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Biochar and Biochar with N Fertilizer Impact on Soil Physical Properties in a Silty Loam Haplic Luvisol

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ABSTRACT
Recently, a lot of studies focused on the effects of biochar application to agricultural soils and its influence on the soil properties. However, only limited information is available on the simultaneous impact of N-fertilizer combined with biochar to soil physical propersies such as: soil moisture, soil temperature, bulk density and water-filled pore space. Therefore, the aim of this study was to evaluate the changes in the soil physical properties of a silty loam Haplic Luvisol affected by the biochar application and its combination with N fertilizer during the years 2014–2016 (Experimental site of SUA-Nitra, Dolná Malanta, Slovakia). The field experiment was carried out in 2014 with different biochar application doses (0, 10 and 20 t ha^{-1}) and different rate of N fertilization (0, 1st and 2nd level of N fertilization). The results showed that the both biochar amendment and biochar with N fertilizer increased the soil moisture in the range of 1 to 15%, on average. The higher rate of biochar resulted in higher soil moisture in all treatments with biochar in the following order B0 (14.9) < B10 (15.1) < B20 (16.2) as well as in biochar in combination with N fertilization: B0N1 (14.6) < B10N1 (15.7) < B20N1 (16.2) as well as B0N2 (14.8) < B10N2 (15.8) < B20N2 (16.0) during the years of 2014–2016. A positive trend of water-filled pore space increase by the time in all studied treatments was observed. No significant changes in the average soil temperature were observed between the biochar and biochar with N fertilization treatments during the growing seasons of individual years. The higher rate of biochar resulted in lower soil bulk density in all treatments with biochar in combination with N fertilization in the following order: B0N1 (1.49) > B10N1 (1.47) > B20N1 (1.44) as well as B0N2 (1.51) > B10N2 (1.47) > B20N2 (1.39) during years the studied period (2014–2016).

Keywords: biochar; soil moisture; soil temperature; bulk density; N fertilization

INTRODUCTION

Fertilization has become an essential part of modern agriculture, because it is an important source of available nutrients that are essential for plant metabolism, which can provide adequate crop yields of suitable quality [Gu et al. 2004]. However, fertilization is not only about supplying plants with nutrients. The chemical, biological and physical soil properties can also be modified/improved through fertilizers, additives, etc. Nowadays, in addition to monitoring the changes in soil chemistry, a lot of farmers pay attention to the changes in the soil physical properties. Kotorová and Šoltýsová [2011] state that the favourable soil physical properties are currently becoming a target at which agricultural measures should be directed, as their deterioration indirectly affects both the crop production and the economy. Several studies [Edwards and Lofty 1982, Schjonning and Christensen 1994] pointed at the beneficial effects of fertilization in terms of increasing crop yields, but at the same time improving soil water retention, increasing porosity, improving soil structure and reducing bulk density. In the soils with natural high humus content where only mineral fertilization is practiced, it declines [Turski et al. 1980], with a subsequent deterioration of the soil physical characteristics [Campbell et al. 1999]. There is a close relationship between the soil organic matter and soil physical properties [Zeyin and Baran 2003]. However, the long-term effects of the mineral fertilizers application focusing on the changes in the soil properties under different environmental conditions have only begun to appear in the scientific studies over the recent years [Chen et al. 2014, Yang 2011]. These studies mainly focused on optimizing the mineral fertilizer dose depending on the improvement of soil structure, porosity, infiltration of water into the soil on one hand, with relation to soil organic matter balance on the other [Niu et al. 2011]. The problem in the Slovak Republic today involves observing the of organic substances balance in the soils. This problem is mainly related to the decline in the livestock population and poor land management (e.g. absence of crop rotation, non-cultivation of forage crops, non-cultivation of intercrops, removal of crop residues). One of the current alternatives could be biochar application to soils. It is because the recent studies have shown the agronomic potential of biochar (the solid product produced from pyrolysis) in numerous types of soils over the world [Jeff ery et al. 2017, Horák et al. 2017, Faria et al. 2018, Figueiredo et al. 2018, Igaz et al. 2018, Horák 2015, Kondrlová et al. 2017, Šimanský et al. 2018]. The productivity is likely a consequence of increased nutrient contents and water retention, raising the soil pH and improving soil porosity [Hossain et al. 2010, Méndez et al. 2013, Faria et al. 2018]. Biochar can also improve the biological properties of soil [Paz-Ferreiro et al. 2012] and increase crop yields [Jeff ery et al. 2017, Faria et al. 2018, Figueiredo et al. 2018].

The long-term field studies on the effect of biochar and biochar combined with N-fertilizer on soil physical properties such as soil moisture, soil temperature, bulk density and water filled pore space are still rare. Therefore, the aim of this study was to quantify the effect of biochar and biochar combined with N fertilization on the physical properties of a silty loam (Halpic Luvisol). We hypothesize that the higher rate of biochar will improve the soil physical properties in comparison to the lower dose and we also expect that the positive effect will decline in time after its application to soils.

MATERIAL AND METHODS

The field experiment was carried at the experimental site of the Slovak University of Agriculture Nitra, Dolná Malanta Nitra (48°19′00″ N; 18°09′00″ E). The site is in the temperate region with the mean annual air temperature of 9.8°C and average precipitation amounting to 540 mm (30-year climate normal, 1961–1990). The soil was classified as Haplic Luvisol [IUSS WRB 2014] with soil organic carbon content of 9.13 g kg^{-1}, with pH of 5.71 and silt loam soil texture.

The biochar experiment was established in March, 2014 (Figure 1) and included the vegetation periods of the spring barley (*Hordeum vulgare* L.) in 2014, the maize (*Zea mays* L.) in 2015 and the spring wheat (*Triticum aestivum* L.) in 2016. The studied treatments are explained in Table 1. Nine treatments with three replicates (total of 27 experimental plots, 4×6 m) were arranged

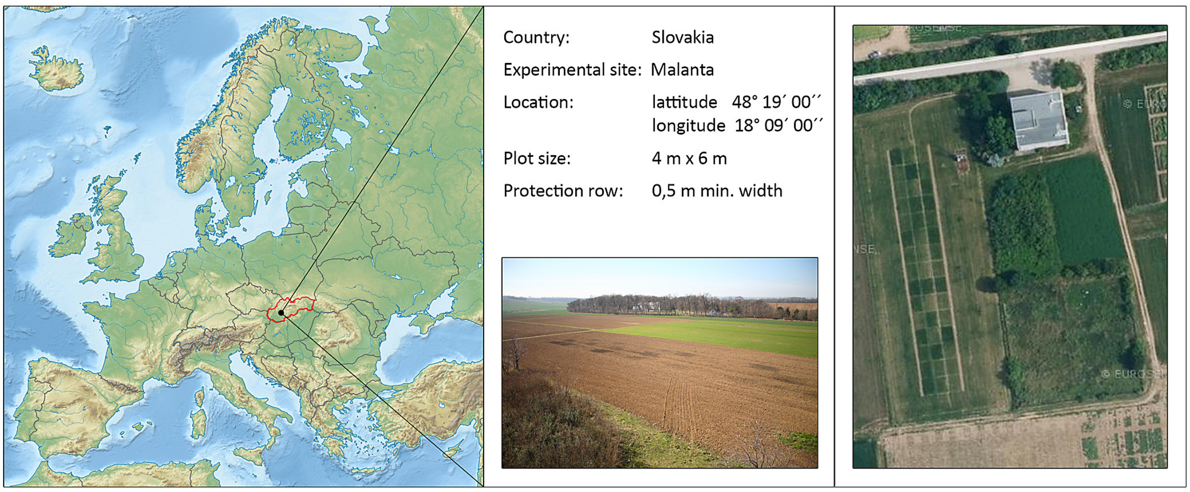

Figure 1. Experimental field and areal view on the individual biochar applications

Table 1. The investigated treatments

Treatment	Description
B0N0	no biochar, no N fertilization
B10N0	biochar at rate of 10 t ha^{-1}
B20N0	biochar at rate of 20 t ha^{-1}
B0N1	no biochar combined with first level of N fertilization: dose of N were, 40, 160 and 100 kg N ha^{-1} in 2014, 2015 and 2016, respectively.
B10N1	biochar at rate of 10 t ha^{-1} with N: dose of N were, 40, 160 and 100 kg N ha^{-1} in 2014, 2015 and 2016, respectively.
B20N1	biochar at rate of 20 t ha^{-1} with N: dose of N were, 40, 160 and 100 kg N ha^{-1} in 2014, 2015 and 2016, respectively.
B0N2	no biochar combined with second level of N fertilization: dose of N were, 80, 240 and 150 kg N ha^{-1} in 2014, 2015 and 2016, respectively.
B10N2	biochar at rate of 10 t ha^{-1} with N: dose of N were, 80, 240 and 150 kg N ha^{-1} in 2014, 2015 and 2016, respectively.
B20N2	biochar at rate of 20 t ha^{-1} with N: dose of N were, 80, 240 and 150 kg N ha^{-1} in 2014, 2015 and 2016, respectively.

in a randomised block design separated by 0.5 m wide protection strips. The biochar and N-fertilizers were evenly applied to the soil surface and incorporated into the 0–10 cm soil layer. The biochar used in this experiment was commercially available at Sonnenerde Company, Riedlingsdorf, Austria. The biochar was produced by pyrolyzing paper fiber sludge and grain husks (in a 1:1 per weight ratio) at 550°C for 30 min in a Pyreg reactor (Pyreg GmbH, Dörth, Germany). On average, it contained 53.1% of C, 1.4% of N, 38.3% of ash and the C:N ratio of 37.9 with the particle size of biochar between 1–5 mm. The pH of the biochar was 8.8 with the specific surface area (SSA) of 21.7 m^2 g^{-1}. The N-fetilizers used in fertilized treatments was Calc-Ammonium nitrate with dolomite (LAD 27).

Soil sampling for determination of the soil moisture (w) (determined gravimetrically) was conducted for all treatments from the soil depth of 0–10 cm during the growing seasons of individual crops over years 2014–2016. The soil temperature was measured by means of (thermometer Volcraft DET3R) in soil depth 5 cm, also during the crop growing seasons. Bulk density (BD) was determined twice a year during spring and autumn sampling in undisturbed soil samples (sampled to steel core in volume 10 cm^3 from the depth of 2–7 cm). The volumetric water content of soil (Θ) was calculated using the water content data and the bulk density of soil. The water filled pore space (WFPS) on each experimental area was then calculated from the soil volumetric water content and the bulk density assuming that the specific soil density was 2.65 g cm^{-3}.

The individual parameters of the soil physical properties (Haplic Luvisol) were evaluated by statistical analysis of the Statgraphic Centurion XV Program I. (Statpoint Technologies, Inc., USA) using ANOVA one-way analysis. LSD test with a significance level of α=0.05 was peformed to compare the effect of biochar and biochar with N fertilization on soil physical properties.

RESULTS AND DISCUSSION

Both solo biochar amendment and biochar combined with N fertilizer increased average soil moisture (w) in the range of 1 to 15% compared to the individual control treatments during the years 2014–2016 (Figure 2). Hovewer, a significant increase was found only for B20N0 treatment compared to control (B0N0) in 2014 as well as for B20N2 compared to control (B0N2) in 2016. At the same time, it was found that w values increased along with the application rate of biochar in all years (2014–2016) in the folowing order B0 <B10 <B20 in all treatments with biochar but also with biochar and N fertilization. On the other hand, the above-mentioned trend was not observed in B10N0 compared to B0N0 as well as in B20N2 compared to B10N2 in the following year (2015). Our findings regarding to soil moisture are consistent with current studies of several autors [Barrrow 2012, Agegnehu et al. 2015, Leelamanie 2014, Liyanage and Leelamanie 2016, Igaz et al. 2018], who suggest that the organic matter inputs to the soils increase the water retention capacity of the soil. The positive effect of organic matter is explained as follows: the organic matter has a high sorption capacity and the swelling ability that results in an increase in the total porosity of the soils. Soil organic

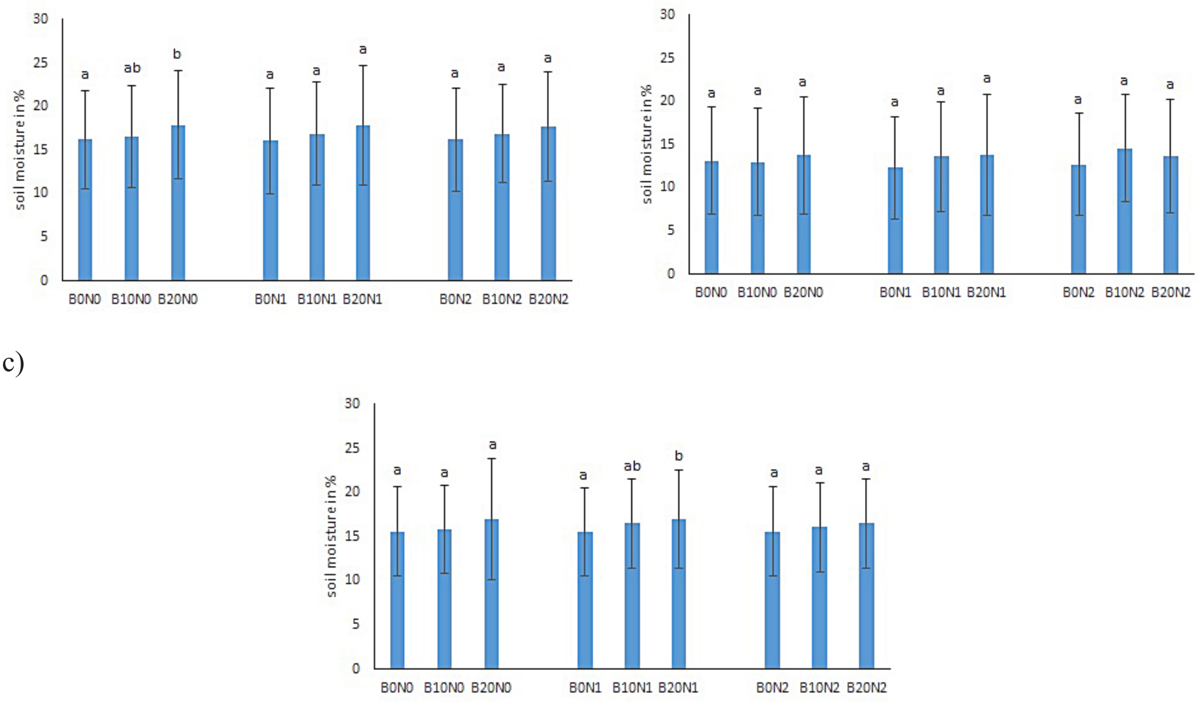

Figure 2. Effect of biochar on soil moisture A) in 2014, B) in 2015, and C) in 2016

matter (SOM) can retain large amount of water, in some cases up to 20-times their own weight, and in the case of biochar – 11-times its weight [Kinney et al. 2012]. This is primarily due to the solid structure of the biochar, which means that its swelling capacity is much lower than SOM. Improvement of soil moisture after biochar application is caused partly indirectly (e.g. due to improve soil structure), but also due to direct effects such as the biochar capacity to retain water. Biochar with its large surface area and a large number of micropores, alters the average surface area of the soil, the pore size distribution, and thus the water retention capacity of the soil [Chintala et al. 2014]. Incorporation of biochar into the soil can increase the specific surface area up to 4.8-times and can also enhance the volume of capillary pores compared to the soils without biochar application [Liang et al. 2006]. The higher rate of biochar resulted in higher w values in all treatments with solo biochar B0 (14.9) < B10 (15.1) < B20 (16.2). The same was found when biochar was applied with lower level of N fertilization: B0N1 (14.6) < B10N1 (15.7) < B20N1 (16.2) as well as with higher level of N fertilization B0N2 (14.8) < B10N2 (15.8) < B20N2 (16.0) during the years of 2014–2016.

Generally, the solo application of biochar and biochar together with N fertilization (except B10N0 treatment) decreased the water filled pore space (WFPS) (insignificantly) in 2014 (Figure 3). The WFPS values were significantly reduced (17%) in treatment B20N1 compared to B0N1. The application of biochar and biochar in combination with higher level of N fertilization did show any significant effect on WFPS values in the second year (2015) after the start of the experiment. However, the opposite was found between B10N1 and B20N1 treatments (significant differences in WFPS values). The results of the last year (2016) showed an ambiguous trend compared to the treatment with no biochar (control). A significant reduction of WFPS values was determined in B10N0, B20N1 and B20N2 treatments, compared to their controls (B0N0, B0N1, B0N2). On the other hand, a statistically significant increase of the WFPS values were observed in B20N1 and B10N2 in comparison to B0N1 and B0N2, respectively. Generally, a positive trend of WFPS values increasing through the time was found (the lowest WFPS values in 2014 and the highest in 2016). These results showed an improvement of the soil saturation with water after biochar and biochar with N fertilization and the its effectiveness increased through the time after its application.

The content of water in soil is closely related to the soil temperature. We assumed that the average soil temperature during the growing season in each year would increase due to the

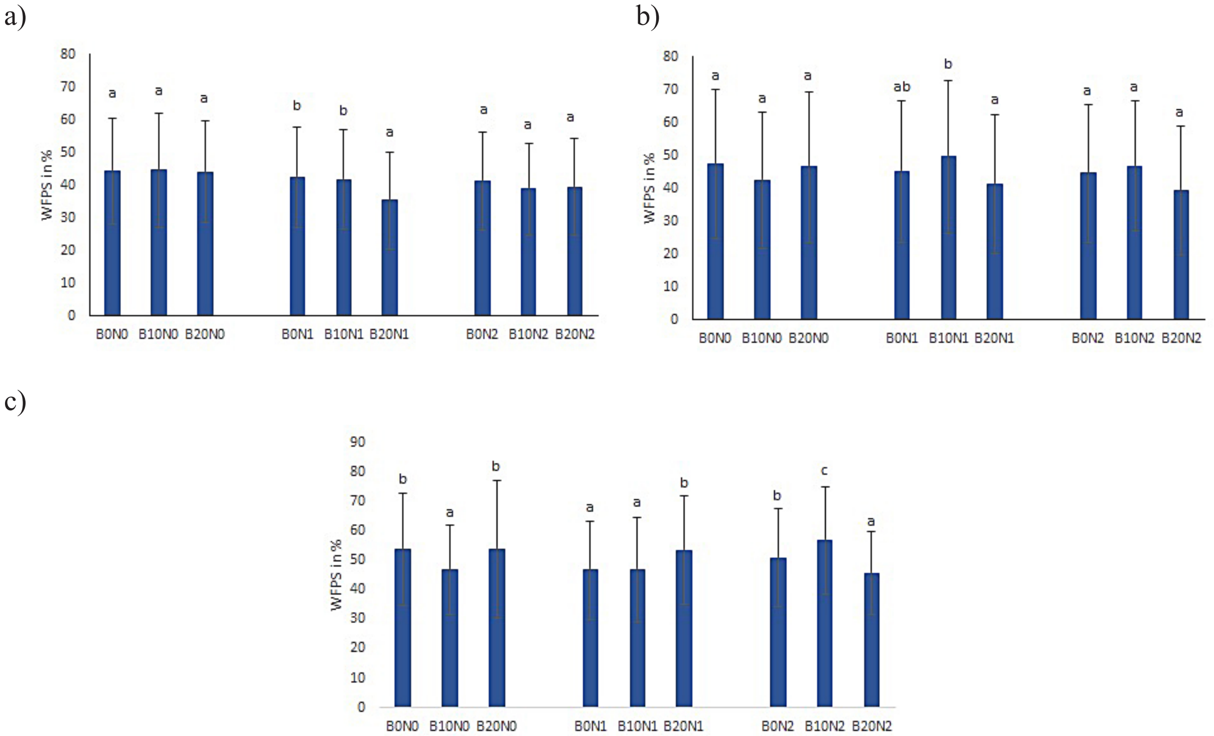

Figure 3. Effect of biochar on water filled pore space A) in 2014, B) in 2015, and C) in 2016

application of biochar and the biochar in combination with N, not as a result of biochar decomposition but as a result of soil colour intensification. Soil is not significantly heated from the decomposition of organic matter and the heat that is released slowly in the form of gases is not measurable [Fulajtár 2006, Šimanský et al. 2018]. Soil acts as a transformer because it transforms the solar energy into the thermal energy. At the same time, it is the accumulator of this energy and the temperature regime regulator of the soil layers. The heat adsorption of the surface of the soil depends on the elevation, relief, exposure of slopes, vegetation, soil structure, porosity, humidity, vapor, heat capacity and conductivity of the individual soil components. Vegetation and incorporated crop residues on the soil surface are insulating because they reduce both direct heating and radiant heat from the soil. The dark and lumpy surface absorbs more heat than a light and smooth surface [Šimanský et al. 2018]. Vítková et al. [2017] reported that the crop yields increased after the biochar application due to the fact that the soil surface where the biochar was applied was darker (Figure 1), which intensified the absorption of the Sun rays with a consequent increase in the soil temperature. Our results did not confirm this (Figure 4), since no statistically significant changes in the average soil temperature were observed between the different biochar and biochar with N fertilization treatments during the individual growing seasons.

Biochar and biochar with N fertilization decreased bulk density of soil (BD) analysed at the begining as well as at the end of growing season (GS) in 2014 and 2015 in comparison to respective controls without biochar (Figure 5). However, significant differences in BD was determined between B20N1 and B0N1 at the beginning of GS in 2014 as well as between B10N2, B20N2 treatments and B0N2 at the beginning of GS in 2015. The BD value in B20N2 decreased by 8% compared to B0N2 (control) at the end of GS of the last year (2016). The higher rate of biochar resulted in a lower BD values in all treatments with biochar in combination with N fertilization: B0N1 (1.49) > B10N1 (1.47) > B20N1 (1.44) as well as B0N2 (1.51) > B10N2 (1.47) > B20N2 (1.39) during the years of 2014–2016. This finding is in line with several studies that indicated that the bulk density has been reduced after the biochar application to the soil [Schnell et al. 2012, Case et al. 2012, Zhang et al. 2010, Igaz et al. 2018]. The decrease of BD values can be explained by the lower density of biochar particles (0.2 g cm^{-3}) applied to the soil compared to soil density of sandy (2.65 g cm^{-3}) and loamy-clay (2.35–2.70 g cm^{-3}) soils (Biochar in European Soils and Agriculture: Science and Practice).

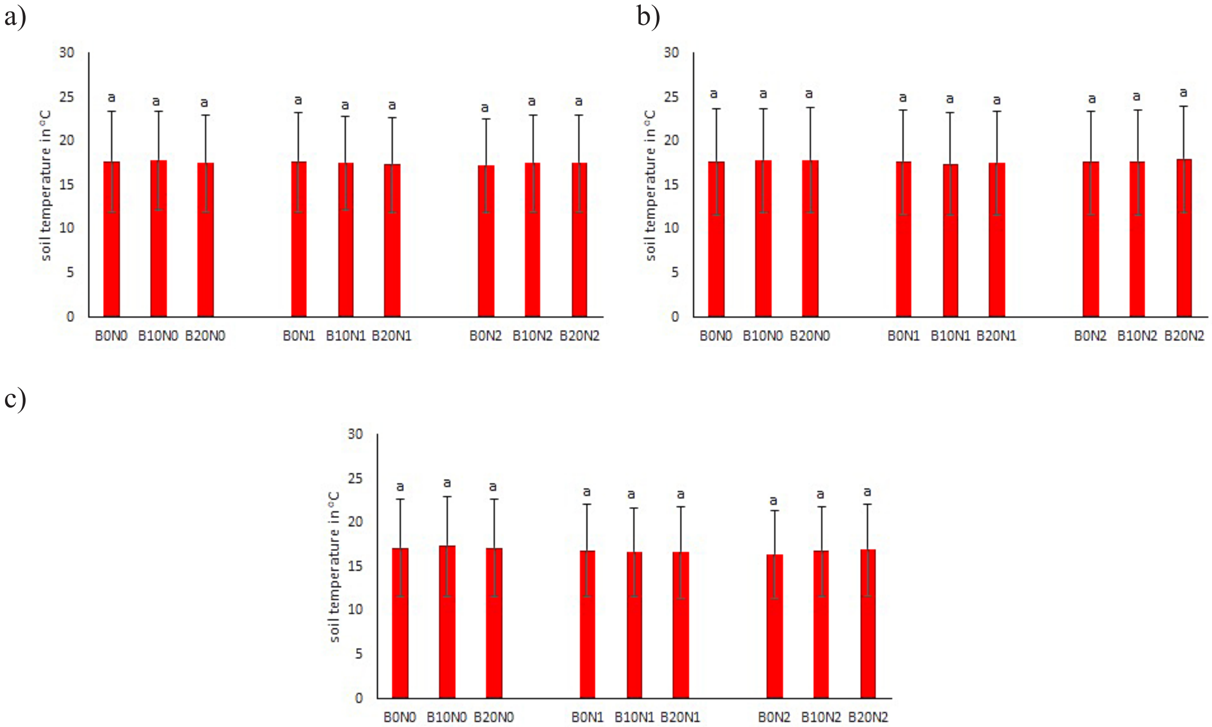

Figure 4. Effect of biochar on soil temperature A) in 2014, B) in 2015, and C) in 2016

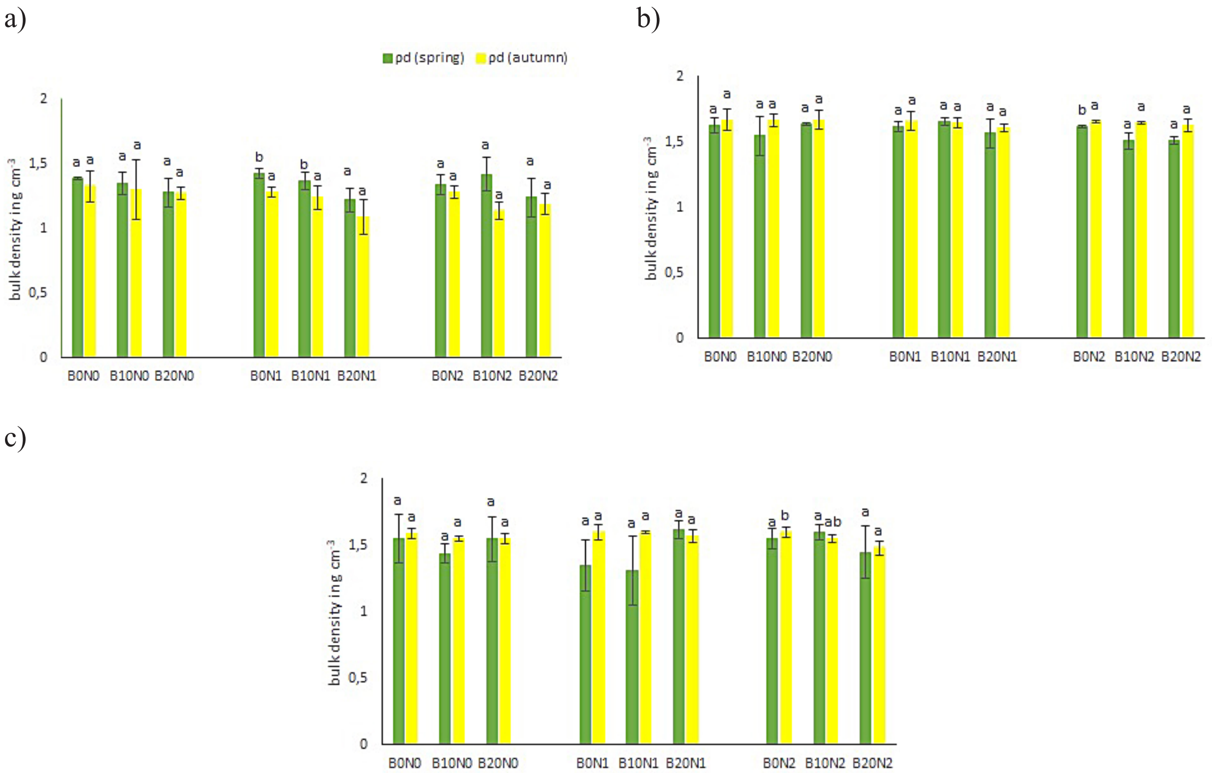

Figure 5. Effect of biochar on soil bulk density A) in 2014, B) in 2015, and C) in 2016

CONCLUSION

The application of biochar into the soil had a positive effect on the reduction of soil bulk density, which is related to the specific density of the biochar itself that is significantly lower than the specific soil density. At the same time, the results pointed at the fact that the average soil moisture was increased after the addition of biochar and this effect was even more pronounced with the increasing application rate of biochar. This positive increase in soil water content after the application of biochar is attributed to the large surface area of the biochar with a large number of micropores, which in turn alters the average soil surface area, pore size distribution and thus the retention water capacity of the soil. Our results showed an improvement of soil saturation with water after the application of biochar and the biochar with N fertilization; the effectiveness increased in time after its application.

On the basis of the above-mentioned information, the application of biochar to soil, either alone or in combination with N fertilization, appears to be a promising tool for improving the sustainability of intensive farming throught the enhancement of soil physical properties (improved soil retention and soil structure and decreased soil bulk density).

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