doi: 10.17221/564/2017-PSE

Analysis of soil water content and crop yield after biochar application in field conditions

Justina VITKOVA[1,*], Elena KONDRLOVA[2], Marek RODNY[1], Peter SURDA[1], Jan HORAK[2]

[1]*Institute of Hydrology of the Slovak Academy of Sciences, Bratislava, Slovak Republic*
[2]*Department of Biometeorology and Hydrology, Slovak University of Agriculture, Nitra, Slovak Republic*
**Corresponding author: vitkova@uh.savba.sk*

ABSTRACT

Vitkova J., Kondrlova E., Rodny M., Surda P., Horak J. (2017): Analysis of soil water content and crop yield after biochar application in field conditions. Plant Soil Environ., 63: 569–573.

Biochar has been studied extensively in terms of its influence on soil hydrophysical properties, but only small part of results was obtained from the field experiments. In this study, the soil water content was measured in 5–10 cm depth at experimental plots which received 20 t/ha and 0 t/ha (control) of biochar amendment at the Malanta area (Slovakia). The experimental area was cultivated with maize in 2015 and spring wheat in 2016. Our field measurements show that the positive effect of biochar amendment (20 t/ha) on soil water content is strongly related to the type of the crop grown and not straightforward. Unexpectedly, during the monitoring campaign in 2015 the soil water content of the biochar-amended soil was lower than control. In 2016, negligible differences were observed in soil water contents at both experimental plots, especially during the dry spells. However, higher soil water content was measured at the plot with biochar amendment after the series of precipitation events during the physiological maturity of the spring wheat. Moreover, the biochar amendment did not increase the biomass production and yields of maize in 2015, but it significantly increased the biomass production and yields of spring wheat in 2016.

Keywords: climate change; biochar; *Zea mays*; *Triticum aestivum*; field measurements

During the recent decades, mankind has witnessed a variety of weather extremes. It is experiencing intense torrential rainfall, prolonged periods of drought and extreme temperature records in winter and summer months. Regardless of whether this is due to climate change or the frequent extremity of weather, soil production capacity is one of the factors that are the most primarily affected. Biochar is a porous, carbon-rich material produced by heating organic matter to temperatures between 300°C and 1000°C in an environment with limited or no oxygen (Verheijen et al. 2010). Recently, in the context of climate change, there has been much interest in studying the black carbon often referred to as biochar or charcoal (Lehmann 2007). Production of biochar and its storage in soils were suggested as a means of abating climate change by sequestering carbon, while simultaneously providing energy and increasing crop yields (Woolf et al. 2010). The addition

Supported by the Slovak Research and Development Agency, Project No. APVV-0512-12; by the Scientific Grant Agency, Projects No. VEGA 2/0013/15, No. VEGA 2/0189/17 and No. VEGA 1/0604/16; by the Cultural and Educational Grant Agency, Project No. KEGA 026SPU-4/2017; by the Centre of Excellence for the Integrated River Basin Management in the Changing Environmental Conditions, Project No. ITMS 26220120062, and by the Research and Development Operational Programme funded by the ERDF.

doi: 10.17221/564/2017-PSE

of biochar to agricultural soils is recommended to improve soil functions and plant growth such as soil chemical properties, hydrophysical soil characteristics, and also biological properties of soil (Glaser et al. 2002, Lehmann et al. 2006). A positive effect of biochar on plant growth was shown by Zemanová et al. (2017). Kraska et al. (2016) showed that the effect of biochar on the yield is related to its effect on the bioavailability of P, K, Mg, Cu, Zn, Mn and B and on the soil pH. Reactions in the soil after the addition of biochar depend on the characteristics of biochar, soil, climate and soil-inhabiting organisms. Due the variable quality of biochar, its effects on soils and plants are likely to differ (Hagner et al. 2016). Pyrolysis temperature has a large effect on biochar characteristics (Keiluweit et al. 2010, Angin and Sensöz 2014). Xiao et al. (2012) showed that the conductivity of biochar drastically increases at pyrolysis temperatures greater than 500–600°C. The impact of biochar on soil water content in the field conditions has not been studied yet on large scales in Slovakia. In our study, the soil water content and crop yield were considered as the core indicators of the real impact of biochar addition on agricultural soil in the field conditions.

MATERIAL AND METHODS

Study site. The study site is located in Malanta, approximately 5 km north-east of the Nitra city, Slovakia (48°19'00''N; 18°09'00''E) at an altitude of 175 m a.s.l. (Surda and Vitkova 2016). The soil type is classified as the Haplic Luvisol (WRB 2006), with the content of sand 15.2%, silt 59.9% and clay 24.9% – silt loam. Soil organic carbon content was 9.13 g/kg and soil pH_{KCl} was 5.71 (Šimanský and Klimaj 2017).

Characteristics of the used biochar. The biochar used in the field experiment was produced from paper fiber sludge and grain husks, 1:1 per weight (company Sonnenerde, Riedlingsdorf, Austria) by pyrolysis at 550°C for 30 min in a Pyreg reactor (Pyreg GmbH, Dörth, Germany). Table 1 shows the biochar characteristics. The biochar composition and the content of carbon (C), hydrogen (H) and nitrogen (N) were measured by Eurofins (Halsbrücke, Germany); methods described in DIN 51732 (2007). The oxygen (O) content was calculated following the procedure described in DIN 51733 (2008). Ash content was measured by DIN 51719 (1997). The specific surface area of the biochar was measured by DIN 66132 (1975)/ISO 9277 (2010). The pH of biochar was measured by DIN ISO 10390 (2005). On average; biochar contained 57 g/kg of Ca, 3.9 g/kg of Mg, 15 g/kg of K and 0.77 g/kg of Na (Šimanský and Klimaj 2017). The size of the biochar was 0–5 mm.

The whole site was divided into plots with the size 6 × 4 m separated by 0.5 m bands. The experiment was performed in the configuration: control – without biochar addition and B20 variant with a dose of 20 t/ha of biochar. The experiment started on March 10, 2014, prior to sowing when the experimental area was ploughed by harrow cultivator up to 10 cm depth.

Soil water content measurements. The measurements were performed with 5TM dielectric sensors (Decagon Devices, Pullman, USA). Two sensors were installed in 5–10 cm depth at each experimental plot. Correlation coefficient between two sensors at the same plot was 0.95 or 0.98, respectively (Vitkova and Surda 2016). The soil water content data were collected in five-minute interval and stored using the EM 50 data loggers (Decagon Devices, Pullman, USA).

The control plot and the B20 plot were analysed during the growing periods of 2015 and 2016. Continuous measurements of soil water content at top soil layer were initiated at both plots on August 12, 2015 and were conducted till October 22, 2015 and from June 14 up to July 20, 2016, respectively. In 2016, complementary gravimetric measurements of soil water content were performed.

Crop analysis. During the experimental measurements the whole site was agriculturally cultivated. Maize (*Zea mays* subsp. *mays*) was sown in 2015 and spring wheat (*Triticum aestivum* L.) in 2016, respectively. In 2016, four digital images of wheat canopy were taken at control and B20 plots by

Table 1. Biochar characteristics

	C	N	H	O	pH_{CaCl_2}	Ash (%)	Specific surface area (m^2/g)
	(%)						
Biochar	53.1	1.4	1.84	5.3	8.8	38.3	21.7

doi: 10.17221/564/2017-PSE

SONY NEX-3 (Tokyo, Japan) on June 14. The digital pictures were obtained holding the camera at about 160 cm from the ground in a zenithal position focusing on the wheat canopy near the centre of the plot. Based on the green fraction representation on the digital images, vegetation index was estimated according to the methodology by Casadesus and Villegas (2012). The plants for biomass evaluation were collected from 0.5 m^2 per plot during the harvest time (October 29, 2015 and July 20, 2016). The above-ground dry biomass was determined by drying in the oven at 60°C until the constant weight. The final grain yield was calculated by multiplying the total number of ears per m^2, the number of grains per ear and the average grain weight.

RESULTS AND DISCUSSION

The daily averages of soil water content at 5–10 cm depth at the control and B20 plots in 2015 are shown in Figure 1a. It was expected that the soil water content at the B20 plot will present higher values compared to the control plot because of known higher water retention capacity of the biochar. However, our results for 2015 showed the opposite. The control plot had higher values of soil water content than B20 during the monitored time period, no matter if there was a higher or lower water content in the soil before.

The average measured soil water contents at both plots in 2016 are shown in Figure 1b. The

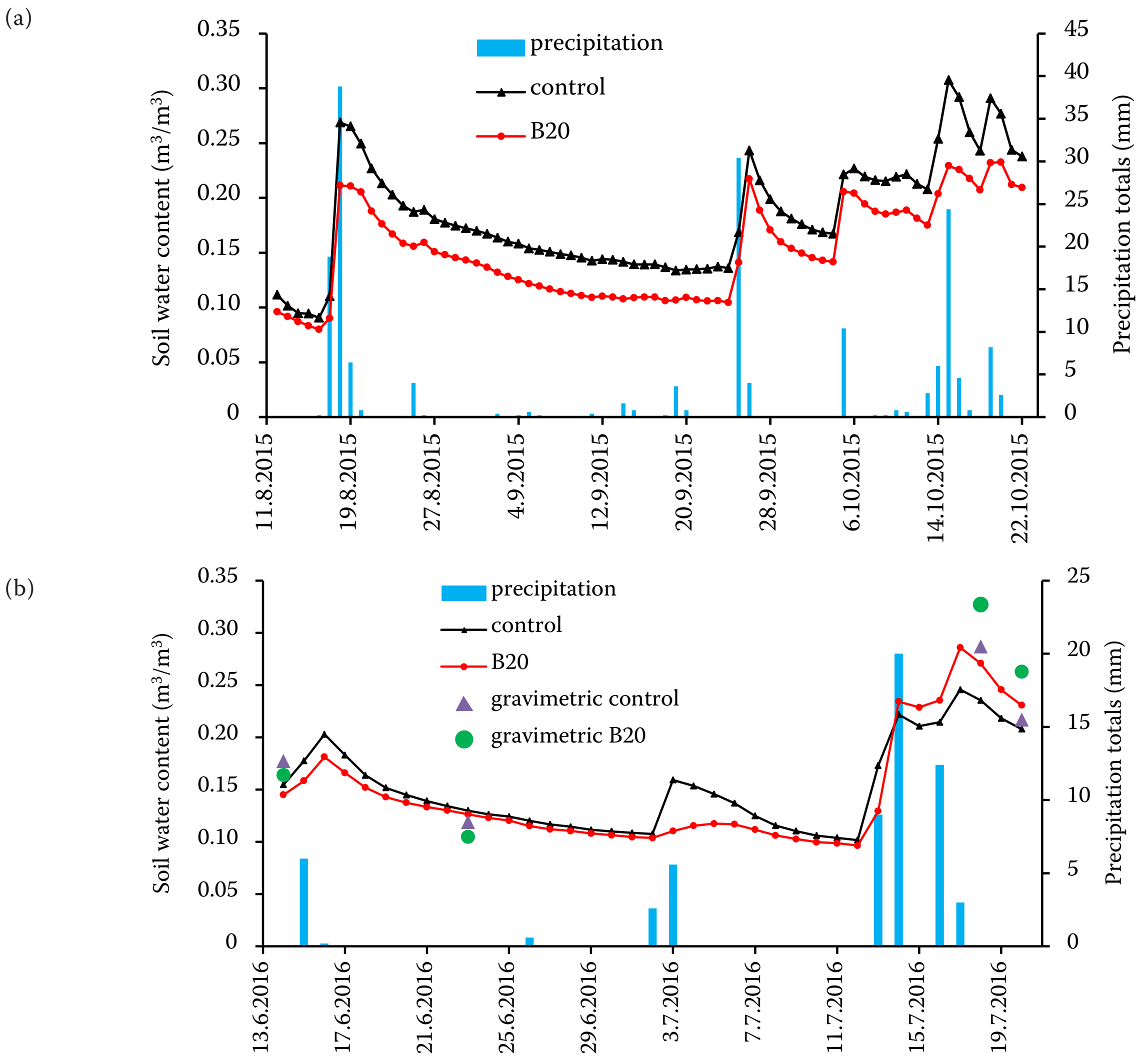

Figure 1. Average soil water content at the control and at the B20 plots measured by the 5TM sensors in comparison with (a) daily precipitation totals at the Malanta site in 2015, and (b) daily precipitation totals and gravimetrically determined soil water content at the Malanta site in 2016

doi: 10.17221/564/2017-PSE

Table 2. Effect of biochar application on crop biomass

Year	Crop	Treatment	Above-ground dry biomass (t/ha)	Final grain yield (t/ha)	Vegetation index
2015	maize	control	27.5	12.0	N/A
		B20	18.8	7.1	N/A
2016	spring wheat	control	8.8	2.4	0.66 ± 0.03[a]
		B20	10.1	3.3	0.76 ± 0.03[b]

Different superscript letters represent significant differences between plots at the $P \leq 0.05$ level (one-way analysis of variance (ANOVA)) for the purposes of the vegetation index evaluation (n = 4). N/A – not applicable

differences between control and B20 plots were smaller especially during non-precipitation days. The top soil water content started to differentiate after the precipitation events. While the control plot had higher values of soil water content in the first two thirds of the monitored period (soil water content was around 0.18 m^3/m^3) after an intensive precipitation event on July 14, 2016, the average soil water content at the B20 plot was higher than control plot, as was also confirmed by the gravimetric measurements.

Based on our field measurements, the hypothesis about a positive effect of the biochar on soil water content was only partially confirmed. The sensors recorded higher soil water content at the control plot in 2015 and also in the 'dryer' part of the studied period in 2016. This phenomenon can have several causes i.e., the characteristics of the biochar applied such as the pyrolysis conditions (temperature, rate of heating, and pressure) or specific surface area (Chan et al. 2008). Secondly, the root zone of vegetation plays also a significant role. Two distinct types of vegetation with different root structure within the 5–10 cm depth were grown at the study plots. Thirdly, it is assumed that different soil water evaporation pattern due to different soil colour and soil surface coverage by plants could also play a role. In 2015, a higher yield was observed at the control plot in comparison to the B20 plot (Table 2). Considering the visibly darker colour of soil including biochar on the top of the soil surface at B20 plot, it is assume that the evaporation rates from the bare ground might be higher than at the control plot because the ground was not protected by the broad-row grown maize canopy. In the contrary, when the spring wheat was grown in narrower rows in 2016, the observed crop yields were slightly higher at the B20 plot (10.1 t/ha of the aboveground biomass and 3.3 t/ha of grain yield) in comparison to the control plot (8.8 t/ha and 2.4 t/ha). The statistically significantly higher vegetation index (Table 2) at plot treated with biochar suggests that the soil water content at B20 plot at the begging of June 2016 might be lower due to higher transpiration of wheat plants.

Although biochar application had an uncertain effect on biomass production of maize in 2015, it significantly increased the vegetation biomass during the growing period 2016 (as assessed by vegetation index). Wheat final grain yield and above-ground biomass was also higher at plots with added biochar. These results are in agreement with the work of Major et al. (2010). According to this study the maize grain yield did not significantly increase in the first year after the biochar application, but it increased at plots with the 20 t/ha of biochar over the control by 28, 30 and 140% in three following years. Our results from the field conditions show that the application of 20 t/ha of biochar with the above-mentioned characteristics did not significantly affect the soil water content within the top soil layer. Moreover, it was proven that the investigation of the biochar amendment strategies is rather complex and the soil-plant-atmosphere system interactions are not simple and straightforward. Assessing the impact of biochar addition on soil water content clearly requires hypothesis testing in the field conditions during long-term experiments and it should not be substituted by the measurements in laboratory conditions.

REFERENCES

Angin D., Sensöz S. (2014): Effect of pyrolysis temperature on chemical and surface properties of biochar of rapeseed (*Brassica napus* L.). International Journal of Phytoremediation, 16: 684–693.

doi: 10.17221/564/2017-PSE

Casadesus J., Villegas D. (2012): Biomass assessment for cereal breeding using vegetation indices obtained with conventional digital cameras. Available at: http://www.ub.edu/optichinagriculture/data/uploads/workshop2/presentations/casadesus-irta.pdf (accessed on September 20, 2017)

Glaser B., Lehmann J., Zech W. (2002): Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal – A review. Biology and Fertility of Soils, 35: 219–230.

Hagner M., Kemppainen R., Jauhiainen L., Tiilikkala K., Setälä H. (2016): The effects of birch (*Betula* spp.) biochar and pyrolysis temperature on soil properties and plant growth. Soil and Tillage Research, 163: 224–234.

Chan K.Y., Van Zwieten L., Meszaros I., Downie A., Joseph S. (2008): Using poultry litter biochars as soil amendments. Australian Journal of Soil Research, 46: 437–444.

Keiluweit M., Nico P.S., Johnson M.G., Kleber M. (2010): Dynamic molecular structure of plant biomass-derived black carbon (biochar). Environmental Science and Technology, 44: 1247–1253.

Kraska P., Oleszczuk P., Andruszczak S., Kwiecińska-Poppe E., Różyło K., Pałys E., Gierasimiuk P., Michałojć Z. (2016): Effect of various biochar rates on winter rye yield and the concentration of available nutrients in the soil. Plant, Soil and Environment, 11: 483–489.

Lehmann J. (2007): Bio-energy in the black. Frontiers in Ecology and the Environment, 5: 381–387.

Lehmann J., Gaunt J., Rondon M. (2006): Bio-char sequestration in terrestrial ecosystems – A review. Mitigation and Adaptation Strategies for Global Change, 11: 403–427.

Major J., Rondon M., Molina D., Riha S.J., Lehmann J. (2010): Maize yield and nutrition during 4 years after biochar application to a Colombian savanna oxisol. Plant and Soil, 333: 117–128.

Šimanský V., Klimaj A. (2017): How does biochar and biochar with nitrogen fertilization influence soil reaction? Journal of Ecological Engineering, 5: 50–54.

Surda P., Vitkova J. (2016): Impact of biochar application on soil moisture dynamics and saturated hydraulic conductivity. In: Proceedings of the 16th International Multidisciplinary Scientific GeoConference SGEM 2016, Hydrology and Water Resources, 1: 445–451.

Verheijen F., Jeffery S.L., Bastos A.C., van der Velde M., Diafas I. (2010): Biochar Application to Soils – A Critical Scientific Review of Effects on Soil Properties, Processes and Functions. Luxembourg, European Communities.

Vitkova J., Surda P. (2016): Impact of biochar application on moisture in the top soil layer. Acta Hydrologica Slovaca, 2: 287–292.

Woolf D., Amonette J.E., Street-Perrott F.A., Lehmann J., Joseph S. (2010): Sustainable biochar to mitigate global climate change. Nature Communications, 1: 56.

World Reference Base for Soil Resources (2006): World Soil Resource Report No. 84. Rome, Food and Agriculture Organisation of the United Nations.

Xiao G., Xiao R., Jin B.S., Zuo W., Liu J.C., Grace J.R. (2012): Study on electrical resistivity of rice straw charcoal. Journal of Biobased Materials and Bioenergy, 4: 426–429.

Zemanová V., Břendová K., Pavlíková D., Kubátová P., Tlustoš P. (2017): Effect of biochar application on the content of nutrients (Ca, Fe, K, Mg, Na, P) and amino acids in subsequently growing spinach and mustard. Plant, Soil and Environment, 7: 322–327.

Received on September 6, 2017
Accepted on December 1, 2017
Published online on December 8, 2017