EFFECTIVE DOSE OF BIOCHAR WITHIN THE FIRST YEAR AFTER APPLICATION

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Abstract
Uneven spatial and temporal distribution of precipitation is becoming a major issue of modern agriculture. Biochar, as a natural soil conditioner, is supposed to modify soil properties and enhance water infiltration. Field experiment was conducted in order to evaluate the effective dose and its impact on soil and vegetation properties within the first season. Four small-scale plots were established within a maize field in 2017. Each plot was treated with a different dose of biochar. Penetration resistance measurements were carried out to indicate physical soil properties. Concurrently, the chlorophyll content and Normalized Difference Vegetation Index were estimated. Acquired data variability was calculated and evaluated in relation to results of measurement conducted on the plot that was established in 2014. A conclusion was drawn that biochar stimulates crop growth and the improvement reached by a lower amount after longer period may be substituted by a higher dose in the first season.

Key words: *maize; soil properties; chlorophyll content; spectral index; drought.*

INTRODUCTION

Nowadays, modern agriculture faces numerous challenges. Most of them are caused by rapid population growth, while the area of agricultural land is simultaneously decreasing. According to Czech Statistical Office (*2018*), more than one third of agricultural land in the Czech Republic was lost in the past 100 years. Concurrently, intensive farming systems have depleted the soil by using mineral fertilizers and various pesticides, very often in overdoses. In connection with the application of these substances, soil compaction has become increasingly serious issue. This phenomenon has had a negative effect, mainly on water infiltration (*Chyba, Kroulík, Krištof, Misiewicz, & Chaney, 2014*). It consequently reduces soil biodiversity and changes roots growth that affects a wide range of key functions staple for crop production (*Stolte et al., 2016*). The root system has a significant effect on plant health, not only the density and length of the roots, but as well the root volume and surface area, which are very important for plant growth (*Saleem, Law, Sahib, Pervaiz, & Zhang, 2018*). It is generally known that crop yields depend not only on soil fertility, but also on the alterations of physical and hydraulic soil properties (*Gülser, Ekberli, & Candemir, 2016*). Crops access to water sources during drought periods has become one of the key factors defining crop yields in the Central European region (*Žalud et al., 2017*). In the Czech Republic, drought is the second most extensive natural disaster (*Potop, Možný, & Soukup, 2012*) and therefore plans on how to prevent crop water stress status must be developed. One promising solution could be the utilization of biochar (*Fischer et al., 2019*).

Biochar is a very stable carbon-based material, which is usually produced from waste biomass during the pyrolysis process. The waste material is usually subjected to the decomposition process and thus it becomes a source of CO2 emissions. On the contrary, biochar production is considered to be environmentally clean technology, since most of the carbon is incorporated into the pyrolysis product (*Bordoloi et al., 2019*). This material is supposed to be applied directly into the soil where it acts as a soil conditioner (*Zhao & Zhou, 2019; Fang, Zhan, Ok, & Gao, 2018*). Many studies were undertaken to monitor the influence of biochar on soil properties. It was confirmed that the soil physical properties had improved, such as the decrease of penetration resistance or bulk density (*Jien, 2019*). Additionally, due to high organic content and high total pore volume, biochar increased water and nutrient retention (*Abel et al., 2013*) and also reduced the mobility of some organic and inorganic pollutants in a soil profile (*Bolan et al., 2014*). Regarding this, biochar application on an agricultural plot is beneficial and results in higher crop yields (*Agegnehu, Srivastava, & Bird, 2017*) since naturally all these soil properties benefit plant status as well. Although there are many studies about biochar and its impact on soil properties, the dosing is an issue which has not gained very much attention so far. Hence the main aim of the study was to evaluate biochar dose influence on soil and crop properties within a maize field after one year after biochar application.

MATERIALS AND METHODS

Site and crop management

The study was conducted within an agricultural plot located near the Šumperk town in the Olomouc region, Czech Republic (49° 59' 8.8296" N, 16° 59' 47.0904" E). In total 13.24 ha field was divided into plots with a variable area and also varying agricultural management. Besides biochar, the area dedicated to examining its impact on the soil and crop properties was treated by standard complex fertilizers (N, P, K). According to the FAO Soil Units, the soil type was classified as Gleyic Luvisols, which are usually developed on flat surfaces. Practically no sloping of the plot enables a wide-row crops cultivation without any erosion exposure. In the 2018 growing season, LAVENA variety of a maize crop was cultivated; sown on the 26th April 2018 and harvested on the date 27th August 2018. Biochar used for this study was produced from plant biomass and wooden waste in the Czech Republic. Tab. 1 gives technical specifications more in detail. Five small-scale plots 15 x 30 m with a different dose of microgranular biochar were examined within this study (Tab. 2), where specific doses were applied into the soil profile ± 25 cm during standard tillage in the autumn of 2017.

Tab. 1 Technical specifications of biochar used for the study

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	[%]

Tab. 2 Specific doses of biochar applied to small-scale plots under investigation and related maize yield from the 2018 growing season.

Plot code	Biochar dose [t ha^{-1}]	Year of application	Yield [t ha^{-1}]
B15c	15	2014	51.9
B15	15	2017	50.8
B30	30	2017	53.0
B45	45	2017	54.6
B60	60	2017	55.8

Weather conditions

The growing season of 2018 is generally considered extremely dry compared to past years. This drought period was caused not only by high temperatures, but also by sporadic and insufficient rainfall. These conditions had a negative impact on crop yield, specifically 30–40% loss on maize yields in the area of interest (*Intersucho, 2019*). Fig. 1 provides information about the temperature trend and Fig. 2 about precipitation during year-long time period compared to the long-term normal (1981–2010) in the Olomouc region according to the data of Czech Hydrometeorological Institute.

Terrestrial measurements and Data Analysis

On two occasions, on-site terrestrial measurements were conducted in order to acquire empirical soil and vegetation data. The first visit, the 5th June 2018, focused on the leaf development stage (BBCH 18) while the second, 3rd July 2018, concentrated on the stem elongation stage (BBCH 32).

There were 9 sampling points regularly distributed within each of the examined plots, where all measurements were focused.
Regarding the soil properties, penetration resistance (PR) data was obtained during the first field visit. Soil moisture was measured using Theta Probe (Delta-T Devices Ltd, UK). PR was measured using the registered penetrometer PEN 70 (CULS, Prague).
To determine crop condition, Leaf Chlorophyll Content (LCC) was measured using CCM 300 sensor (OptiSciences, USA) that works with proven chlorophyll fluorescence ratio (F735 nm/F730 nm), in three repetitions for each sampling point. Concurrently, a spectral index was derived based on images captured by GreenSeeker handheld sensor (Trimble, USA). This device is designed to calculate NDVI as a basic indicator of vegetation greenness.
Statistical testing on the influence of specified doses on above-mentioned variables was entirely conducted in an open-source software environment R (*R Core Team, 2018*; *Wickham, 2009*). Since the data did not meet the assumption for using one-way ANOVA, Kruskal-Wallis distribution-free test was used to evaluate the data variability.

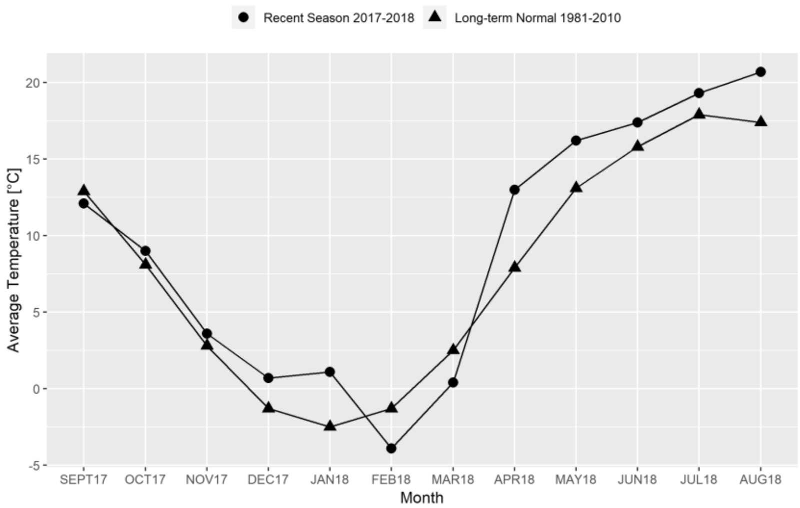

Fig. 1 Temperature conditions in the Olomouc region in the recent season compared to a long-term normal (1981–2010).

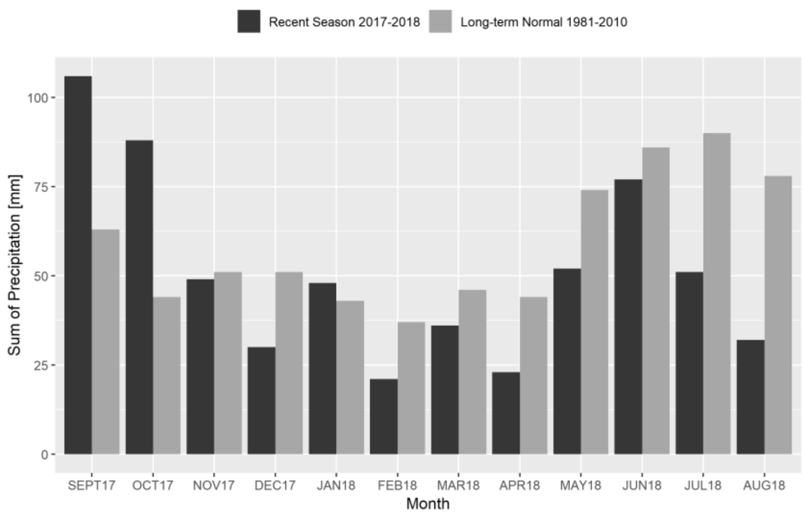

Fig. 2 Precipitation conditions in the Olomouc region in the recent season compared to a long-term normal (1981–2010).

RESULTS AND DISCUSSION

First, the influence of specified biochar doses on soil PR was examined. However, statistical analysis showed that there was no significant difference found between the examined plots. PR as a soil factor may reduce crop growth and yields in its higher values (*Colombi, Torres, Walter, & Keller, 2018*; *Haider, Steffens, Moser, Müller, & Kammann, 2017*). For maize, the top 10 cm of a soil profile is considered the most crucial due to the importance of shoot-borne nodal roots within its root system (*Colombi et al., 2018*). Since PR is a function of soil water content (*Dec, Dörner, & Balocchi, 2011*) and many studies described an increase of soil moisture when treated by biochar (*Haider et al., 2017*), the performance of this soil conditioner may not be considerable in a drought period. Nevertheless, (*Bengough, McKenzie, Hallett, & Valentine, 2011*) determined the value of 3 MPa as a threshold, since when PR becomes a limiting factor for root elongation. The data indicated that the topsoil profile values were below that critical 3 MPa threshold despite the drought period. Therefore, it is likely the short period of biochar effect produced no relevant results in terms of PR.
Regarding the impact of biochar addition on crop yield, current studies do not provide consistent results. Non-economic benefits, such as a decrease in nitrate leaching or an increase in organic carbon in a soil profile rather than direct impact on yield, are highlighted (*Aller et al., 2018*; *Haider et al., 2017*). Spectral index NDVI did not give significant statistical results. For maize, NDVI value is typically increasing during the growing season till the beginning of canopy senescence (*Verhulst et al., 2011*). Study of *Liu et al.* (*2018*) compares the performance of NDVI and chlorophyll fluorescence in periods of drought detected in winter wheat. Their conclusion supports the fact that NDVI is able to indicate a rather a long-term drought conditions, while solar-induced chlorophyll fluorescence appears to be a good indicator of the early drought period.

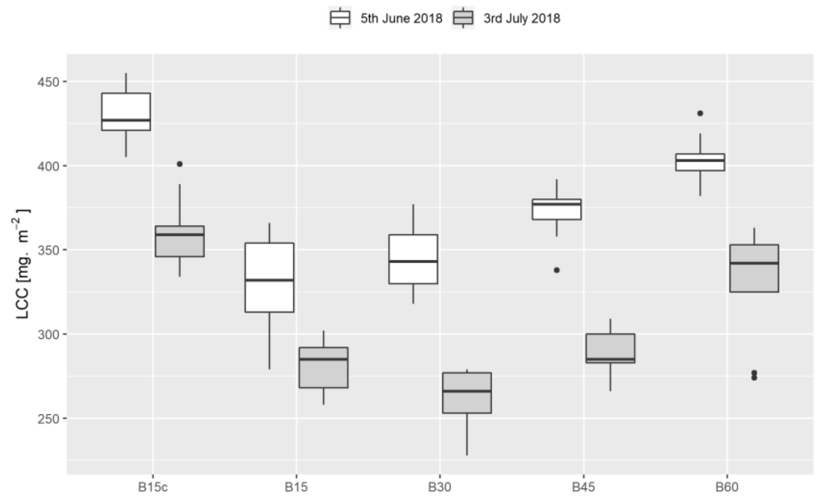

Fig. 3 Leaf Chlorophyll Content (LCC) data variability measured using CCM 300 chlorophyll meter during both field visits.

NDVI is correlated closely with LCC, regarding the study of *Cui, Li, & Zhang* (*2009*). However, in contrast with NDVI values measured in this study, LCC provided significant results for both sampling terms (Fig. 3). Nevertheless, there was no significant difference between plots B15c and B60, even though the latter plot had been treated with four times a higher dose. This, in some way, opens a discussion about the effective biochar management. *Pandit et al.*, (*2018*) conducted a three-year (six cropping seasons) field experiment in Nepal with the aim to evaluate the biochar dosage mostly from an economic perspective. According to their results, 15 t ha-1 is the optimum. Eventually, *Gavili, Moosavi, & Kamgar Haghighi (2019)* point out the fact that based on specific biochar used, higher doses may have had a negative impact on the soil salinity levels. Apparently, the time, respectively the duration of biochar effect, is also a crucial factor, since the impact of the highest dose with short effect duration (B60) on LCC levels may be considered equal to the lowest dose after four years appearance in a soil profile (B15c). Moreover, multi-year studies often describe that there is no observable effect on a crop growth until at least the second or third year (*Pandit et al., 2018*). This study, nevertheless, gained significant results (LCC) already in the first year after biochar application even though there were no alterations recorded by soil properties, very likely because of the drought period.

CONCLUSIONS

Biochar has gained a lot of attention in recent years. Besides its substantial environmental influence, since it is produced from organic waste material, it is considered to have various positive effects in the field of crop production. This study aimed to evaluate the impact of specific biochar dosage on soil properties together with the growth of maize in the first year after biochar application. Based on the results, it was concluded that biochar stimulates the crop growth. Additionally, the improvement reached by a lower dose over longer period may be substituted by a higher dose already in the first season. However, there are some concerns about the negative influence of high doses of biochar in terms of increasing soil salinity levels as well as being economically demanding. Since there are mainly non-economic benefits highlighted in the studies, such as increasing organic carbon levels or decreasing nitrate leaching, the biochar application should not be considered as a tool for increasing economic income in the first place. To better observe biochar dose effects on soil properties and crop growth alterations, a multi-year study is required. However, the influence of increasing dose on LCC may be observed already within the first year.

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