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Biochar dosage impact on physical soil properties and crop status

V. Novák[1,*], K. Křížová[1,2] and P. Šařec[1]

[1]Czech University of Life Sciences Prague, Faculty of Engineering, Department of Machinery Utilization, Kamýcká 129, CZ16500 Prague, Czech Republic
[2]Crop Research Institute, Division of Crop Protection and Plant Health, Drnovská 507/73, CZ16106 Prague, Czech Republic
[*]Correspondence: novakvaclav@tf.czu.cz

Abstract. In the context of climate change and the ongoing population growth, current agriculture inevitably faces many challenges. Long periods of drought are often followed by shorter periods of heavy precipitation and degraded soil is often unable to retain the rainfall water properly. Apart from common organic fertilizers, soil amendments are currently considered a promising solution that might improve soil quality. The most discussed one is biochar, a natural soil conditioner that might under certain conditions improve soil properties. This study is based on the experiment that was established in 2017 in order to determine the impact of biochar dosage and it's effect over time. Four parcels approximately 15×30 m were designed in Rapotín, Czech Republic. Each of them was treated with a specific dose of biochar (15, 30, 45, 60 t ha^{-1}), and selected soil physical properties such as penetration resistance and reduced bulk density were then measured at the beginning of the cropping season 2019. In addition, vegetation properties were investigated with the use of handheld sensors repeatedly during the season on winter wheat. The dataset contained information about chlorophyll and nitrogen content as well as Normalized Difference Vegetation Index estimations. Acquired values were later compared with the results obtained from the fifth variant founded in 2014 with a 15 t ha^{-1} dose and from the control variant. Although the dosage levels applied were quite substantial, no significant difference was found when evaluating selected soil properties. Crop response gave similar results. Any of the examined characteristics differed among the 2017 variants and control. Nevertheless, when compared to the 2014 variant, clearly different results were detected. Thus, this study concluded that the effect of biochar dosage is might not be as significant factor, however, the time effect likely is. Therefore, the study has to continue and soil/crop properties will be observed in the upcoming season as well.

Key words: soil conditioner, penetration resistance, reduced bulk density, handheld sensor, vegetation index.

INTRODUCTION

Ensuring sufficient quantity and quality of foodstuff while protecting the environment is one of today's agricultural dilemmas. Today, the situation is dire due to various constraints related to soil properties such as soil degradation, soil compaction or carbon losses, all of which are often mentioned topics not only among scientific literature. Essentially, compacted soil has low water infiltration capacity, which is a crucial fact in terms of agricultural drought mitigation (Chyba et al., 2014). Consequently, there are significant constraints in nutrients uptake under soil compaction, namely nitrogen uptake might decrease by 30% by spring wheat (Kuht & Reintam, 2004). Moreover, the infiltration capacity is jeopardized even more during long drought periods or large amounts of precipitation in short periods of time. Due to reduced infiltration capacity, floods may occur, affecting the surrounding landscape. These negative changes are very often strengthened by anthropogenic activities, here in particular by the intensification of the agricultural practice (Kopittke et al., 2019). Also, the impact of ongoing climate change must be considered. Despite the undeniable progress in crop breeding and field management, drought still causes significant fluctuations which affect crop growth during the whole cropping season resulting in yield losses (Potopová et al., 2015).

Biochar is a carbon-rich material referred to as a soil conditioner. Its potential in terms of drought-related agricultural issues is an ongoing discussion in recent scientific studies. Primarily, the carbon content of this material is considered apparently beneficial. Depending on the properties of biomass as the input for the pyrolysis process as well as the pyrolysis conditions, the carbon content can reach up to 90%. Therefore, this material is believed to increase carbon sequestration application activities (Ippolito et al., 2017). Moreover, biochar processing can provide an efficient treatment of residual waste from food production, when taken as an input biomass (Tamelová, et al., 2019). Utilizing the waste biomass in this manner is a promising instrument for reducing greenhouse gases produced by agricultural practice (Lehmann et al., 2006).

The intrinsic links between soil and plants are undeniable facts. By means of the vegetation state, soil properties can be indirectly determined. With developments in the field of technology in recent decades, various non-destructive methods can be used to determine vegetation properties. While using the satellite imagery is suitable for larger areas, for smaller plots UAV (Unmanned Aerial Vehicles) or a variety of handheld devices is more appropriate (Tunca et al., 2018). The major difference between these two methods is the form of information which the devices provide. Apparently, the latter is used rather for direct measurement, while gathering mainly the point information. Those can be interpolated through various algorithms to acquire the spatial information about the plot as a whole. However, when requiring such data, UAVs are more recommended to be used, since today a very high resolution can be achieved by most of the sensors on the market. Spectral responses of different kinds of surface materials has been studied extensively and the achievements resulted in the development of Remote Sensing practices. Based on source imagery, hundreds of spectral indices are not only used describe plant properties. The NDVI (Normalized Difference Vegetation Index) was one of the first indices describing the vegetation biomass and health and it is one of the most widespread used even till today (Li et al., 2019). Furthermore, the nitrogen content in a plant material is one of the key indicators for predicting yields and vegetation status (Cartelat et al., 2005), since closely correlated with the chlorophyll content (Yoder & Pettigrew-Crosby, 1995).

As mentioned above, many studies look at biochar, however, the subject is often focused on physical or chemical properties of the biochar itself (de la Rosa et al., 2014; Yargicoglu et al., 2015; Yuan et al., 2015; Conti et al., 2016) or its general behaviour when applied to the soil profile respectively (Lehmann et al., 2006; Rasa et al., 2018; Razzaghi et al., 2019). The question of potential ecotoxicity is being also discussed

(Zhang et al., 2020). Nevertheless in terms of its effect, other biochar-based studies suggest that it may be responsible for reducing the soil bulk density and increase water infiltration and later availability for plants (Razzaghi et al., 2019; Tanure et al., 2019). It has been shown that the effect on reducing bulk density of the soil as well as on water-holding capacity is strongly correlated with the particle size. However, the entire effect may vary depending also on the soil type (Verheijen et al., 2019).

Although there have been many studies published on the subject of biochar, the experiment described in this paper is focused on its dosage rather than the effect itself. The objective here is to determine the potential differences in soil and crop performance based on the specific levels of biochar dose. Its impact on soil physical properties and related crop growth are about to be evaluated.

MATERIALS AND METHODS

Site and crop management

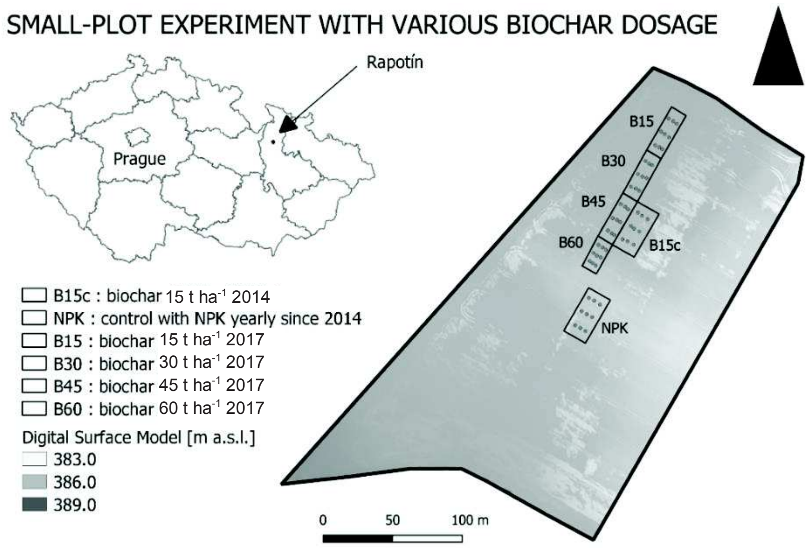

Figure 1. Experimental plot location and small-plots treatment specification.

This study was undertaken in the Czech Republic on agricultural plot located near the town of Šumperk in the Olomouc region (49° 59' 8.8296" N, 16° 59' 47.0904" E). The 13.24 ha field was divided into smaller plots with a variable area and also varying agricultural management. Five small-plots approximately 30×15 m treated by biochar in specific doses have been chosen for this study (Fig. 1). A control has also been included and marked as 'NPK' since the whole area was, besides investigated soil conditioners and fertilizers, treated by standard complex fertilizers (N, P, K) in a dose of 280'kg'ha^{-1} that is in accordance with the common practice. According to the FAO Soil Units, the soil type was classified as Gleyic Luvisols, which usually develops on flat surfaces. Complex soil analysis was undertaken before biochar application to obtain information about initial soil conditions (Table 1). Practically no sloping of the plot enables a wide-row crops cultivation without any erosion exposure. Crop rotation in recent years started with maize (2015) followed by in growing season 2019. *Proteus* (Soufflet Agro) wheat variety was sown on the 24th October 2018 and cultivated till the harvest date 10th August 2019. According to the producer it is semi-early to mid-late wheat with excellent resistance to laying flat and healthy leaf development. Disc harrow was used in 2014–2016 and 2018 at depths 9–12 cm, while in 2017 reversible plough at a depth of 25 cm was used during the soil tillage.

Biochar used for this study was produced from plant biomass and wood waste in the Czech Republic by the company BIOUHEL.CZ. Table 2 gives its technical specifications more in detail. The dosage levels were designed intentionally high to assure the substantial difference in an effort to establish some threshold that defines the biochar effectivity. Since the common practice works with 10–15 t ha^{-1}, the doses for this experiment were 15, 30, 45 and 60 t ha^{-1}.

Table 1. Results of soil analysis that has been undertaken by the research company Agrovýzkum Rapotín in 2014

	Soil profile [cm]		
	0–30	30–60	
Clay (< 0.002 mm)	27	22	[%]
Clay particles (< 0.01 mm)	40	34	[%]
Silt (0.01–0.05 mm)	40	38	[%]
Fine sand (0.05–0.1 mm)	3	5	[%]
Sand (0.1–2 mm)	17	23	[%]
Bulk density	1.38	1.66	[g cm^{-3}]
Total porosity	47.72	38.91	[%]
Volumetric moisture	34.35	29.95	[%]
Humus content	1.93	1.09	[%]
pH (KCl)	5.13	5.4	–

Table 2. Technical specifications of biochar used for the study as provided by the BIOUHEL.CZ company

Total C in dry matter	min 45	[%]
Total N in dry matter	min 1	[%]
Total P (P_2O_5) in dry matter	16	[%]
Total K (K_2O) in dry matter	17	[%]
pH	9–11	–
Particle size < 2 mm	min 40	[%]
Particle size > 10 mm	max 10	[%]

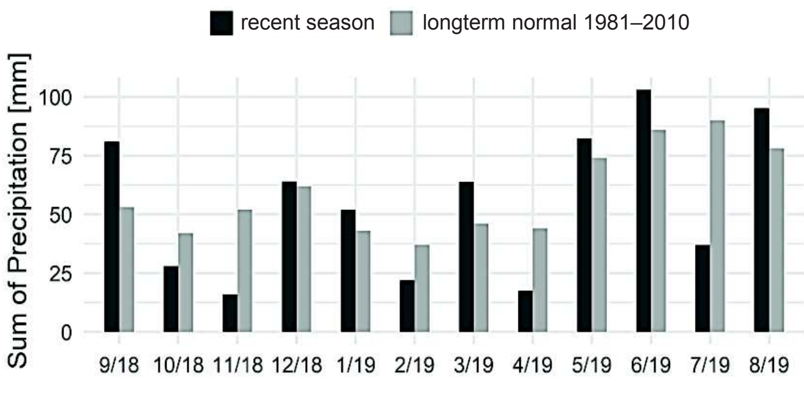

Figure 2. Precipitation condition in cropping season 2019 in comparison with the long term normal according to the Czech Hydrometeorological Institute.

Figs 2, 3 Represent meteorological conditions of the investigated cropping season. As shown on Fig. 2, the rainfall varied considerably in comparison with the long-term normal. In general, the total amount of precipitation in 2019 was 45.1 mm lower. The especially low amount of precipitation during April must have had a critical impact on the crop development. Furthermore, the temperature during this period exceeded the long-term normal during the entire season, excluding the month of May (Fig. 3). The range of temperature differences varied from -2.2 °C to 4.7 °C, however, the overall average temperature resulted in 1.6 °C higher than normal.

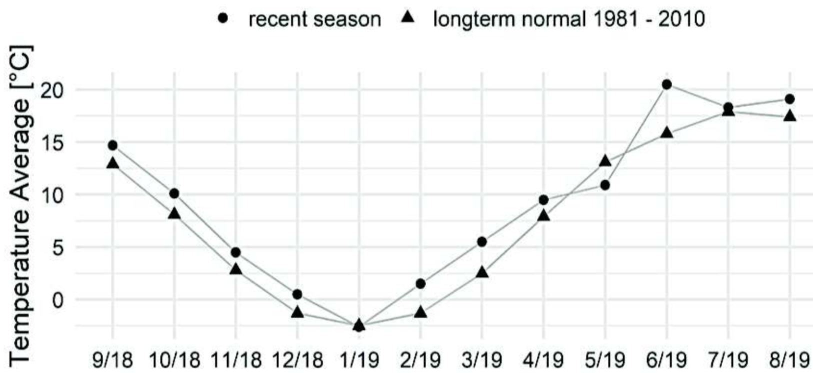

Figure 3. Monthly average temperature in cropping season 2019 in comparison with the long term normal according to the Czech Hydrometeorological Institute.

Data Acquisition and Processing

Field visits and in-situ terrestrial measurements were undertaken on the 18th April (term I; BBCH 30), 8th May (term II; BBCH 34) and 24th May 2019 (term III; BBCH 37) to obtain the terrestrial data. Soil physical properties were measured solely at the beginning of the cropping season (term I) in a period when the soil profile was saturated with water, as it is a common practice. For the information regarding Reduced Bulk Density, (BD) standard Kopecky's cylinders were used. Furthermore, Penetration Resistance (PR) of the soil profile was investigated. Using the instrument PEN 70, developed by Czech University of Life Sciences in Prague exclusively for these kinds of measurements. PR values in depths 4, 8, 12, 16 and 20 cm were recorded. Crop status data was monitored within all field visit terms. Namely it was Leaf Chlorophyll Content (LCC) measured by the CCM-300 sensor (OptiSciences), nitrogen content (N) and derived Normalized Difference Greenness Index (NDGI) measured by N-Pen (Photon Systems Instruments) and last Normalized Difference Vegetation Index (NDVI) acquired by GreenSeeker sensor (Trimble). 9 sampling points were established within each small-plot. Its GPS coordinates were recorded and the exact spot was marked by the red plastic pin to ensure the consistency of measurements in the exact spot.

The whole dataset was then processed in an open-source environment of R Studio (R Core Team, 2019) using packages tidyverse (Wickham et al., 2019), readxl (Wickham and Bryan, 2019), reshape2 (Wickham, 2007), pgirmess (Giraudoux, 2018) and multcompView (Graves et al., 2019).

The distribution of data was tested using the Shapiro-Wilk normality test in order to choose an appropriate statistical test. Since the data was not confirmed to be normally distributed, non-parametric statistical testing had to be utilized. To determine potential differences among investigated variables based on the biochar dose, the Kruskal-Wallis test was used instead of ANOVA.

RESULTS AND DISCUSSION

First of all, BD has been used to describe soil profile conditions. Since the process of collecting such data is time-consuming, the amount of information has been used for initial description of soil environment rather than for statistical testing. As shown by Fig. 4, the control (NPK) has the lowest values, while the B60 has the highest. According to the United States Department of Agriculture, the ideal bulk densities for plant growth related to present soil texture is lower than 1.10 g cm^{-3}. The bulk density which affects root growth is 1.49 g cm^{-3} and bulk densities that restrict root growth are higher than 1.58 g cm^{-3} (United States Department of Agriculture, 2019). Based on this recommendation, NPK performed the best, while by B60 the volume density limit was exceeded and the root growth was likely restricted. Variant B15c is still below USDA limit which on one hand affects the root growth, but still there is no root growth restriction. While a large number of studies have reported positive effects of biochar on soil bulk density (Walters & White, 2018; Alotaibi & Schoenau, 2019; Oni et al., 2020), there was no improvement observed in this study after two years from biochar application.

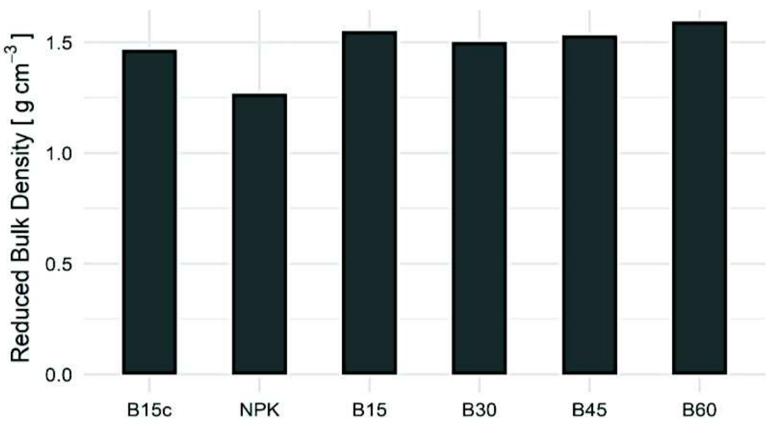

Figure 4. Values of reduced soil bulk density (0–0.05 m) - 18th April 2019.

PR results are illustrated by Fig. 5, where all investigated depths are represented. Nonetheless, neither here statistically significant difference has been observed among the variants (see also Table 3). Based on the results of other studies conducted on changes in PR, biochar is considered to reduce penetration resistance in the upper layers of the soil without increasing it in the deeper layers (Ahmed et al., 2017; Šařec et al., 2019). This is in accordance also with another study, where PR was reduced in the upper part of the sandy loam soil, but by loamy fine sand soil any influence of biochar on penetration resistance was observed (Obia et al., 2017). The measurement of soil physical parameters was undertaken in the springtime (term I) when higher water saturation of soil profile is expected. However, the precipitation in April 2019 was lower more than 50% less the normal precipitation rate. For this reason, the potential of biochar could not be sufficiently demonstrated. Otherwise, this would probably result in a decrease of PR, mainly due to the porosity of the biochar and thus its ability to retain water.

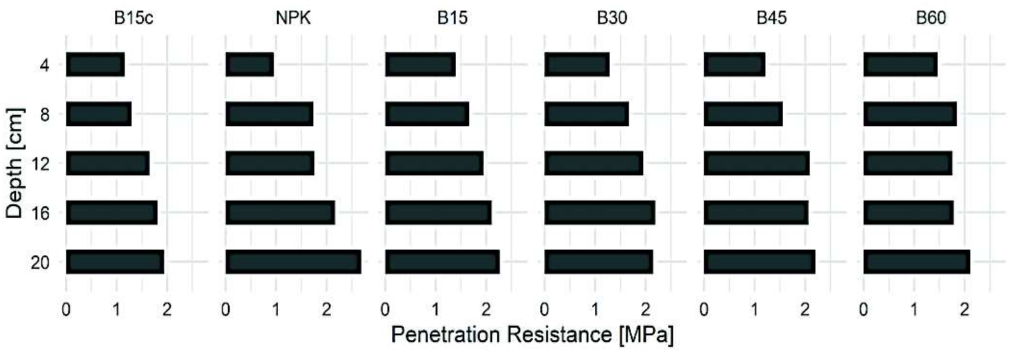

Figure 5. Soil penetration resistance values recorded during the term I in selected depth levels.

Regarding the crop growth indicators, results have been rather homogeneous as well. Table 3 provides the complex overview of Kruskal-Wallis analysis results. As shown here, only the LCC has indicated some significant differences, namely in term II and term III (see also Fig. 6).

Table 3. Kruskal-Wallis test of variance describing the variability of LCC (Leaf Chlorophyll Content), N (nitrogen content), NGDI (Normalized Difference Greenness Index) and PR (soil Penetration Resistance) in relation to small-plots treated by different dose of biochar

	Term	*p*-value	B15c	NPK	B15	B30	B45	B60
LCC	I	0.062	a	a	a	a	a	a
	II	0.023	ab	ab	a	ab	ab	b
	III	< 0.001	a	b	b	b	b	ab
N	I	0.235	a	a	a	a	a	a
	II	0.494	a	a	a	a	a	a
	III	0.344	a	a	a	a	a	a
NDGI	I	0.234	a	a	a	a	a	a
	II	0.489	a	a	a	a	a	a
	III	0.344	a	a	a	a	a	a
NDVI	I	0.035	a	a	a	a	a	a
	II	0.570	a	a	a	a	a	a
	III	0.192	a	a	a	a	a	a
	depth							
PR	4	0.129	a	a	a	a	a	a
	8	0.155	a	a	a	a	a	a
	12	0.740	a	a	a	a	a	a
	16	0.536	a	a	a	a	a	a
	20	0.230	a	a	a	a	a	a

First of all, there is apparently a difference in sensitivity of the sensors used. Although they are designed to indicate different properties, LCC are trusted to be highly correlated with the nitrogen content in a biomass (Evans, 1983). Therefore, similar results among those variables were expected. While the CCM 300 sensor measures the LCC as the chlorophyll fluorescence ratio utilizing the wavelengths assigned to the Red Edge region (CFR = 735 nm /700 nm), the N-Pen calculates the NDGI index according to the information in wavelengths of 560 nm (Green) and 780 nm (NIR). Secondly, the influence of meteorological conditions may explain the LCC data variability. As mentioned above, April was a significantly warm and dry period, which very likely affected the results recorded during the term I. During the month of May, when term II and III measurements taken, precipitation was rich and the recorded temperatures were lower. Such a combination very likely restored the suitable conditions for crop growth and therefore, the differences among the plots could be observed. The study of Tanureet al. (2019) suggest that the impact of biochar on crop growth parameters is strongly influenced by the level of drought. While under the regular conditions, biochar-enriched soils promote the photosynthesis and stomatal conductance, drought conditions cause the slowing down of these processes even more than seen in a control.

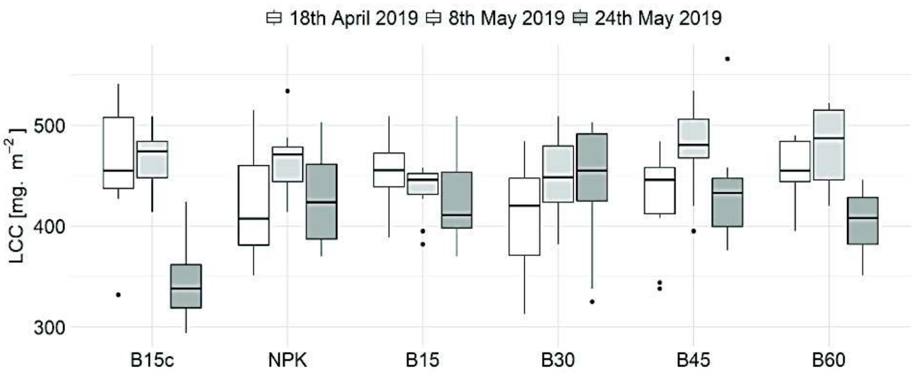

Figure 6. Leaf Chlorophyll Content obtained by CCM 300 handheld sensor during the term I, II and III among investigated small-plot variants.

During term II a significant difference was observed between B15 and B60. However, the situation became clearer in term III, when the chlorophyll content levels were significantly different by B15c compared to all variants with biochar established in 2017, excluding B60, and the control. This trend is in accordance with the previous study conducted on this small-plot experiment in 2018 (Novák et al., 2019). The conclusion of that study conducted on maize crops described the relation of crop growth parameters on variant with the longer biochar effect (B15c) and the largest dose (B60). The results of the term III confirm this conclusion, since B15c is related with the B60 only. Overall the results do not prove any other significant difference between the control NPK and any of the biochar amended variants in regard to the chlorophyll content. A similar conclusion was described by Li et al. (2020), where anatomical traits such as plant height or leaf area reflected the biochar amendment rather than the physiological parameters.

CONCLUSIONS

Based on the results of this study as well as of those from the previous year, the conclusion was drawn that so far the examined substantially different doses do not have any significant influence on i) soil penetration resistance as one of the staple soil physical properties ii) neither on crop growth physiological parameters. The sole observable differences may be found by LCC when comparing the four-year biochar effect to the control and lower-doses two-year biochar variants. Thus, the time effect seems to be more staple factor compared to dosage. Since it is so, this experiment will be observed also in the following seasons to confirm this statement.

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