ACTA UNIVERSITATIS AGRICULTURAE ET SILVICULTURAE MENDELIANAE BRUNENSIS

Volume 70 2 Number 1, 2022

EFFECT OF BIOCHAR APPLICATION RATE ON PHYSICAL AND HYDRO-PHYSICAL PROPERTIES OF A DYSTRIC CAMBISOL

Marketa Zachovalova[1], Jana Simeckova[1], Vitezslav Vlcek[1], Stanislav Hejduk[2], Jiri Jandak[1]

[1] Department of Agrochemistry, Soil Science, Microbiology and Plant Nutrition, Faculty of AgriSciences, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic

[2] Department of Animal Nutrition and Forage Production, Faculty of AgriSciences, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic

Link to this article: https://doi.org/10.11118/actaun.2022.002
Received: 20. 9. 2021, Accepted: 24. 1. 2022

Abstract

The field trial evaluating the effect of biochar on physical and hydro-physical properties of a Dystric Cambisol was carried out at the Research Grassland Station Vatín. The observed variants of the biochar experiment were as follows: 1) the control without biochar, 2) the biochar rate of 15 t/ha applied to the topsoil, 3) the biochar rate of 30 t/ha applied to the topsoil and 4) the biochar rate of 45 t/ha applied to the topsoil. It was found out that even the highest rate of biochar 45 t/ha did not affect saturated hydraulic conductivity of the topsoil at the depth of 0.05–0.20 m. When monitoring bulk density, it was confirmed that the biochar rate of 45 t/ha significantly reduced bulk density from 1218 kg/m^3 to 1169 kg/m^3. In the crop rotation without manure and clover growing the application of biochar at the rate of 45 t/ha resulted in the relevant decline in the average value of bulk density from 1197 kg/m^3 to 1138 kg/m^3. In the Norfolk crop rotation there were the inconclusive differences in bulk density. The rate of 45 t/ha had a highly noticeable impact on porosity. It increased from 53.75% (0 t/ha) to 55.60%. The biochar doses did not affect the value of field capacity. The application of biochar at the rate of 45 t/ha caused the significant increase in the average value of aeration from 31.90% to 34.45%.

Keywords: biochar, bulk density, porosity, field capacity, saturated hydraulic conductivity

INTRODUCTION

Biochar is a sort of a soil amendment that very noticeably influences the crop yield, nutrient cycling and soil properties (especially physical ones) which was demonstrated on sandy soils. The usage of biochar in one of the studies revealed that it leads to lower values of bulk density and higher values of the available water content (Glab *et al.*, 2016). Biochar is connected with technology that aims at waste management, carbon sequestration, cutback in greenhouse gas emissions, improvement of soil properties and increase of crop yield and environmental betterment (Kuppusamy *et al.*, 2016). However, there have not been enough research studies which would entirely prove effects of biochar use on organisms in the soil (e.g. microbes). One of the studies indicated the rise in the values of organic C, total N and total P in the soil of semiarid farmland after the long-term (3.5 years) application of biochar (30 t/ha) (Luo *et al.*, 2017).

Bulk density is considered an essential soil physical characteristic. When its value is high, it makes water and air movement more difficult which affects the soil, influences the root growth and final crop yield (Nawaz *et al.*, 2013). Many studies carried out within the time period 2010–2019 demonstrated that the application of biochar lowers bulk density by 9% as far as all soil textural groups are concerned (Razzaghi *et al.*, 2020). Biochar decreases bulk density by means of its lower bulk density (< 0.6 g/cm^3) in comparison with soils (1.25 g/cm^3) and thanks to its character to make soil aggregation and porosity better (Blanco-Canqui, 2017).

Soil porosity is the ratio of the pore volume to total soil volume (Herath *et al.*, 2013). Changes in porosity of soils are caused by interactions of biochar with organic particles or parent soil minerals (Lehmann *et al.*, 2011). One of the research studies states that biochar has the effect on porosity of soils – it improves sandy soils (Lei and Zhang, 2013). When biochar and porosity are taken into consideration, particle size, shape and structure of biochar influence soil water storage because they change pore features (Liu *et al.,* 2017).

Biochar consists of macropores (> 200 nm) which are suitable to accommodate bacteria, micropores (< 2 nm) and mesopores (2–50 nm) storing water and dissolving substances for microbial metabolism. The size of pores correlates with the temperature of biochar – high temperature results in the greater amount of water and volatilization of the organic matter which generates larger pores. Another factor, biochar feedstock, also infuses the size and surfeit of pores (Gul *et al*., 2015). Biochar can decrease the share of drainable pores and raise the share of mesopores. The soil pore size distribution may also be increased by biochar in the short-term period because particles of biochar have porous nature (Blanco-Canqui, 2017).

Basso *et al.* (2013) states that the addition of biochar increases water holding capacity of the sandy loam soil and may enhance water available for the crop use. Wang *et al*. (2014) published the treatise stating that field capacity of the sandy soil in Beijing in China can be raised by the large specific surface area of biochar. The studies show that biochar noticeably augments field capacity for the coarse-textured soils by 51% and for the medium-textured soils by 13%. On the other hand, field capacity is almost unaltered after the use of biochar in the instance of the fine-textured soils (Razzaghi *et al.,* 2020).

Biochar contributes to the formation of macroaggregates more in the sandy loam soil than in clay dust (Libutti *et al.,* 2016). Esmaeelnejad *et al*. (2016) came to the conclusion that biochar declined saturated hydraulic conductivity compared to the control treatment. They also found out that after the application of biochar from wood chips saturated hydraulic conductivity decreased more than after the rice husks biochar application. The above mentioned authors state that saturated hydraulic conductivity was reduced not merely due to the impermeability of pores through biochar particles, but also due to the reduction of the pore interior size, available space for flow and last but not least because of high field capacity of biochars. Blanco-Canqui (2017) confirmed that biochar influences water infiltration and saturated and unsaturated hydraulic conductivity. Biochar interfered with saturated hydraulic conductivity in 22 out of 28 cases of the monitored soils. Biochar contributed to the reduction of saturated hydraulic conductivity in 12 out of 15 coarse-grained soils.

The ideal aeration for grasslands is 10% by volume and it is up to 24% by volume for soils intended for growing barley (Dos Santos Bernardes, 2011). Laghari *et al.* (2016) and Widowati *et al.* (2020) claim that the application of biochar in the agricultural soil increases soil aeration, which is highly dependent on groundwater, soil granularity and porosity. Speratti *et al.* (2017) note the improvement of soil aeration after the addition of biochar from sugar cane and eucalyptus waste.

The aim of this work was to find out the effect of the different biochar doses on the observed properties of a Dystric Cambisol which were applied in two different crop rotations.

MATERIALS AND METHODS

The experiment was accomplished at the area of the Research Grassland Station Vatín – Faculty of AgriSciences, Mendel University in Brno, the Czech Republic in 2016 to investigate the impact of the biochar application on the changes in the agro-ecological stand. This locality is situated in the Bohemian-Moravian Highlands, Region Highlands (Vysočina), about 5 km south of the town Žďár nad Sázavou, in the area with an altitude of 560 metres above sea level. The average annual temperatures in this moderately warm region were as follows: 7.8 °C in 2017, 9.1 °C in 2018, 8.5 °C in 2019 and 8.3 °C in 2020. The sum of annual precipitation was 733.2 mm in 2017, 514.4 mm in 2018, 736.7 mm in 2019 and 862.9 mm in 2020. The soil cover of the field trial is made up of a Dystric Cambisol from paragneiss, textural class sandy loam. The content of the soil organic matter (Cox) in the topsoil in the years of the field experiment was 1.17–2.01% (determined using the Walkley-Black method) (Jandák *et al.,* 2015) and pH values (KCl) ranged from 3.68–5.63 (determined according to ISO/DIS 10390). Therefore, this soil is acidic.

The raw materials for the production of biochar were digestate (80%) and cellulosic fibre. Biochar was produced in the process of termochemical reduction (pyrolysis). The temperature of continuous pyrolysis ranged from 450 to 470 °C. The biochar composition was as follows: CaO 64 400 mg/kg, MgO 6 720 mg/kg, K_2O 16 400 mg/kg, P_2O_5 15 800 mg/kg, total dry matter 93.42%, pH_{H2O} 8.4, total nitrogen 1.17 (% in dry matter), C:N ratio 29, ash 68.0 (% in dry matter), Cu 27.2 mg/kg, Mo 4.73 mg/kg, Ni 9.05 mg/kg, Pb < 2.50 mg/kg, Zn 60.7 mg/kg.

The field experiment involved the following biochar variants: 0 t/ha, 15 t/ha, 30 t/ha and 45 t/ha. The concentrations correspond to the individual doses of biochar: 0.63% of the weight for 15 t/ha of biochar, 1.25% of the weight for 30 t/ha of biochar and 1.88% of the weight for 45 t/ha. Biochar was incorporated into the topsoil by a rotavator (to the depth of 0–0.20 m). Each variant of the field trial was in three repetitions, the size of the plot was 12 m^2.

The first crop rotation (corn, spring barley, corn, winter wheat, winter rape) accords with the agricultural production without the livestock production, without manure application and clover growing (hereinafter referred to as W). The second crop rotation (corn, spring barley with clover, red clover, winter wheat, winter rape) refers to the conditions of management in agriculture, including animal production (manure application once per crop rotation and inclusion of red clover in crop rotation). It is commonly known as the Norfolk crop rotation (hereinafter referred to as N).

In total, 132 measurements of saturated hydraulic conductivity (hereinafter referred to as Kfs) of the topsoil (for the depth 0.05–0.20 m) were carried out by the Guelph permeameter in summer months and after the end of vegetation in 2016, 2017, 2018 and 2019.

The soil samples for analysis of the physical qualities were collected using 100 cm^3 soil cylinders (Kopecky's cylinders) from the depths of 0.03–0.07 m (the centre of the core sample 0.05 m) and 0.13–0.17 m (the centre of the core sample 0.15 m). The undisturbed samples were taken in the spring, summer and autumn 2016, 2017, 2018 and 2019. The total number of the taken samples was 512. The physical qualities (bulk density, porosity, field capacity, aeration) were pinpointed and appraised employing the standard methods according to Zbíral *et al.* (2016).

The statistical evaluation of the results was made via the ANOVA programme (STATISTICA CZ 12). Then they were tested using the Tukey test at a 95% ($P < 0.05$) level of significance.

RESULTS

Saturated Hydraulic Topsoil Conductivity

Even the biochar rate of 45 t/ha did not affect the Kfs of the topsoil at the depth of 0.05–0.20 m. We measured almost identical average values, the average value of Kfs was 3.403 m/day in the variant without the application of biochar and after the use of the rate of 45 t/ha it was 3.543 m/day.

While in the crop rotation without manure and clover growing we could see a partial but inconclusive increase in the average value of Kfs from 3.858 m/day to 4.470 m/day, in the Norfolk crop rotation we measured the average values almost identical: 2.949 m/day without the biochar application and 2.615 m/day after the application of 45 t/ha.

Bulk Density

Whole Topsoil

The dose of biochar reduces bulk density from 1218 kg/m^3 to 1169 kg/m^3 (see Fig. 1) in a highly significant way ($p = 0.00026$). The dependency of topsoil bulk density on the dose of biochar can be expressed by means of the polynomial equation

$$y = -0.0177x^2 - 0.3097x + 1218.2. \quad (1)$$

$R^2 = 0.999.$

Depth of 0–0.10 m

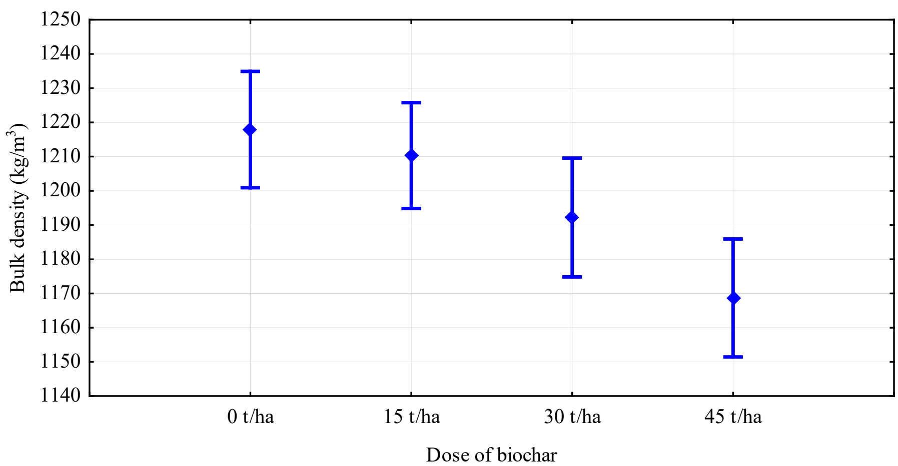
The soil is affected by more mechanical interventions in the upper part of the topsoil (0–0.10 m), which is probably the reason for the inconclusive effect of the biochar doses on bulk density of the soil.

Depth of 0.10–0.20 m

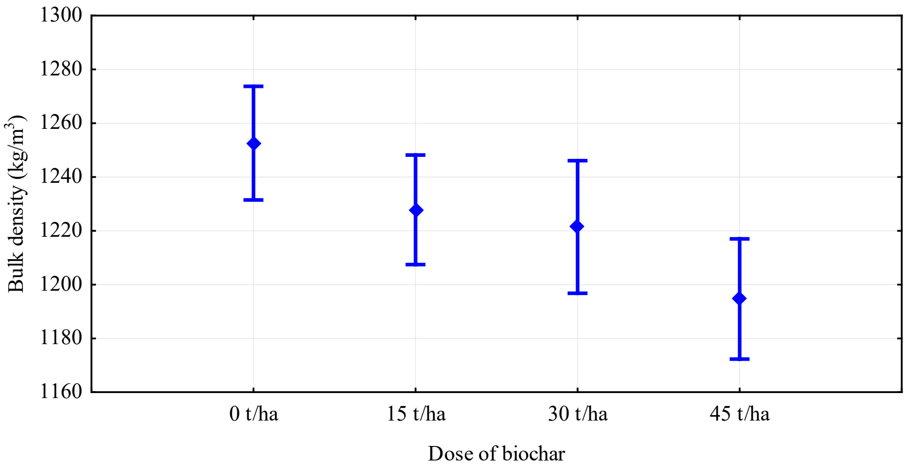
The application of biochar at the rate of 45 t/ha resulted in a highly relevant reduction in the average value of bulk density from 1253 kg/m^3 to 1195 kg/m^3 at the depth of 0.10–0.20 m (see Fig. 2). The dependence of bulk density on the dose of biochar at the depth of 0.10–0.20 m can be expressed by the polynomial equation

$$y = -0.0019x^3 + 0.1269x^2 - 3,1267x + 1252.6. \quad (2)$$

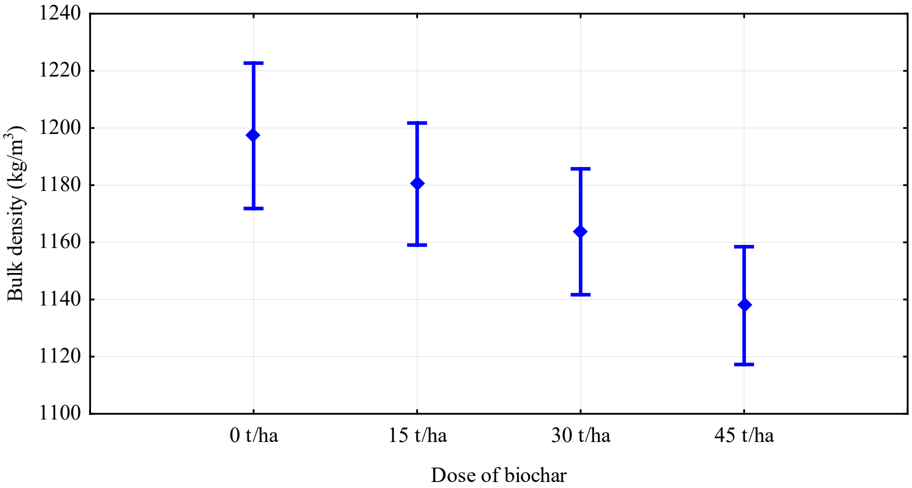
$R^2 = 1.$



1: *Effect of the biochar doses on average bulk density in the topsoil*
Vertical bars indicate a confidence interval of 0.95



2: *Effect of the biochar doses on average bulk density at 0.10–0.20 m depth*
Vertical bars indicate a confidence interval of 0.95



3: *Effect of the biochar doses on average bulk density in the topsoil in the crop rotation without manure application and clover growing*
Vertical bars indicate a confidence interval of 0.95

Crop Rotation Without Manure Application and Clover Growing

The application of biochar at the rate of 45 t/ha led to a noticeable decrease ($p = 0.001192$) in the average value of bulk density from 1197 kg/m³ to 1138 kg/m³ (see Fig. 3). The dependence of bulk density on the dose of biochar can be expressed by the polynomial equation

$$y = -0.0005x^3 + 0.0211x^2 - 1.34x + 1197.3. \quad (3)$$

$R^2 = 1$.

Crop Rotation W, Depth of 0–0.10 m

At the depth of 0–0.10 m, the inconclusive effect of biochar on soil bulk density was ascertained. The average values were 1151 kg/m³ in the control and 1159 kg/m³ in the variant 15 t/ha. In the variants 30 t/ha and 45 t/ha, lower average values of bulk density (1117 kg/m³ and 1115 kg/m³) were identified.

Crop Rotation W, Depth of 0.10–0.20 m

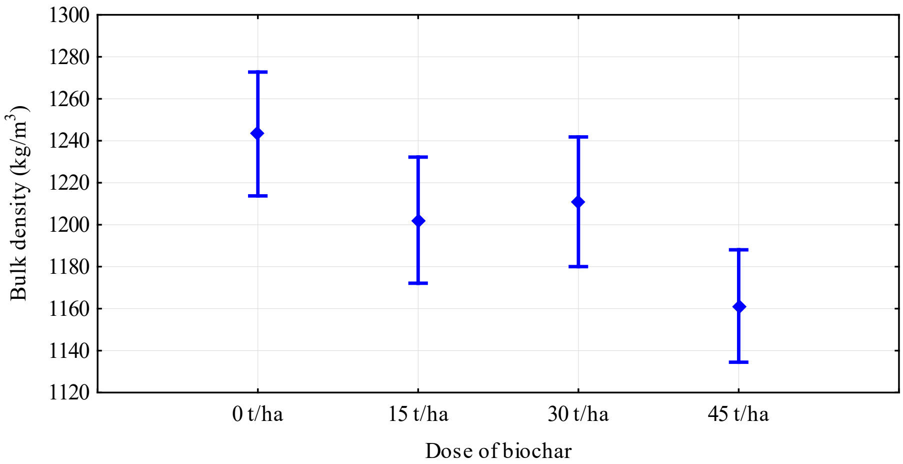
At the depth of 0.10–0.20 m, the dose of biochar reduces bulk density from 1243 kg/m³ to 1161 kg/m³ (see Fig. 4) in a highly significant way ($p = 0.000460$). The average values of bulk density were 1202 kg/m³ in the variant 15 t/ha and 1211 kg/m³ in the variant 30 t/ha. The dependence of bulk density on the dose of biochar can be expressed by the polynomial equation

$$y = -0.0053x^3 + 0.3504x^2 - 6.79x + 1243.2. \quad (4)$$

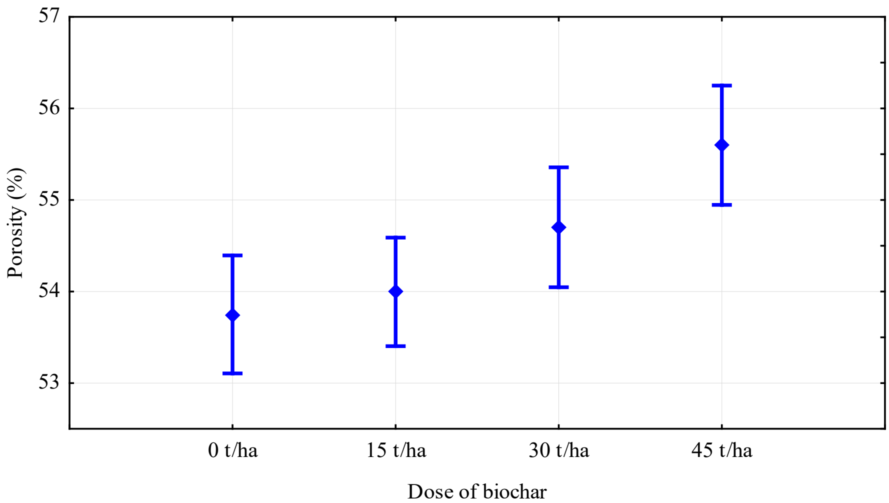
$R^2 = 1$.

Norfolk Crop Rotation

In the crop rotation with manure application and clover growing, the inconclusive differences between the average bulk density values were observed. In the control and in the variant 15 t/ha (1239 kg/m³ and 1240 kg/m³) the average bulk density values



4: *Effect of the biochar doses on average bulk density at 0.10–0.20 m depth in the crop rotation without manure application and clover growing*
Vertical bars indicate a confidence interval of 0.95



5: *Effect of the biochar doses on average porosity in the topsoil*
Vertical bars indicate a confidence interval of 0.95

were almost identical. In the variants 30 t/ha and 45 t/ha, the average values of bulk density (1221 kg/m^3 and 1200 kg/m^3) were identified lower.

Crop Rotation N, Depth of 0–0.10 m

At the depth of 0–0.10 m, the effect of biochar on bulk density was found out as inconclusive. In the zero variant, the average value of bulk density was 1215 kg/m^3. After the application of 15 t/ha dose, the higher value of bulk density was determined (1227 kg/m^3) whereas in the variant 45 t/ha, the lowest average value of bulk density 1171 kg/m^3 was recorded. The bulk density in the variant 30 t/ha was 1209 kg/m^3.

Crop Rotation N, Depth of 0.10–0.20 m

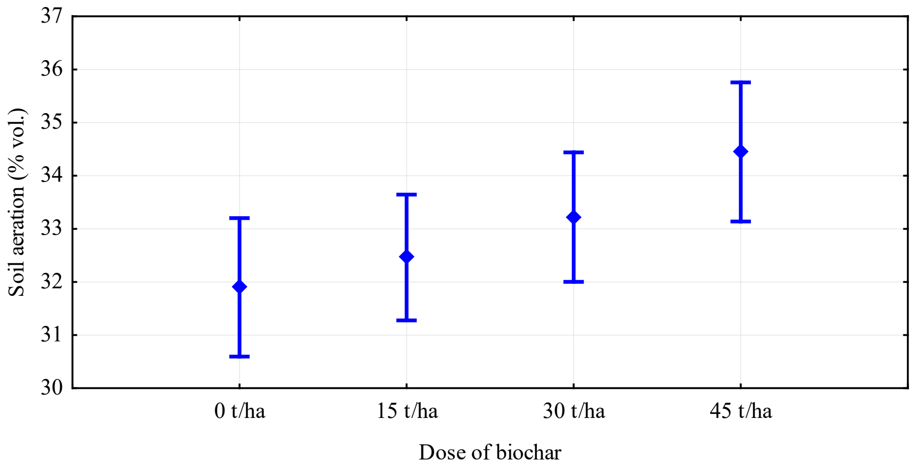
In the crop rotation with manure application and clover growing, the inconclusive differences between the average bulk density values at the depth of 0.10–0.20 m were found out. In the control variant, the average value of bulk density was 1262 kg/m^3. In the variant with the rate of 15 t/ha, the lower average value of bulk density 1254 kg/m^3 was ascertained. In the variants with the rate of 30 t/ha and 45 t/ha, the average bulk density values 1232 kg/m^3 and 1228 kg/m^3 were determined.

Porosity of Topsoil

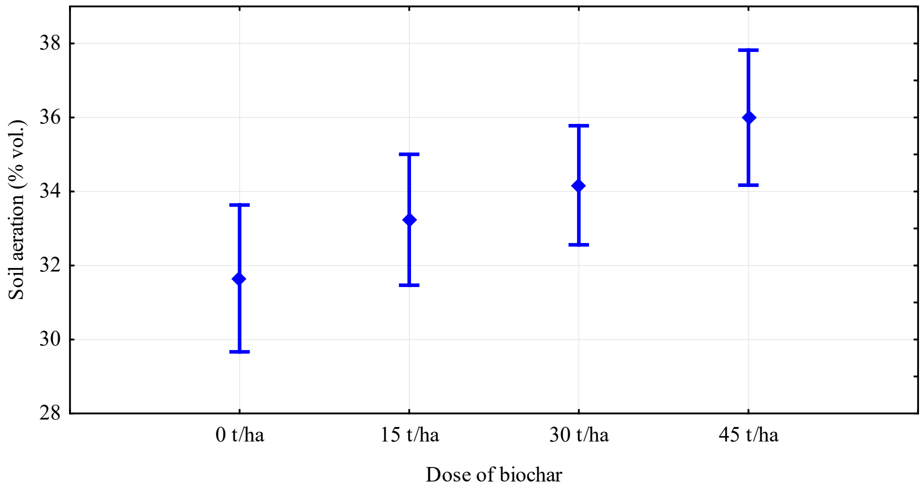
The dose of biochar of 45 t/ha had a highly relevant impact ($p = 0.000303$) on porosity of the topsoil, which increased from 53.75% to 55.60% (see Fig. 5). The dependence of porosity on the biochar dose can be expressed by the polynomial equation

$$y = 0.0007x^2 + 0.0092x + 53.737. \quad (5)$$

$R^2 = 0.998.$



6: *Effect of the biochar doses on average soil aeration in the topsoil*
Vertical bars indicate a confidence interval of 0.95



7: *Effect of the biochar doses on average soil aeration in the topsoil in the crop rotation without manure application and clover growing*
Vertical bars indicate a confidence interval of 0.95

Field Capacity of Topsoil

The biochar doses did not affect the field capacity values, in the individual variants of the biochar doses the values are as follows: 0 t/ha 28.79% vol., 15 t/ha 28.99% vol., 30 t/ha 29.82% vol. and 45 t/ha 28.68% vol. The fact that field capacity is not affected by the biochar doses is confirmed by almost identical average soil moisture values: 0 t/ha 21.85% vol., 15 t/ha 21.54% vol., 30 t/ha 21.48% vol. and 45 t/ha 21.15% vol.

Soil Aeration

Whole Topsoil

The application of biochar at the rate of 45 t/ha caused a significant increase ($p = 0.0240$) in the average value of aeration from 31.90% to 34.45% (see Fig. 6).

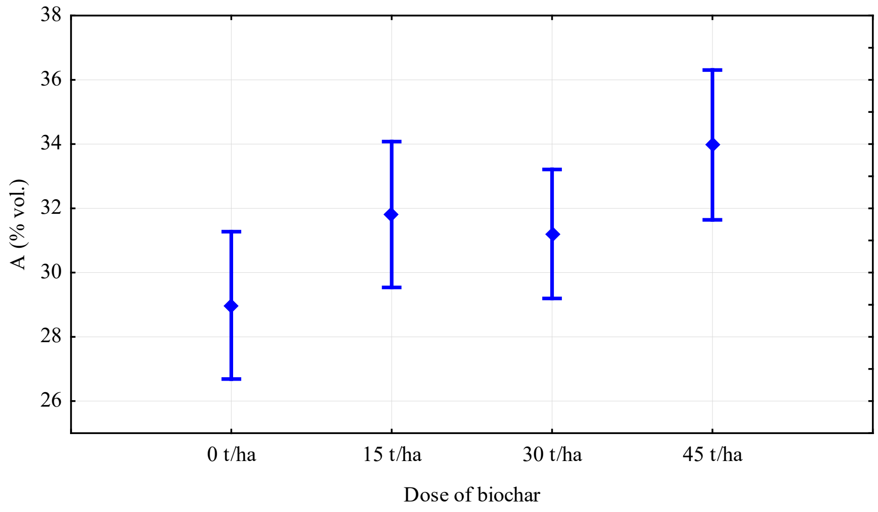
The dependence of aeration on the biochar doses can be expressed by the polynomial equation

$$y = 0.0007x^2 + 0.0228x + 31.912. \qquad (6)$$

$R^2 = 0.999$.

Depths: 0–0.10 and 0.10–0.20 m

In the upper and lower part of the topsoil, the significant impact of the biochar doses on the average aeration of the soil was not found although in both depths there was a partial increase in the average aeration values due to the application of biochar. At the depth of 0–0.10 m, the biochar dose of 45 t/ha increased soil aeration by 2.31% compared to the control variant and at the depth of 0.10–0.20 m by 2.79%.



8: *Effect of the biochar doses on average soil aeration at 0.10–0.20 m depth in the crop rotation without manure application and clover growing*
Vertical bars indicate a confidence interval of 0.95

Crop Rotation Without Manure and Clover Growing

The application of biochar at the rate of 45 t/ha resulted in a significant raise ($p = 0.004$) in the average value of soil aeration of the topsoil from 31.65% to 36.00% (see Fig. 7). The dependence of soil aeration on the dose of biochar can be expressed by the polynomial equation

$$y = 8E^{-05}x^3 - 0.0049x^2 + 0.1616x + 31.651. \quad (7)$$

$R^2 = 1.$

Crop Rotation W, Depth of 0–0.10 m

At the depth of 0–0.10 m, the inconclusive impact of biochar on soil aeration was ascertained. The average values were 34.32% in the control and 34.66% in the variant 15 t/ha, in the variant 30 t/ha 37.13% and in the variant 45 t/ha 38.02%.

Crop Rotation W, Depth of 0.10–0.20 m

At the depth of 0.10–0.20 m, the dose 45 t/ha of biochar increased soil aeration in a highly significant way ($p = 0.008$) from 28.98% to 33.98% (see Fig. 8). The average values of soil aeration were 31.81% in the variant 15 t/ha and 31.20% in the variant 30 t/ha. The dependence of soil aeration on the dose of biochar can be expressed by the polynomial equation

$$y = 0.0003x^3 - 0.0228x^2 + 0.4542x + 28.981. \quad (8)$$

$R^2 = 1.$

Norfolk Crop Rotation

In the crop rotation with the manure application and clover growing, the inconclusive differences were recorded among the averages of soil aeration of the topsoil, because the average soil aeration values after the application of the individual doses of biochar were almost identical: in the control variant 32.15%, after the dose of 15 t/ha 31.69%, after the dose of 30 t/ha 32.27% and after the dose of 45 t/ha 32.90%.

Crop Rotation N, Depths of 0–0.10 m and 0.10–0.20 m

In both depths of the topsoil, almost identical average values of soil aeration were determined after the application of the individual doses of biochar: at the depth of 0–0.10 m in the control 33.03%, after the application of 15 t/ha of biochar 32.27%, after the application of 30 t/ha 32.47% and after the application of 45 t/ha 33.95%, at the depth of 0.10–0.20 m in the control variant 31.27%, after the application of 15 t/ha of biochar 31.11%, after the application of 30 t/ha 32.08% and after the application of 45 t/ha 31.85%.

DISCUSSION

In our research study we found out that even the dose of biochar 45 t/ha did not influence saturated hydraulic conductivity of the topsoil at the depth of 0.05–0.20 m. Laird *et al.* (2010) and Jeffery *et al.* (2015) came to the same conclusion. They stated that biochar had no impact on saturated hydraulic conductivity in the measured soil samples. The concentration within our field trial corresponds with the individual dose of biochar: 1.88% of the weight for 45 t/ha. Contrary to the mentioned data, Devereux *et al.* (2012) ascertained that saturated hydraulic conductivity was lower with the higher biochar concentration (2.5% and 5% w/w) in the initial phase of the trial. It indicates the significance of biochar – the more biochar was included, the more water was retained. The experiment of Edeh and Mašek (2021) also showed that the use of biochar (1, 2, 4 and 8%) on loamy sand and sandy loam decreased saturated hydraulic conductivity and the higher dose of biochar was more effective for all the particle sizes. However, Edeh *et al.* (2020) do not neglect the type of the soil which has an important impact. According to them, biochar leads to higher soil water retention and lower saturated hydraulic conductivity in sandy soils and reduced runoff in clayey soils. Field capacity (20.4%) raised and bulk density decreased (0.8%) after the biochar usage regardless of the sort of the soil. It is apparent that biochar is the best as far as enhancement of soil water properties in coarse-textured soils with dose between 30 and 70 t/ha is concerned. Esmaeelnejad *et al.* (2016) claimed that the biochar application (2% of the weight for 48 t/ha) decreased saturated hydraulic conductivity compared to the control treatment. Similarly, Blanco-Canqui (2017) confirmed that biochar contributed to the reduction of saturated hydraulic conductivity in soils. By contrast, Stylianou *et al.* (2021) came to the conclusion that applied biochars (5%) from biowaste of sludge and spent coffee grounds considerably increased saturated hydraulic conductivity of the loamy sand soil when compared to the control variant.

The effect of biochar on reducing bulk density was demonstrated by Liu *et al.* (2016), Razzaghi *et al.* (2020) and Omondi *et al.* (2016). The same trend was observed in the research studies by Mukherjee *et al.* (2014) and Peake *et al.* (2014). Our treatise ascertained that the biochar dose of 45 t/ha significantly reduces bulk density. However, Yan *et al*. (2019) are convinced that only the biochar rate of 60 t/ha can assure low soil bulk density. Aslam *et al.* (2014) claim that the concentration of biochar at 1–2% brings down soil bulk density and improves soil porosity and the infiltration rate by raising the total soil porosity. According to Mishra and Shinogi (2018), the dose of biochar 5% w/w (rice husk biochar, pine wood biochar, bamboo saw dust biochar and bermuda grass biochar) decreased bulk density of the clayey loam and sandy soil. In the study of Nikravesh *et al.* (2019), bulk density was lowered and total porosity increased after the application of the different rates of wheat straw biochar (0, 10, 25 and 50 t/ha). In the variant 10 t/ha of biochar, there was the decrease in bulk density by 7.59%, in the variant 25 t/ha by 10.34% and in the variant 50 t/ha by 13.10% in comparison with the control treatment (0 t/ha). The two-year experiment of Yan *et al*. (2019) demonstrated the similar findings: the rates of 20, 40 and 60 t/ha of maize straw biochar contributed to decrease of soil bulk density – by an average of 4.2%, 6.5% and 9.6% at the mentioned doses. As far as the soil depth is concerned, the lower layer, the more important decline of soil bulk density – at the depth of 20–40 cm it went down by an average of 2.5%, 4.4% and 5.9% in the variants of 20, 40 and 60 t/ha in comparison with the control variant and at the depth of 0–20 cm the decline was even more noticeable. In the study of Abrishamkesh *et al.* (2015), biochar (0.4%, 0.8%, 1.6%, 2.4% and 3.3%) was derived from rice husk added to a Calcaric Cambisol. These authors also state that higher biochar dose decreases bulk density of the soil in a more relevant way.

In the work of Glab *et al.* (2016), total porosity was dependent on the size and the rate of biochar. In our study, the biochar dose of 45 t/ha essentially increased porosity from 53.75% to 55.60%. The experiment conducted by Ghorbani *et al.* (2019) reported that the biochar rate of 1% and 3% w/w greatly increased porosity of clay from 50.56% in the zero variant to 51.69% and 54.33%. Blanco-Canqui (2017) indicated that biochar has the tendency to increase porosity preferably in the coarse-textured soils in relation to the fine-textured ones. Liu *et al.* (2020) carried out the research which revealed that biochar (5% and 10% w/w) produced from corn straw improves total porosity of the alkaline soil by 4.14% and 5.09% in comparison with the control variant. Omondi *et al.* (2016) confirmed that the biochar application increases soil porosity by 8.4%. On the other hand, Da Silva Mendes *et al.* (2021) found out that poultry litter biochar in the soil raises porosity (14.15%) – even more than Omondi *et al.* (2016) mentioned in their trial. According to Igaz *et al.* (2018), the results of the experiment in Malanta proved that biochar amendment after the spring sampling substantially raised porosity of soil in all the variants (10 t/ha, 20 t/ha, 10 t/ha + + 160 kg/ha N, 20 t/ha + 160 kg/ha N) contrary to the control variant. The different situation occurred in autumn (less than 2 years after the application of biochar) when statistically inconclusive differences in soil porosity were monitored. Before the beginning of the trial in Tasmania, Hardie *et al.* (2014) were convinced that biochar would increase soil porosity. Surprisingly, it did not happen.

Verheijen *et al.* (2019) confirmed that field capacity of the soil is affected by the dose of the different biochar particle sizes as well as soil type. The biochar doses did not affect the value of field capacity within our field trial. Similarly, Major *et al.* (2012) observed that biochar derived from wood did not influence field capacity of the clay soil. Hardie *et al.* (2014) carried out a thirty-month study involving the effect of acacia green waste biochar. They also came to the conclusion that biochar did not influence field capacity in a relevant way. Razzaghi *et al.* (2020) stated that field capacity remained the same when taking into account the fine-textured soils. On the contrary, other authors claim that the biochar application increases field capacity (Liu *et al.,* 2020; Peake *et al.*, 2014; Karhu *et al*., 2011; Liu *et al.*, 2017). Da Silva Mendes *et al.* (2021) are of the same opinion: biochar causes higher field capacity (17.79%) in comparison with the control treatment. Mishra and Shinogi (2018) reported the same findings: biochar (5% w/w) in the clayey loam and sandy soil leads to higher field capacity. Rice husk biochar raised field capacity by 6.2% and bermuda grass biochar by 12.59% in the clayey loam compared to the control treatment. Biochar produced from bermuda grass enhanced field capacity by 9.25% and pine wood biochar noticeably by 32.92% in the sandy soil compared to the control variant. Chen *et al.* (2018) point out that higher doses (3 and 5% w/w) of wheat straw biochar improved field capacity of the sandy soil. Wang *et al.* (2019) expressed the opposite opinion. According to them, the rate of biochar ≥ 10 t/ha is sufficient to increase field capacity of the coarse-textured soil.

The application of biochar at the dose of 45 t/ha within our research induced the significant increase in the average value of aeration. Laghari *et al.* (2016), Widowati *et al.* (2020) and Speratti *et al.* (2017) published the same outcomes. Šrank and Šimanský (2020) claim that biochar (10 and 20 t/ha) resulted in the decrease in soil aeration after two years of its application. Contrarily, use of biochar with mineral fertilizers increased aeration in the sandy soil.

According to the results of our study, the application of biochar 45 t/ha is the most suitable for practice.

CONCLUSION

In the field experiment, saturated hydraulic conductivity, bulk density, porosity, field capacity and aeration were monitored. Based on our results, it was found out that none of the biochar doses affected saturated hydraulic conductivity of the topsoil at the depth of 0.05–0.20 m. In the crop rotation without manure application, the effect of the dose of biochar 45 t/ha was manifested on bulk density and soil aeration only in the lower part of the topsoil at the depth of 0.10–0.20 m. None of the biochar rates influenced bulk density and aeration in the Norfolk crop rotation. It was confirmed that the application of biochar 45 t/ha increased porosity in a highly significant way. The biochar doses did not affect the value of field capacity.

REFERENCES

ABRISHAMKESH, S., GORJI, M., ASADI, H. *et al.* 2015. Effects of rice husk biochar application on the properties of alkaline soil and lentil growth. *Plant Soil and Environment,* 61(11): 475–482.

ASLAM, Z., KHALID, M. and AON, M. 2014. Impact of biochar on soil physical properties. *Scholarly Journal of Agricultural Science,* 4(5): 280–284.

BASSO, A. S., MIGUEZ, F. E., LAIRD, D. A. *et al.* 2013. *Assessing potential of biochar for increasing water-holding capacity of sandy soils. Global Change Biology and Bioenergy,* 5(2): 132–143.

BLANCO-CANQUI, H. 2017. Biochar and Soil Physical Properties. *Soil Science Society of America Journal,* 81(4): 687–711.

CHEN, C., WANG, R., SHANG, J. *et al.* 2018. Effect of Biochar Application on Hydraulic Properties of Sandy Soil under Dry and Wet Conditions. *Vadose Zone Journal,* 17(1): 1–8.

DA SILVA MENDES, J., FERNANDES, J. D., CHAVES, L. H. G. *et al.* 2021. Chemical and Physical Changes of Soil Amended with Biochar. *Water, Air & Soil Pollution,* 232(8): 1–13.

DEVEREUX, R. C., STURROCK, C. J. and MOONEY, S. J. 2012. The effects of biochar on soil physical properties and winter wheat growth. *Earth and Environmental Science Transactions of the Royal Society of Edinburgh,* 103: 13–18.

DOS SANTOS BERNARDES, M. A. 2011. *Biofuel's Engineering Process Technology.* 1st Edition. Croatia: InTech.

EDEH, I. G. and MAŠEK, O. 2021. The role of biochar particle size and hydrophobicity in improving soil hydraulic properties. *European Journal of Soil Science,* 73(1): e13138.

EDEH, I. G., MAŠEK, O. and BUSS, W. 2020. A meta-analysis on biochar's effects on soil water properties – New insights and future research challenges. *Science of the Total Environment,* 714: 136857.

ESMAEELNEJAD, L., SHORAFA, M., GORJI, M. *et al.* 2016. Enhancement of physical and hydrological properties of a sandy loam soil via application of different biochar particle sizes during incubation period. *Spanish Journal of Agricultural Research,* 14(2): e1103.

GHORBANI, M., ASADI, H. and ABRISHAMKESH, S. 2019. Effects of rice husk biochar on selected soil properties and nitrate leaching in loamy sand and clay soil. *International Soil and Water Conservation Research,* 7(3): 258–265.

GLAB, T., PALMOWSKA, J., ZALESKI, T. *et al.* 2016. Effect of Biochar Application on Soil Hydrological Properties and Physical Quality of Sandy Soil. *Geoderma,* 281: 11–20.

GUL, S., WHALEN, J. K., THOMAS, B. W. *et al.* 2015. Physico-chemical properties and microbial responses in biochar-amended soil: Mechanisms and future directions. *Agriculture, Ecosystems and Environment,* 206: 46–59.

HARDIE, M., CLOTHIER, B., BOUND, S. *et al.* 2014. Does biochar influence soil physical properties and soil water availability? *Plant Soil,* 376: 347–361.

HERATH, H. M. S. K., ARBESTAIN, M. C. and HEDLEY, M. 2013. Effect of biochar on soil physical properties in two contrasting soils: An Alfisol and an Andisol. *Geoderma,* 209–210: 188–197.

ISO. 2019. *Soil, sludge and treated biowaste – Determination of pH*. ISO/DIS 10390. Available at: https://www.iso.org/obp/ui/#iso:std:iso:10390:dis:ed-3:v1:en

IGAZ, D., ŠIMANSKÝ, V., HORÁK, J. *et al.* 2018. Can a single dose of biochar affect selected soil physical and chemical characteristics? *Journal of Hydrology and Hydromechanics,* 66(4): 421–428.

JANDÁK, J., POKORNÝ, E., HYBLER, V. *et al.* 2015. *Cvičení z půdoznalství.* 1st Edition. Brno: Mendelova univerzita v Brně.

JEFFERY, S., MEINDERS, M. B. J., STOOF, C. R. *et al.* 2015. Biochar application does not improve the soil hydrological function of a sandy soil. *Geoderma,* 251–252: 47–54.

KARHU, K., MATTILA, T., BERGSTRÖM, I. *et al.* 2011. Biochar addition to agricultural soil increased CH_4 uptake and water holding capacity – Results from a short-term pilot field study. *Agriculture, Ecosystems and Environment,* 140(1–2): 309–313.

KUPPUSAMY, S., THAVAMANI, P., MEGHARAJ, M. *et al*. 2016. Agronomic and Remedial Benefits and Risks of Applying Biochar to Soil: Current Knowledge and Future Research Directions. *Environment International,* 87: 1–12.

LAGHARI, M., NAIDU, R., XIAO, B. *et al.* 2016. Recent developments in biochar as an effective tool for agricultural soil management: a review. *Journal of the Science of Food and Agriculture,* 96(15): 4840–4849.

LAIRD, D. A., FLEMING, P., DAVIS, D. D. *et al*. 2010. Impact of Biochar Amendments on the Quality of a Typical Midwestern Agricultural Soil. *Geoderma,* 158(3–4): 443–449.

LEHMANN, J., RILLIG, M. C., THIES, J. *et al.* 2011. Biochar effects on soil biota – A review. *Soil Biology and Biochemistry,* 43: 1812–1836.

LEI, O. and ZHANG, R. 2013. Effects of Biochars Derived from Different Feedstocks and Pyrolysis Temperatures on Soil Physical and Hydraulic Properties. *Journal of Soils and Sediments,* 13: 1561–1572.

LIBUTTI, A., MUCCI, M., FRANCAVILLA, M. *et al.* 2016. *Effect* of biochar amendment on nitrate retention in a silty clay loam soil. *Italian Journal of Agronomy,* 11(4): 273–276.

LIU, Z., DUGAS, B., MASIELLO, C. A. *et al.* 2016. Impacts of biochar concentration and particle size on hydraulic conductivity and DOC leaching of biochar – sand mixtures. *Journal of Hydrology,* 533: 461–472.

LIU, Z., DUGAN, B., MASIELLO, C. A. *et al.* 2017. Biochar Particle Size, Shape, and Porosity Act Together to Influence Soil Water Properties. *PLoS ONE* 12(6): e0179079.

LIU, D., FENG, Z., ZHU, H. *et al.* 2020. Effects of Corn Straw Biochar Application on Soybean Growth and Alkaline Soil Properties. *BioResources,* 15(1): 1463–1481.

LUO, S., WANG, S., TIAN, L. *et al.* 2017. Long-term biochar application influences soil microbial community and its potential roles in semiarid farmland. *Applied Soil Ecology,* 117–118: 10–15.

MAJOR, J., RONDON, M., MOLINA, D. *et al.* 2012. Nutrient leaching in a Colombian savanna oxisol amended with biochar. *Journal of Environmental Quality,* 41(4): 1076–1086.

MISHRA, A. and SHINOGI, Y. 2018. Effects of biochar on soil physico-chemical properties. In: *Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES).* Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, pp. 102–105.

MUKHERJEE, A., LAL, R. and ZIMMERMAN, A. R. 2014. Effects of biochar and other amendments on the physical properties and greenhouse gas emissions of an artificially degraded soil. *Science of the Total Environment,* 487: 26–36.

NAWAZ, M. F., BOURRIÉ, G. and TROLARD, F. 2013. Soil Compaction Impact and Modelling. A review. *Agronomy for Sustainable Development,* 33(2): 291–309.

NIKRAVESH, I., BOROOMANDNASAB, S., NASERI, A. A. *et al.* 2019. Wheat Straw Biochar Application to Loam-Sand Soil: Impact on Yield Components of Summer Maize and Some Soil Properties. *World Journal of Environmental Biosciences,* 8(1): 54–60.

OMONDI, M. O., XIA, X., NAHAYO, A. *et al*. 2016. Quantification of Biochar Effects on Soil Hydrological Properties Using Meta-analysis of Literature Data. *Geoderma,* 274: 28–34.

PEAKE, L. R., REID, B. J. and TANG, X. 2014. Quantifying the influence of biochar on the physical and hydrological properties of dissimilar soils. *Geoderma,* 235–236: 182–190.

RAZZAGHI, F., OBOUR, P. B. and ARTHUR, E. 2020. Does Biochar Improve Soil Water Retention? A Systematic Review and Meta-analysis. *Geoderma,* 361: 114055.

SPERATTI, A. B., JOHNSON, M. S., SOUSA, H. M. *et al.* 2017. Impact of Different Agricultural Waste Biochars on Maize Biomass and Soil Water Content in a Brazilian Cerrado Arenosol. *Agronomy,* 7(3): 49.

STYLIANOU, M., PANAGIOTOU, C. F., ANDREOU, E. *et al.* 2021. Assessing the influence of biochars on the hydraulic properties of a loamy sand soil. *Biomass Conversion and Biorefinery,* 11(2): 315–323.

ŠRANK, D. and ŠIMANSKÝ, V. 2020. Physical properties of texturally different soils after application of biochar substrates. *Agriculture (Polnohospodárstvo),* 66(2): 45–55.

VERHEIJEN, F. G. A., ZHURAVEL, A., SILVA, F. C. *et al.* 2019. The influence of biochar particle size and concentration on bulk density and maximum water holding capacity of sandy vs sandy loam soil in a column experiment. *Geoderma,* 347: 194–202.

WANG, D. Y., YAN, D. H., SONG, X. S. *et al.* 2014. Impact of Biochar on Water Holding Capacity of Two Chinese Agricultural Soils. *Advanced Materials Research,* 941–944: 952–955.

WANG, D., LI, C., PARIKH, S. J. *et al.* 2019. Impact of biochar on water retention of two agricultural soils – A multi-scale analysis. *Geoderma,* 340: 185–191.

WIDOWATI, S., KARAMINA, H. and FIKRINDA, W. 2020. Soil amendment impact to soil organic matter and physical properties on the three soil types after second corn cultivation. *AIMS Agriculture and Food, Indonesia,* 5(1): 150–168.

YAN, Q., DONG, F., LI, J. *et al.* 2019. Effects of maize straw-derived biochar application on soil temperature, water conditions and growth of winter wheat. *European Journal of Soil Science,* 70(6): 1280–1289.

ZBÍRAL, J., ČIŽMÁROVÁ, E., OBDRŽÁLKOVÁ, E. *et al.* 2016. *Analysis of soils I.: Unified techniques* [in Czech: *Analýza půd I: Jednotné pracovní postupy*]. 4th Edition. Brno: Ústřední kontrolní a zkušební ústav zemědělský.

Contact information

Markéta Zachovalová: xzachova@mendelu.cz (corresponding author)