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Impact of the biochar fraction sizes on the selected hydrophysical properties of silty loam soil

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Biochar is a widely known soil amendment. In the presented study, we aimed to evaluate the effect of biochar produced from Swedish willow ((Salix schwerinii x S. viminalis) x S. viminalis), ground into three different size fractions (<125µm, 125µm–2 mm and >2 mm) on selected hydrophysical properties of silty loam soils. Biochar was applied in the amount of 1.5% per weight of dry matter and the results were compared with pure silty loam soil (control). Data of biochar application impact on the selected hydrophysical properties of silty loam soil were statistically analyzed. In general, our results suggest that applied different size fractions of biochar does not have a statistically significant effect on particle density, however does have an effect on bulk density, porosity and saturated hydraulic conductivity of silty loam soil. With regard to bulk density, a statistically significant decrease *($p<0.05$)* was observed compared to the control and it ranged from 4.18 to 8.13% from the smallest to the largest biochar fraction. The decrease of bulk density further led to a statistically significant increase *($p<0.05$)* in porosity of all three treatments. Saturated hydraulic conductivity tended to increase as the size fraction of the biochar used was progressively reduced. This increase ranged from 63.77% (for biochar with size fraction >2 mm) to 112.42% (for biochar with size fraction <125µm) compared to pure silty loam soil (control).

KEY WORDS: hydrophysical properties, silty loam soil, biochar fraction size

Introduction

Biochar is a carbon–rich product made from biomass by pyrolysis process that takes place at high temperatures ranging from 300°C up to 900°C under low oxygen or no oxygen conditions (Spokas, 2010; Lehmann and Joseph, 2015). The positive impact of biochar was discussed in agricultural journals and scientific papers until it was developed into commercial products as a form of fertilizer in the first half of the 19th century. Current interest in this material has been primarily motivated by research in the Amazon (Terra Preta de Indio) (Lehmann and Joseph, 2015). Biochar, as a stable carbon-rich material (Lehmann and Joseph, 2015), is being investigated to mitigate global warming; and it may also have promising properties in relation as a soil amendment.

The benefits of biochar application also in terms of its impact on other agro–environmental parameters of soils such as bulk density, porosity, hydraulic conductivity, water retention, pH, organic carbon content, organic matter content, soil structure and soil aggregate stability was discussed in many scientific papers (Peng et al., 2011; Ajayi and Horn, 2016). These functions in only one product are possible, because the biochar is composted by aromatic moieties that give biochar its black color and are responsible for its stability, which makes biochar an interesting compound for carbon sequestration (Zhu et al., 2019).

The properties of biochar, to a large extent depend on the characteristics of the input raw materials (feedstock) and on the conditions of pyrolysis (Antunes et al. 2017). The subsequent effects of the biochar application on the hydrophysical properties of the soil are dependent on the biochar amount, pyrolysis conditions, feedstock type and biochar particle size (Liu et al., 2012).

In most biochar experiments, biochar has been added to the soil without selecting specific particle sizes. A likely reason for this is the added cost of sorting biochar particles (Verheijen et al., 2019). Whereas, discrete particle size experiments can provide valuable insights into multiple mechanisms occurring simultaneously. Few studies have focused on the effect of biochar particle sizes on the hydrophysical properties of the soil (Blanco–Canqui, 2017; Duarte et al., 2019). Duarte et al. (2019) states, that small particle size of biochar can reduce the volume of soil pores (<0.15 mm diameter). However, it can increase the volume of mesopores (0.15–0.50 mm diameter) and macropores (>0.50 mm diameter). Changing the volume of mesopores and macropores in the soil plays an important role (Lehmann and Joseph, 2015; Liu et al. 2017). The high volume of mesopores

in the soil can increase the area of water available for plants (Mollinedo et al., 2015). Some studies states that biochar addition can increase saturated hydraulic conductivity in clay soils and loamy soils (Dan et al., 2015) by increasing the number of connected macropores.
This paper aims to analyze the impact of three different biochar fraction sizes on selected hydrophysical properties of the silty loam soil in the concentration of 1.5% per weight of dry matter in laboratory conditions. In our study we hypothesized that biochar application will decrease bulk density, soil porosity and saturated hydraulic conductivity.

Material and methods

Soil and biochar mixtures laboratory set up

The silty loam soil used for this laboratory experiment was collected from the area of Dolna Malanta (Nitra, Slovakia). The soil on average contained 36.04% of sand, 48.83% of silt and 15.13% of clay and is classified as a silty loam texture (WRB, 2015). The average soil organic carbon content and soil pH (KCl) was 10.2 g kg^{-1} and 5.58, respectively (Kondrlova et al., 2018).
The willow biochar used in this experiment was produced in the UNYPIR reactor, which is part of the AgroBioTech Centre belonging to the Slovak University of Agriculture in Nitra. The input material was Swedish willow, variety Tordis ((Salix schwerinii x S. viminalis) x S. viminalis). A more detailed description of the reactor operation is given by Gaduš and Giertl (2019). Basic chemical analysis of biochar was performed by the Dionýz Štúr State Institute of Geology (Table 1). Biochar was produced at a pyrolysis temperature of 300°C and a pressure of 101 kPa. The produced biochar was ground on an electric grinder and sieved on 2 mm and 125 µm mesh sieves into three size fractions (Fig. 1).
Mixtures of the silty loam soil and the willow biochar were prepared in laboratory conditions with a biochar concentration 1.5% (which is equivalent to 20 t ha^{-1} in field conditions) in Kopecky cylinders with a volume of 100 cm^3. Overall, three treatments, representing different particle size fractions (<125 µm, 125 µm–2 mm and >2 mm), were prepared. For each treatment were prepared 3 replications of soil and biochar mixtures. These prepared mixtures were compared with the control treatment (without amendment), which was prepared in 3 replicates as well. The following treatments of the laboratory experiment were prepared:

- silty loam soil – control (3 replications)
- soil + willow biochar (<125µm) (3 replications)
- soil + willow biochar (125µm–2 mm) (3 replications)
- soil + willow biochar (>2 mm) (3 replications)

Table 1. Basic chemical analyses of the willow biochar

	C [%]	H [%]	N [%]	Ash [%]	pH [–]
biochar	82.2	2.74	0.86	6.16	9.14

Fig. 1. Biochar fraction sizes a) <125µm, b) 125µm–2mm and c) >2mm.

Determination of the selected hydrophysical properties

The bulk density (BD), particle density (PD), soil porosity (P) and saturated hydraulic conductivity (K) of the samples (control samples, samples treated with biochar) were determined by three replications using standard laboratory methods. Prepared soil samples (100 cm^3) were dried in the oven at 105°C until the samples were at a constant weight. BD was calculated based on the sample weight and core section volume (Brogowski et al., 2014; Obidike–Ugwu et al., 2022). PD was measured with an air pycnometer method. This procedure determines the volume of solid phase of the soil (Eijkelkamp Soil and Water, 2020). Consequently, the BD and PD were used to calculate P of the soil samples. K of the samples was determined in the laboratory conditions using an empty extension cylinder placed on the top of saturated soil sample and filled with water creating a variable hydraulic slope (falling–head method) (Igaz et al., 2017). We performed 3 measurements on each soil sample (n=9).

Statistical analysis

In our study we used Microsoft Excel program for descriptive statistics (Mean, Standard deviation – SD) to describe and summarize the basic feature of the given dataset. Consequently, the effect of biochar application on PD, BD, P and K of the silty loam soil was evaluated using a one-factor analysis of variance (One-Way ANOVA). Statistically significant effects at $p<0.05$ were determined by LSD test. All analyses were performed using Statgraphics Centurion XV. I software (Statpoint Technologies, Inc., Warrenton, VA, USA).

Results and discussion

In general, our results indicate that applied willow biochar does not have a statistically significant effect on PD, but does have an effect on BD, P and K (Table 2). Regarding BD, there we observed a statistically significant reduction ($p<0.05$) on all three biochar treatments compared to the control treatment (Table 2). Biochar itself is a porous material (Adekiya et al., 2020), and when it is added into the soil, it decreases BD and increases P (Nyambo et al., 2018). Biochar has also ability to improve structural properties of soil (Šimanský et al., 2019). Gradual oxidation of biochar in soil also increases the number of functionality groups on its surface (Obia et al., 2016), which can absorb soil particles and minerals, which can turn contributes to the formation of soil aggregates and to reduction of BD. Biochar is a highly porous material with low BD (Adekiya et al., 2020) and therefore its application to soil can increase P. According to Hseu et al. (2014) the change of P in soils treated with biochar is mainly due to the formation of macropores and rearrangement of soil particles. We observed a statistically significant increase ($p<0.05$) in P compared to control treatment (Table 2), which is therefore to be expected after BD reduction. Our results are in agreement with other studies in this area (Githinji, 2014). Very important soil property in solving the problems with soil water regime is also K (Blanco-Canqui, 2017). We observed a statistically significant increase ($p<0.05$) in K values compared to the control treatment (Table 2). Our results are in agreement with other results (Dan et al., 2015; Esmaeelnejad et al., 2017). The changes in K are associated with changes in P, aggregation, and water retention capacity.

By the results, we can further see that biochar produced from willow has different effects on selected soil characteristics at different size fractions (Table 2). If we look at the results, we notice that the BD values tend to decrease gradually as the size fraction of biochar increases. This decrease ranges from 4.18% (biochar with a fraction <125μm) to 8.13% (biochar with a fraction >2mm) compared to the control. Consequently, the P-values tend to increase as the size fraction of biochar is gradually increased. This increase is from 4.27% (biochar with a fraction <125μm) to 7.95% (biochar with a fraction >2 mm) compared to the control. Similar results were reported by Duarte et al. (2019) for loamy soil, explaining that the increase in the particle size reduces the homogeneity of the pore distribution and increases the P. In the case of K, the measured values tend to increase as the size fraction of the biochar used is

Table 2. Effect of biochar application on the selected hydrophysical properties of silty loam soil (SD – standard deviation)

	PD (n=3) [g cm^3]		BD (n=3) [g cm^3]		P (n=3) [%]		K (n=9) [cm h^{-1}]	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
silty loam soil (control)	2.566^{a}	0.004	1.316^{d}	0.006	48.697^{a}	0.171	0.966^{a}	0.558
soil + willow biochar (<125μm)	2.562^{a}	0.044	1.261^{c}	0.000	50.776^{b}	0.863	2.052^{b}	0.732
soil + willow biochar (125μm–2 mm)	2.552^{a}	0.094	1.235^{b}	0.001	51.570^{bc}	1.801	1.878^{b}	1.146
soil + willow biochar (>2 mm)	2.563^{a}	0.036	1.209^{a}	0.001	52.815^{c}	0.700	1.582^{ab}	0.537

Note: Different letters (a, b, c) indicate that treatment means are significantly different at p <0.05 according to least significant difference test (one–way ANOVA).

progressively reduced. This increase can be expressed as a percentage from 63.77% (biochar with a fraction >2 mm) to 112.42% (biochar with a fraction <125µm) compared to the control. According to Esmaeelnejad et al. (2017), finer biochar fractions can better fill the spaces between soil particles.

Conclusion

Our results showed that the hydrophysical properties of soil, such as bulk density, porosity and saturated hydraulic conductivity were depended on the biochar particle size. The results indicated that biochar produced from willow can statistically significantly (*p<0.05*) reduce bulk density, increase soil porosity and increase saturated hydraulic conductivity of silty loam soil. The most significant trend towards a reduction of bulk density (8.13%) was observed in the treatment with biochar fraction size >2 mm compared with control. At the same time, the application of the biochar increased soil porosity up to 7.95%. Positive effect of the saturated hydraulic conductivity was also observed. In this case, the highest increase was showed in treatment with a lowest fraction size <125µm, this increase was 112.42% compared to the control treatment. Based on the results observed in our laboratory experiment, by using willow biochar, we can conclude that the application of biochar leaded to positive trends in changes of studied silty loam soil hydrophysical properties. For agricultural producers, to obtain improvement in the selected hydrophysical properties, the biochar can be used by the largest fraction >2 mm with the concentration 1.5% of the willow biochar, because of its biggest changes in bulk density and porosity. In the case of saturated hydraulic conductivity, was observed the smallest increase (63.77%) compared to the finest biochar applied, but it was enough to improve soil properties. We assume, that the biochar application results in an improvement of the soil structure and in the interconnection of the soil pores.

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