginning of silking, M – beginning of the kernel milk stage, DP – dry period, ER – extreme rainfall.

reached a depth of 0.4–0.5 m, while our soil water contents were determined just at the depth of 0.05–0.1 m. So the water contents here represent only the water content of biochar-enriched surface layer of soil and not the available water storage needed for transpiration.

In the period from 17th up to 18th August 2015 an intense rainfall event occurred (57.6 mm). After subsequent soil sampling (24th August 2015) the water contents increased in the order: Control < B10 < B20 < B10+N = B20+N and 17.3 < 27.8 < 28.9 < 29.1 = 29.1% vol., respectively. We conclude that the biochar-enriched soil is capable of retaining more water after such rainfall events compared to the soil without biochar. This has a positive effect on the rainfall-runoff processes and presumably the storage of available water in the root zone.

The soil water content in 2015 reached its minimum during the dry period lasting for 20 days (7th July up to 28th July 2015). That was interrupted only by two episodes with little rainfall of 0.4 mm (13th July 2015) and 0.05 mm (25th July 2015). The soil moistures ranged in the order: Control < B20+N+< B10 = B20 < B10+N and 3.6 < 5.6 < 6.0 = 6.0 < 6.2% vol., respectively. The ability of biochar to maintain higher water contents during the dry period of 20 days agrees with the results of several authors (Jones et al., 2010; Karhu et al., 2011).

Biochar effect on soil water retention characteristics

From the spring sampling collected 12 months after the biochar application, we found that the applied biochar significantly increased the water content in the soil at the pressure potentials of –1 kPa and –5.5 kPa in all treatments (Table 1). An increase in the water content was recorded also at the pressure potentials of –20 kPa and –55kPa for treatments B20, B10+N and B20+N. At the pressure potentials of –100 kPa and –300 kPa, water contents significantly higher than control were found only in B10+N and B20+N treatments. Similar results have been presented by Brockhoff et al. (2010) and Abel et al. (2013), who observed the increase of water content after biochar application in their laboratory experiment. However, for the autumn sampling, some 20 months after biochar application, there were no significant differences between control and the biochar-amended treatments (Table 1). With decreasing moisture content there is a trend of decreasing differences in soil water content (compare Table 1 at –300 kPa), while at moister conditions (especially at the pressure potentials of –5.5, –20 and –55kPa) all amended treatments displayed higher water contents than the control.

Impact of biochar on available water content of soil

The trends of the soil water retention curves influenced by biochar application are shown in Fig. 3. The figure shows the measured soil water content at different pressure potentials and trends of retention curves modeled by RETC. A noticeable effect of biochar on the water retention curves can be seen for the spring sampling. In autumn, such noticeable changes were not recorded. Table 2 presents RAWC values. Biochar has increased RAWC for all treatments in the spring and autumn samples. A statistically significant increase was observed in the treatment of B20 + N. Table 2 also presents the individual retention-curve shape parameters of α, and *n* as well as the individual limits. When evaluating the impact of biochar on plant available water content (AWC), sometimes also referred to as plant available water (PAW), the AWC was considered as the difference between FC and permanent wilting point (WP, at pressure potential of –1500 kPa).

One year after biochar application, in the spring soil samples a trend of an AWC increase was found in all treatments. In the case of the B20+N treatment the increase was statistically significant (Table 2). Based on the results from autumn sampling, a positive influence of biochar on AWC still remained, since the AWC was higher across all treatments as compared to control. A statistically significant increase was found in the B20+N treatment (Table 2). These findings are consistent with the study of Abel et al. (2013).

Effect of biochar on soil porosity

A statistically significant increase in soil porosity was observed during spring for all treatments (B10, B20, B10+N, B10+N) (Table 1). Similar observations were presented by Masulili (2010), who recorded an increase in the porosity after biochar application at the rates of 10 $t\ ha^{-1}$ and 15 $t\ ha^{-1}$. The increase of soil porosity has also been pointed out by several other authors (Ajayi and Horn, 2016; Jones et al., 2010; Lin et al., 2012). This might be due to the high porosity and therefore higher water-retention capacity of biochar (Hlaváčiková et al., 2016; Obia et al., 2016). In addition, the process of incorporation, or certain sorption with the multivalent cations as the

Table 1. Effect of the biochar application on the bulk density, porosity and water content in the soil at pressure potentials of –1, –5.5, –20, –55, –100 and –300 kPa (means ± standard deviations).

Treatments	BD	P	WC–1.0kPa	WC–5.5kPa	WC–20kPa	WC–55kPa	WC–100kPa	WC–300kPa
	($g.cm^{-3}$)	(%vol.)						
Spring								
Control	1.6±0.06ab	35.4±0.84a	32.7±1.08a	31.8±1.29a	30.8±1.17a	28.6±2.15a	27.2±1.71a	26.1±1.31a
B10	1.6±0.08ab	37.7±1.58b	35.3±2.20b	33.7±2.30b	32.1±1.84ab	30.3±2.34ab	28.4±2.17ab	27.3±2.17ab
B20	1.6±0.03b	37.5±1.68b	35.2±1.50b	34.2±1.61bc	33.4±1.52bc	30.7±1.73b	29.0±1.35ab	27.8±1.31ab
B10+N	1.7±0.04b	37.1±1.02b	35.0±0.91b	33.8±1.01b	32.7±0.99bc	31.0±1.01b	29.3±1.10b	28.2±0.96b
B20+N	1.6±0.05a	39.8±1.45c	37.4±1.40c	35.7±1.65c	34.3±1.83c	31.6±1.51b	29.4±1.64b	28.4±1.14b
Autumn								
Control	1.7±0.07ab	38.4±1.23b	35.3±0.92b	33.2±0.45a	31.1±0.89a	29.5±0.91a	28.7±0.97a	27.2±1.37a
B10	1.7±0.39ab	37.7±1.54ab	34.9±1.31ab	33.6±1.36a	32.1±0.79a	30.5±0.83a	28.6±0.86a	27.2±1.37a
B20	1.7±0.06b	36.7±1.29a	34.0±1.24a	33.3±1.09a	31.8±0.68a	30.5±0.56a	29.5±0.93a	26.9±1.79a
B10+N	1.6±0.03ab	38.6±0.97b	36.7±1.08c	34.1±1.14a	32.1±1.24a	30.0±1.44a	29.2±1.93a	26.4±1.49a
B20+N	1.6±0.05a	38.2±1.98ab	35.9±1.19ab	33.8±1.09a	31.6±1.13a	30.2±0.82a	29.2±1.03a	27.2±2.34a

BD – bulk density, P – porosity, WC – water content by different pressure potential.
Different letters (a, b, c) indicate that treatment means are significantly different at $p < 0.05$ according to LSD test.

Table 2. Effect of the biochar application on the basic limits and water retention curve shape parameters α and *n* determined according van Genuchten model (means ± standard deviations).

Treatments	FC	RP	RAWC	*α*	*n*	WP	AWC
	(%vol.)			(cm^{-1})	–	(%vol.)	
Spring							
Control	30.8±1.17a	26.1±1.31a	4.5±1.38a	0.08±0.06a	1.06±0.02a	25.0±2.51a	5.5±1.71a
B10	32.1±1.84ab	27.3±2.17ab	4.9±1.44a	0.06±0.08a	1.07±0.02a	26.1±1.99a	6.5±1.56a
B20	33.4±1.52bc	27.8±1.31ab	5.2±1.63ab	0.06±0.09a	1.07±0.03a	26.3±2.19ab	6.7±2.05ab
B10+N	32.7±0.99bc	28.2±0.96b	4.7±1.22ab	0.04±0.03a	1.06±0.02a	27.0±1.91ab	5.9±1.83ab
B20+N	34.3±1.83c	28.4±1.14b	6.5±0.65b	0.44±1.13a	1.08±0.01a	28.2±2.27b	8.2±1.10b
Autumn							
Control	31.1±0.89a	27.2±1.37a	3.8±1.46a	0.31±0.56a	1.06±0.02a	25.0±1.75a	5.4±1.29a
B10	32.1±0.79a	27.2±1.37a	4.7±1.04ab	0.07±0.09a	1.08±0.02ab	24.2±2.00a	6.7±1.81ab
B20	31.8±0.68a	26.9±1.79a	5.1±1.46ab	0.02±0.02a	1.09±0.03ab	23.8±2.43a	7.5±2.02ab
B10+N	32.1±1.24a	26.4±1.49a	5.2±2.20ab	0.05±0.08a	1.1±0.04ab	23.5±2.08a	7.7±2.30ab
B20+N	31.6±1.13a	27.2±2.34a	4.8±1.67b	0.23±0.05a	1.08±0.02b	24.1±1.79a	6.7±1.66b

FC- field capacity (measured), RP – refill point (measured), RAWC – readily available water content,
α, *n* – shape parameters, WP – wilting point (modelled), AWC – available water content.
Different letters (a, b, c) indicate that treatment means are significantly different at $p < 0.05$ according to LSD test.

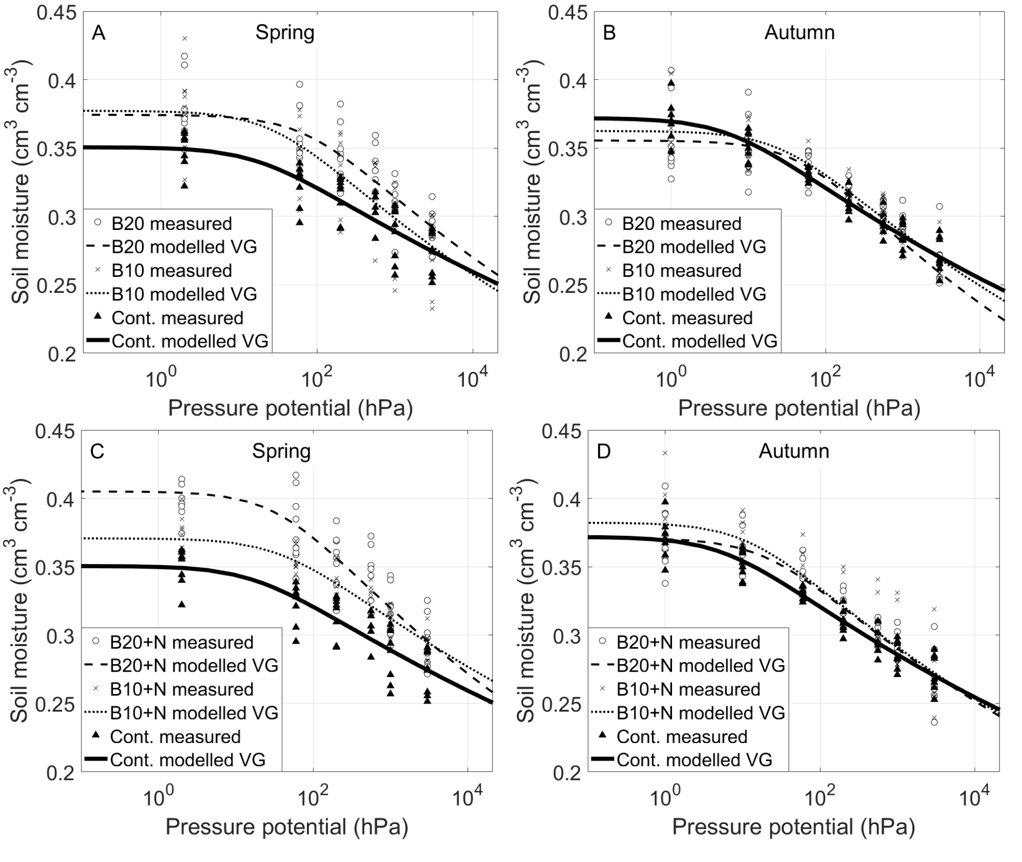

Fig. 3. The effect of biochar (A, B) and biochar with N fertilizer application (C, D) on the water retention curves found by the RETC software using the measured water contents. Soil samples were sampled from 0.05–0.10 m during spring (A, C) and autumn (B, D).

bonding material has been observed between the biochar and the mineral particles of the soil (Joseph et al., 2013, Lin et al., 2012). It has been pointed out that the bonding to the mineral particles of the soil occurs around the biochar particles, which in turn physically prevents draining of biochar-amended soil. As biochar particles bond with soil minerals, soil aggregates are formed, and this contributes to the formation of the more favorable soil structure (Sohi et al., 2009). After the autumn sampling, some 20 months after the biochar application, no significant increase in the soil porosity was recorded (Table 1).

Effect of biochar on soil sorption parameters and organic carbon content

The parameters characterizing the soil sorption capacity in relation to application of the biochar with, or without nitrogen, are shown in Table 3. For the hydrolytic acidity (Ha), a decreasing trend was observed with biochar with, or without, fertilizer. A significant decrease of Ha was observed after the autumn sampling, except for the B10 treatment. A reason for the complex acid-basic equilibrium following biochar application to the soil could lie in the mixture of the organic and inorganic functional groups of alkali present in the biochar (DeLuca et al. 2009; Yuan et al. 2011). The acidic effect of the N fertilizer itself was eliminated by the addition of Ca and Mg in fertilizer (LAV 27), but also by relatively high buffering capacity of the soil (Hanes, 1999) and the organic matter content (Šimanský and Poláková, 2014; Stevenson, 1982). In the spring soil samples a significant increase of the sum of exchange base cations (SBC) and cation exchange capacity (CEC) was observed in the B20, B10+N and B20+N treatments, while in autumn the differences were no longer significant. Neff et al. (2002) reported that fertilization may cause change in soil pH and the electrolyte concentrations, which is then reflected in the sorption parameters of soil (Thomas et al., 2007). The base saturation (Bs) significantly increased in spring after the application of biochar at the rates of 10 and 20 t ha^{-1} with N fertilizer. It means that the sorption complex was fully saturated by basic cations. For the autumn sampling, no significant differences between treatments were observed. In our case, the biochar is a significant source of basic cations, as 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. Rajkovich et al. (2012) noted that biochar ash contains nutrients, including base cations such as Ca and Mg, which cause a positive effect on the values of Bs, but that the effectiveness will decrease with time after its application (Šimanský et. al., 2018).

Incorporation of biochar in the soil has had a favorable effect on the retention of soil carbon (Agegnehu et al., 2016; Mekuria et al., 2014). Our study showed that biochar significantly contributed to an increase in the SOC in all treatments as compared to control, except for the B10 treatment at the autumn sampling. The highest SOC contents were determined in the following order B20+N > B20 > B10 = B10+N as compared to the control at spring sampling. In autumn, the content of SOC decreased in the following order: B20+N > B20 > B10+N > B10. The results show that the higher the application of biochar and N fertilizer resulted in higher SOC values (Table 3). These findings correspond with the other data from this experiment (Šimanský et al., 2016), that have already been published.

Relationships between organic carbon content, soil sorption parameters, porosity and water content at different negative pressure potentials

We have found significant linear relationships between the SBC, CEC and the Bs with total porosity (Fig. 4A, 4B and 4C). With increasing base saturation due to the application of biochar, the total porosity of the soil increased (Fig. 4C). Biochar contains base cations (Rajkovich et al., 2012), which can be joined by the means of cationic bridges with clay and organic particles (Bronick and Lal, 2005) thereby creating a favorable soil structure condition. But, the general increase in SOC content did not have any significant effect on total porosity (data not shown). The same applies to the water contents at different pressure potentials. Thus, it can be concluded that increasing SOC content did not show a direct impact on the soil water retention characteristics. Several studies have been published where authors report that the addition of biochar increases porosity (Ajayi and Horn, 2016; Lin et al., 2012; Masulili, 2010). However, our findings indicate that the total SOC content is not the only driver for increasing the soil porosity. Biochar is a material characterized by a high content of stable organic matter (Fischer and Glaser, 2012). The biochar used in our experiment was produced from the paper fiber sludge and grain husks by pyrolysis at 550°C for 30 minutes in a Pyreg reactor. Our biochar could be more stable. The reaction of stable C with soil particles is more complicated and thus the direct effect of C on the porosity was not statistically significant. The effects of biochar on soil properties largely depend on the properties of the biochars properties, which can vary widely

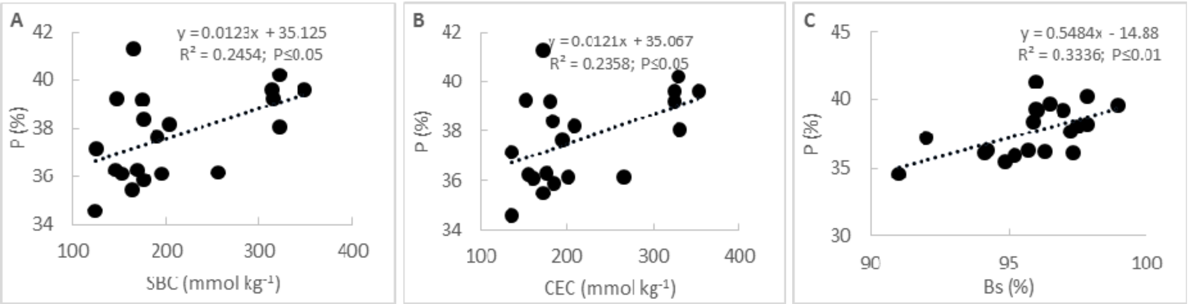

Fig. 4. The linear relationship between the porosity (P) and sum of base cations (SBC) (A), cation exchange capacity (CEC) (B) and base saturation (Bs) (C) at both (spring and autumn) samplings.

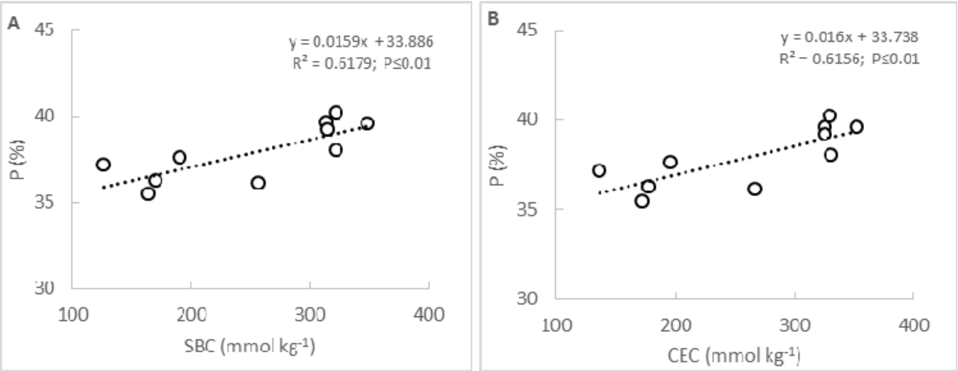

Fig. 5. The linear relationship between porosity (P) and sum of base cations (SBC) (A), cation exchange capacity (CEC) (B) at the autumn sampling.

Table 3. Statistical evaluation of soil sorption parameters and soil organic carbon (means ± standard deviations).

Treatments	Spring					Autumn				
	Ha	SBC	CEC	Bs	SOC	Ha	SBC	CEC	Bs	SOC
	(mmol kg^{-1})			(%)	(g kg^{-1})	(mmol kg^{-1})			(%)	(g kg^{-1})
Control	10.6 ± 2.27^{b}	135.4 ± 16.1^{a}	146.1 ± 13.9^{a}	92.6 ± 2.25^{a}	11.5 ± 1.22^{a}	11.1 ± 0.31^{d}	220.3 ± 23.3^{a}	231.4 ± 23.6^{a}	94.3 ± 3.17^{a}	12.6 ± 1.28^{a}
B10	7.84 ± 2.39^{ab}	150.3 ± 3.50^{ab}	158.2 ± 5.90^{ab}	95.1 ± 1.33^{ab}	14.2 ± 0.12^{b}	9.83 ± 0.06^{cd}	286.2 ± 41.4^{a}	296.1 ± 41.3^{a}	96.7 ± 0.49^{a}	14.1 ± 0.26^{ab}
B20	8.01 ± 1.16^{ab}	175.6 ± 1.40^{c}	183.6 ± 2.57^{c}	95.7 ± 0.57^{ab}	15.7 ± 0.57^{b}	8.58 ± 0.37^{bc}	243.1 ± 58.2^{a}	251.7 ± 58.9^{a}	96.3 ± 1.85^{a}	16.8 ± 0.14^{c}
B10+N	4.94 ± 0.61^{a}	200.4 ± 5.61^{d}	205.4 ± 5.00^{d}	97.6 ± 0.35^{b}	14.2 ± 1.08^{b}	4.51 ± 1.23^{a}	269.9 ± 60.2^{a}	274.4 ± 60.0^{a}	98.1 ± 1.21^{a}	14.8 ± 0.25^{b}
B20+N	7.23 ± 0.43^{ab}	171.2 ± 7.70^{bc}	178.4 ± 8.14^{c}	96.0 ± 0.06^{b}	16.2 ± 1.05^{b}	7.28 ± 0.37^{b}	246.1 ± 38.1^{a}	253.3 ± 37.6^{a}	96.8 ± 1.50^{a}	17.5 ± 0.55^{c}

Ha - hydrolytic acidity, SBC - sum of basic cations, CEC - cation exchange capacity, Bs - base saturation, SOC – soil organic carbon content.
Different letters between lines (a, b, c, d) indicate that treatment means are significantly different at $p < 0.05$ according to LSD multiple-range test.

between different biochars, mainly due to the variation in feedstock materials (Heitkötter, 2015; Purakayastha et al., 2015) and also due to the pyrolysis conditions (Wang et al., 2013). For example, with increasing temperature of pyrolysis the biochar is more stable. On the other hand with pyrolysis at low temperatures the biochar might have more reactive groups and be available for decomposition processes in the soil (Dickinson et al., 2016). We observed significant and positive linear relationships between SCB, CEC and the porosity at the autumn sampling (Fig. 5A and 5B). These relationships were not observed at spring sampling. We assume that a longer duration of soil processes might be necessary to change the porosity and retention characteristics. As mentioned above, biochar contains base cations (Rajkovich et al., 2012), which can act as a bond between the mineral particles of the soil, and the biochar particles (Joseph et al., 2013; Lin et al., 2012). This process could favorably influence soil sorption parameters.

CONCLUSIONS

Biochar application with, and without N fertilizer, positively influenced the soil water content in our silty loam soil during the corn growing season of 2015. Due to the biochar application, the soil moisture was higher in all treatments during dry summer period, as well as wet season later in the year. Biochar, as well as its combination with nitrogen, substantially increased porosity, RAWC, AWC and the soil water contents at the pressure potentials of –1; –5.5; –20; –55, –100 and –300 kPa as measured after the spring sampling. The higher the rate of biochar applied, the more intense neutralizing effect on the soil was observed. Generally, the most favorable changes in the soil sorption parameters were observed after biochar application at the rate of 10 t ha^{-1} in combination with N fertilizer. In such a case the soil sorption complex became fully saturated and the soil organic carbon content has significantly increased. The most favorable effect on SOC was observed after application of 20 t ha^{-1} of biochar in combination with N fertilizer.

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