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IMPACT OF OAK WOOD BIOCHAR AND NITROGEN FERTILIZER ON SOIL PROPERTIES AND MAIZE BIOMASS GROWTH

Maya Benkova[1*], Lyuba Nenova[1], Tsetska Simeonova[1], Vera Petrova[2], Angelina Mikova[1], and Irena Atanassova[1]

[1]Agricultural Academy, 'N. Poushkarov' Institute of Soil Science, Agrotechnology and Plant Protection, 7 Shosse Bankya Str., 1330 Sofia, Bulgaria. E-mails: majaben@abv.bg*, lyuba_dimova@abv.bg, cecka_simeonova@abv.bg, an15mi011@gmail.com, i.d.atanassova@abv.bg
[2]University of Forestry, Faculty of Agronomy, 14 Anton Naidenov Str., Studentski grad, Building D, 1700 Sofia, Bulgaria. E-mail: vera_zamfirova@abv.bg

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Abstract

The aim of study was to investigate the effect of wood biochar in combination with nitrogen fertilizer on soil properties and maize biomass. The experiment was conducted at the Tsalapitsa field (Plovdiv, Bulgaria) on Fluvisol. A randomised block design was established – three rates (0, 5 and 10 $t \cdot ha^{-1}$) of biochar and two rates (130 and 260 $kg \cdot ha^{-1}$) of N fertiliser (ammonium nitrate). Each treatment was in four replications. Biochar was obtained by pyrolysis (400 ºC) of oak bark. The plant samples (leaves, stems, cobs) were taken in three phases of maize growth. The soil samples were taken during growing period and after maize harvesting. The results showed that treatments with biochar in the presence of N fertilizer significantly increased yields in maize growth ($p \leq 0.05$) compared to the variants with fertilizer only. Greater positive effect of biochar application was observed in the combination of low-rate biochar (5 $t \cdot ha^{-1}$) and low rate of fertilizer (130 $kg \cdot ha^{-1}$) on crop biomass in different growing stages compared to controls and the variant with high N and low biochar rates (increases were +24 % and +44 %, respectively). Slight increases in pH, organic carbon and cation exchange capacity in the variants with both rates of biochar and low level of mineral fertilization were observed in the Fluvisol. When N fertilizer was applied at high rate, soil pH decreased (0.5–0.7 units) and exchangeable Al (1 $cmol \cdot kg^{-1}$) appeared due to the fertilizer acidifying effect. The pH in these variants is not a limiting factor for maize production.

Key words: cation exchange capacity, N fertiliser, oak peels, pH, rich carbon amendment.

Introduction

The increasing anthropogenic impacts, such as incorrect agricultural practices (including unbalanced nitrogen fertilization), result in disturbing arable lands. They have a significant effect on the environment, which is a precondition for a number of environmental risks, such as soil acidification, surface and ground water pollution, etc. A successful method for solving the above-mentioned problems is the use of biochar (BC) as soil organic amendment because of its physical and chemical characteristics (pH, high porosity, large surface area). Biochar is a final product of biomass burning at the absence of oxygen in the pyrolysis process.

A number of experiments have studied the maize growth responses to biochar, as a soil improver without additional organic or inorganic fertilization. In most of them, the application of biochar increased the yield of maize compared to the control (Islami et al. 2011, Sukartono et al. 2011, Cornelissen et al. 2013). Recently, some studies have noted its effect on soil fertility when combined with fertilizers by studying the chemical changes in soil, and effects on plants (Schulz et al. 2013, Glaser et al. 2015, Oladele et al. 2019, Akolgo et al. 2020). Another effect is improvement of soil physicochemical properties, including increasing soil pH, CEC and organic carbon (Paz-Ferreiro et al. 2014, Gao et al. 2016, Hussian et al. 2016). Biochar potential for increasing soil pH of acidic soils is demonstrated in many studies (Novak et al. 2014, Xu et al. 2014). Biochar application depends on soil type, biochar feedstock, biochar pyrolysis temperature, soil properties, plant species and the environmental and experimental conditions (Sohi et al. 2010, Al-Wabel et al. 2018, Muhammad et al. 2018). The application of biochar in fertile, alkaline soils in temperate climatic region is not so efficient (Karer et al. 2013, Jeffery et al. 2017), as adverse effect on yield were observed even at high biochar application rates. In a study involving the use of organic wood charcoal in the production of corn and grass in Wales, soil pH rose by 0.32 over two years (Jones et al. 2012), while electrical conductivity, soil moisture, total N, soluble C, soluble N, available P, exchangeable Na and Ca were not significantly affected by biochar compared to controls. Kloss et al. (2012) compared biochar produced from three raw materials pyrolyzed at different temperatures and found that the two wood-based biochars have lower concentrations of soluble elements, which are not suitable for use as soil fertilizer. Woody charcoal contains less degradable C than other biochars (Lehmann et al. 2006, Nelissen et al. 2015).

In our study we used locally produced wood biochar from oak (*Quercus* spp.) peels, which has the potential to improve soil properties, increase soil nutrient availability and crop biomass in a slightly acidic, loam sandy Fluvisol. The aim of the study was to investigate the effect of wood biochar in combination with nitrogen fertilizer on soil properties and maize biomass.

Materials and Methods

An experiment was conducted at the experimental field of Institute of Soil Science, Agrotechnology and Plant Protection ‘Nikola Poushkarov’ in the village of Tsalapitsa, Plovdiv region (42°10.8’ N, 24°32.5’ E) and climatic region of Eastern Central Bulgaria with suitable conditions for maize growing. The soil type is Alluvial-meadow soil (Fluvisol), which is slightly acidic, with light texture, low content of total N (0.072 %) and organic carbon (0.70 %). Oak woodchip biochar, produced through pyrolysis at 400 °C, was selected for this field study (Table 1).

A randomised block design was established with three levels of вiochar (0, 5 and 10 $t \cdot ha^{-1}$) and 2 levels of N (ammonium nitrate) fertiliser (130 and 260 N $kg \cdot ha^{-1}$). Each biochar level was tested

Table 1. Basic characteristics of the Fluvisol and biochar.

Soil and biochar	pH H_20	min N, $mg \cdot kg^{-1}$	P_2O_5	K_2O	CEC	exch. Ca	exch. Mg	OC, %
			$mg \cdot 100g^{-1}$		$cmol \cdot kg^{-1}$			
Fluvisol	6.1	20.2	17.1	22.4	16.7	11.5	1.8	0.70
BC	9.7	72.0	43.4	499.6	10.3	7.5	2.8	49.0

against each N level. Each treatment was in four replications. Maize hybrid 9903-X299 (according to FAO 430) was used with a plant density 85,000 plants·ha^{-1}. The area of the experimental plot of one variant was 25.2 m^2. The treatments were the following:

- Variant B_1 – K1N130 – control without BC and 130 kg·ha^{-1} nitrogen fertilization;
- Variant B_2 – B5N130 – with 5 t·ha^{-1} BC and 130 kg·ha^{-1} nitrogen fertilization;
- Variant B_3 – B10N130 – with 10 t·ha^{-1} BC and 130 kg·ha^{-1} nitrogen fertilization;
- Variant B_4 – K2N260 – control without BC and 260 kg·ha^{-1} nitrogen fertilization;
- Variant B_5 – B5N260 – with 5 t·ha^{-1} BC and 260 kg·ha^{-1} nitrogen fertilization;
- Variant B_6 – B10N260 – with 10 t·ha^{-1} BC and 260 kg·ha^{-1} nitrogen fertilization.

Phosphorus fertilization (300 kg·ha^{-1}) was done in autumn as triple superphosphate, and potassium fertilization was not applied due to the good soil supply. The biochar and nitrogen fertilizer were spread on the topsoil and were incorporated into the soil (to a depth about 0.20 cm) with a cultivator before maize sowing. Soil samples were taken during maize development (in phenophase ‘10–12th leaf‘– about 45 days after the biochar and nitrogen fertilizer application) and after harvesting. Plant samples were taken from all variants of the experiment in dynamics (in three replications) in the following phenophases: ‘10–12th leaf‘; ‘Tasseling‘, ‘Milky-wax ripeness‘, the absolutely dry biomass was determined. After drying the plant biomass to an air-dry weight, the plant samples were weighed, and the plant production was estimated.

The physicochemical soil properties were determined by the method of Ganev and Arsova (1980). Soil organic matter content and composition were obtained by a modified method of Turin (oxidation with dichromate and H_2SO_4 in a thermostat at 120 °C, 45 min., Ag_2SO_4 catalyst and back titration with $(H_4)_2SO_4.FeSO_4.6H_2O$ and Kononova-Belchikova method (Kononova 1966, Filcheva and Tsadilas 2002). Mineral nitrogen by the method of Kjeldahl (Methods of Soil Analysis 1982) and available P and K following the methods of (Ivanov 1984) were assessed.

Results and Discussion

Physicochemical characteristics

According to the physicochemical analysis of Alluvial-meadow soil in the experimental field Tsalapitsa, it can be classified as slightly acidic (pH = 6.1). The level of colloidal reactivity in the source soil according to the cation exchange capacity (CEC = 16.7 cmol·kg^{-1}) is defined as low. At a degree of base saturation of 78 %, the content of basic cations is about 68 % Ca and 11 % Mg in the source soil (Table 2). Monmorillonite - ilite minerals predominate (CECsa = 11.8 cmol·kg^{-1} about 71 % CEC), according to the size of the strongly acidic positions in the soil (Ganev 1990).

Table 2. Soil physicochemical characteristics by variants during development and after harvesting of maize.

Variants	pH	CEC	CEC_{SA}	CEC_A	exch. $H_{8.2}$	exch. Al	Ca	Mg	BS, %
		cmol·kg^{-1}							
Fluvisol	6.13	16.7	11.8	4.9	3.7	0	11.5	1.8	78.03
In the stage '10–12th leaf'									
B_1 (K1N130)	5.80	17.1	13.8	3.3	3.5	0.2	11.8	1.8	79.53
B_2 (B5N130)	5.30	16.8	14.2	2.6	3.5	0.9	11.2	1.9	79.17
B_3 (B10N130)	5.70	17.0	14.4	2.6	2.8	0.2	12.2	1.8	83.53
B_4 (K2N260)	4.90	17.0	13.3	3.7	4.8	1.0	10.3	1.7	71.77
B_5 (B5N260)	5.20	16.8	14.1	2.7	3.6	0.9	11.2	1.8	78.57
B_6 (B10N260)	6.70	17.2	14.7	2.5	1.6	0.0	14.0	1.8	90.70
After harvesting									
B_1 (K1N130)	6.15	18.0	14.5	3.5	2.3	0.0	14.3	1.70	87.2
B_2 (B5N130)	6.15	18.3	14.7	3.6	2.3	0.0	14.5	1.70	87.4
B_3 (B10N130)	6.15	18.3	14.7	3.6	2.2	0.0	14.6	1.70	85.0
B_4 (K2N260)	5.50	17.2	14.2	3.0	3.2	0.4	12.0	1.80	81.4
B_5 (B5N260)	5.70	17.9	15.1	0.8	3.0	0.3	13.5	1.70	83.2
B_6 (B10N260)	5.70	17.7	14.9	2.8	3.1	0.3	13.0	1.70	82.5

Note: CEC_{SA} – capacity value of strongly acidic ionexchanger of soil colloids; CEC_A – capacity value of weakly acidic ionexchanger; exch. $H_{8.2}$ – total acidity, exch. Al – exchangeable acidity.

Data about pH values of the Alluvial-meadow soil during the phase '10–12th leaf' of maize development (45 days after the nitrogen fertilizer and biochar application) and these after corn harvest are shown in Table 2. The application of nitrogen fertilizer only at a lower rate (N130) causes a slight acidification (up to 5.8 pH), which at the end of the experiment increases to 6.2 pH. The higher N rate (260 kg·ha^{-1}) acidifies soil to ~4.9 pH, but after corn harvesting this value rises to 5.5. Application of the low dose of N 130 kg·ha^{-1} in combination with the two rates of biochar mitigates soil acidification and at the end of the field experiment the value of pH is 6.2. A consequence of a combination of a high dose of nitrogen with a high dose of biochar was a short-term increase of this index (pH 6.7), but at the end of the experiment a decrease within 1.0 unit was observed.

Similar results were also obtained by Mukhina et al. (2019), where they used biochar of woody origin at a rate of 5 t·ha^{-1} in combination with 90 kg·ha^{-1} N fertilizer on Spodosol. Biochar can adsorb nitrogen from the applied fertilizer and reduce the acidity at the beginning of the experiments, but over time nitrogen is slowly released from BC, which can lead to a decrease in soil pH. The combination of biochar with nitrogen fertilizer leads to an increase in pH after the end of the experiment, but both doses (BC) are insufficient to neutralize the soil acidity caused by the high dose of fertilizer. Karer et al. (2013) observed a similar decrease in pH when applying a high rate of 72 t·ha^{-1} BC and a nitrogen fertilizer dose of 150 kg·ha^{-1} after a first year of a sunflower experiment on a Chernozem soil. After maize cultivation, an increase in the exchange capacity is observed in the variants, compared to the CEC during the maize development, when the values did not change or slightly increased. The values after harvesting are higher (CEC 18.0–18.3 cmol·kg^{-1}) in the variants with a low rate of nitrogen fertilizer. During the experiment in almost all the variants, low exchange acidity between 0.2 and 1.0 cmol·kg^{-1} (Table 2) is observed due to the acidifying effect of the nitrogen fertilizer.

After corn harvesting, the application of the low dose of nitrogen only, as well as in combination with biochar, is relatively effective and the exchange acidity is not observed (exch. Al = 0 cmol·kg^{-1}). The total acidity tends to decrease and fluctuates between 1.6–4.8 cmol·kg^{-1}. Lower values of total acidity are maintained in the soil during the experiment, except for variant B_4 (K2N260) (exch. $H_{8.2}$ 4.8 cmol·kg^{-1}). In this variant, the amount of Ca is also the lowest (10 cmol·kg^{-1}). There is a certain tendency for Ca increase in the variants after maize harvesting, especially at the low nitrogen rate in combination with the two doses of biochar, which is reflected in the higher values of base saturation. The Mg content does not show significant differences in CEC either in variants or during sampling.

Alluvial-meadow soils are defined as the most vulnerable to nitrogen loading, which causes a change in the acid-base balance and leads to pollution of shallow groundwater with nitrates. Therefore, the application of nitrogen fertilizer in combination with biochar is effective because it improves the physicochemical status of the soil (increase in pH, basic cations, absence of exchange aluminum and increase in cation exchange capacity) compared to the use of nitrogen fertilizers only.

Agrochemical characteristics of Alluvial-meadow soil before and after the field experiments

It is well known that the processes of permanent acidification are most pronounced in carbonate-free soils with low sorption capacity, relatively low organic matter content and leaching water regime, as is the case with the Alluvial-meadow soil from the area of the experimental field in the village of Tsalapitsa, Plovdiv region. The content of mineral nitrogen is low (20.2 mg·kg^{-1}), the soil is low in P (P_2O_5 17.1 mg·100g^{-1}) and has moderate K content (K_2O 22.4 mg·100g^{-1}) (Table 1).

Mineral nitrogen content

The samples taken for agrochemical analysis during maize cultivation (in stage ’10–12th leaf‘) show that the differences in the mineral nitrogen content in all variants depend on the fertilization doses and the combination with the two doses of biochar (Fig. 1). More significant differenc-

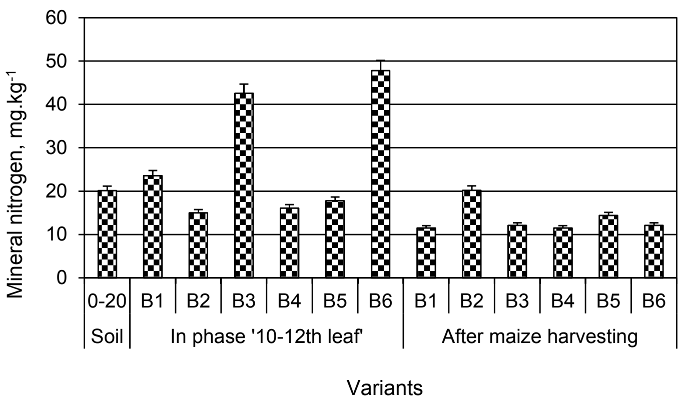

Fig. 1. Content of mineral nitrogen in Alluvial-meadow soil by variants in maize cultivation.

es are observed in the combination with the higher rate of biochar – variants B_3 (B10N130) and B_6 (B10N260), where the values reach 42–47 mg·kg^{-1}. In the other variants, the nitrogen content decreases in the ranges of 15 and 17 mg·kg^{-1}. Only in the variant B_1, with a low dose of N (130 kg·ha^{-1}), the content remains in the range of 23 mg·kg^{-1}, as in the control soil.

The results for the content of mineral nitrogen after maize harvesting (Fig. 1) show that within the experiment N decreases in the range between 11.0 and 14.4 mg·kg^{-1}, but the variant differences are not kept, even some alignment is observed. An exception is variant B_2, where the value of N is 20 mg·kg^{-1}. The results for the content of mineral nitrogen in the Alluvial-meadow soil in maize cultivation show that the application of high doses of BC improves the content of mineral nitrogen in the soil in the initial phase of maize development (45 days after application) in combination with nitrogen fertilizer. Intensive growth processes follow, in which a large part of the nitrogen content in the soil is consumed. The content of mineral nitrogen in the range between 10 and 15 mg·kg^{-1} for this soil can be considered as background, which shows that the crop has created a good precondition for the experiment conducting in the second year.

Content of mobile phosphorus and potassium

Data about the amount of mobile phosphorus during the experiment (Fig. 2) show almost double reduction compared to the control soil and equalization of the values between 7.78–9.4 mg·100g^{-1}. Data about the phosphorus content after maize harvesting show that it increases to 14 mg·100g^{-1} and values are higher compared to those during maize cultivation. Exceptions are the variants B_3 and B_6, where the content of mobile phosphorus remains low, but this is probably because of the low available phosphorus content in

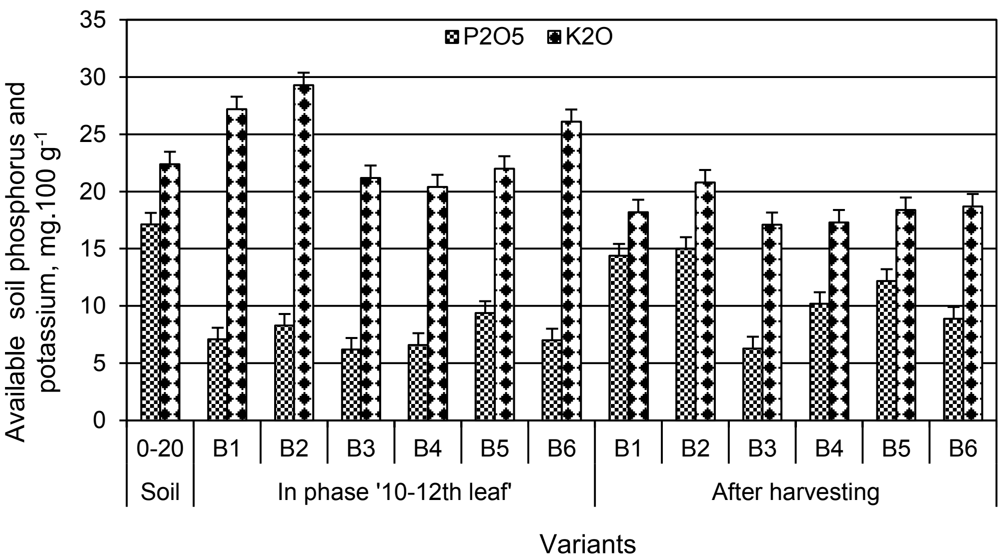

Fig. 2. Mobile phosphorus and potassium in Alluvial-meadow soil by variants in maize cultivation.

BC (Table 1). The decrease in pH, which was observed with increasing rates of N fertilizer at biochar – nitrogen amended variants, could also contribute to the lower values of available phosphorous in soil, due to fixation with sesquioxides in soil. The data obtained for the content of mobile potassium during the experiment (phase 10–12th leaf of maize) do not show high variability compared to the control soil. Only in the variants B_1 (K1N130), B_2 (B5N130) and B_6 (B10N260) is observed slight increase to 27, 26 and 29 mg·100g^{-1}, respectively. The content of mobile potassium after corn harvesting varies between 17–20 mg·100g^{-1} and reaches equal or lower values compared to the control soil.

Changes in the content and composition of organic matter

Total organic carbon is an important indicator of soil organic matter, which is widely used in estimating the total amount of organic compounds in soils. Due to its predominant aromatic structure, biochar is a relatively stable form of C (Purakayastha et al. 2015).

The composition of the organic matter of BC is dominated by humic and fulvic acids (Table 3), which determines the fulvic-humate type of humus (Ch/Cf = 1.12).

Table 3. Content and composition of the organic matter of the source soil, 45 days after nitrogen and biochar application (phase '10–12th leaf') and after maize harvesting.

Variants	TOC	Humus	OC, %			Ch/Cf	OC in HA fraction, %	
	%		Total	HA	FA		Free and bound to R_2O_3	Bound to Ca
Initial soil	0.68	1.17	0.18 / 23.62	0.10 / 13.55	0.08 / 10.08	1.0	0	100
Biochar	49.07		0.53 / 2.77	0.28 / 1.47	0.25 / 1.3	1.12	0.13 / 46.43*	0.15 / 53.57
In phase '10–12th leaf'								
B_1 (K1N130)	0.66	1.14	0.17 / 25.76	0.08 / 12.12	0.09 / 13.64	0.89	0	100
B_2 (B5N130)	0.71	1.22	0.19 / 26.76	0.13 / 18.31	0.06 / 8.45	2.17	0	100
B_3 (B10N130)	0.73	1.26	0.19 / 26.03	0.12 / 16.43	0.07 / 9.59	1.71	0	100
B_4 (K2N260)	0.66	1.14	0.19 / 28.79	0.1 / 15.15	0.09 / 13.64	1.11	0	100
B_5 (B5N260)	0.71	1.22	0.2 / 28.16	0.12 / 16.9	0.08 / 11.26	1.5	0	100
B_6 (B10N260)	0.80	1.38	0.53 / 66.25	0.27 / 33.75	0.26 / 32.5	1.03	0	100
After maize harvesting								
B_1 (K1N130)	0.75	1.29	0.17 / 22.67	0.17 / 22.67	0	-	0	100
B_2 (B5N130)	0.73	1.26	0.17 / 23.61	0.14 / 19.44	0.03 / 4.17	4.66	0	100
B_3 (B10N130)	0.73	1.26	0.18 / 24.66	0.14 / 19.18	0.04 / 5.48	3.5	0	100

Variants	TOC	Humus	OC, %			Ch/Cf	OC in HA fraction, %	
	%		Total	HA	FA		Free and bound to R_2O_3	Bound to Ca
B_4 (K2N260)	0.77	1.32	<u>0.18</u> 23.38	<u>0.14</u> 18.18	<u>0.04</u> 5.2	3.5	0	100
B_5 (B5N260)	0.66	1.14	<u>0.16</u> 24.24	<u>0.16</u> 24.24	0	-	0	100
B_6 (B10N260)	0.70	1.20	<u>0.15</u> 21.43	<u>0.15</u> 21.43	0	-	0	100

Note: TOC – total organic carbon; OC – organic carbon, exstracted with 0.1 M $Na_4P_2O_7$ + 0.1 M NaOH; HA – humic acids, FA – fulvic acids; underlined numbers are % of the soil sample, numbers below them are % of the TOC, and number with * is % of the total content of HA; Ch/Cf is ratio of humic acids to fulvic acids; R_2O_3 is cations of the third degree of oxidation.

Some of the humic acids (46 %) are represented by 'free' and bound with R_2O_3 forms, and most (53 %) are associated with Ca. Only a small fraction of biochar can be mineralized for a short time after application in soil, especially if it is produced at lower pyrolysis temperatures (Mukome and Parikh 2015). According to the classification of Orlov (Orlov 1985), the studied soil is characterized by a low content of humus (1.17 %) of humate-fulvic type (Ch/Cf = 1), low content of humic acids, 100 % bound with Ca and weak degree of humification (13.5 % of total carbon). For those soils that are low in organic carbon, it is beneficial to apply organic materials or composts, to increase the content of organic matter and their fertility. In the variants with nitrogen fertilizer only, during maize development (through 45 days) there is a slight decrease in the amount of total C. In the combination of nitrogen with biochar there is a slight increase in carbon, and this change is the highest (0.8 %) in the variant with high dose BC and nitrogen B_6 (B10N260). In this variant, the type of humus changes from humate-fulvic to fulvic-humate type (Ch/Cf > 1) compared to the variants without biochar. The humic acids present are 100 % bound to the alkaline earth elements. After maize harvesting, the content of organic C in the low-dose nitrogen variants in combination with BC does not change, and in the high-dose nitrogen combination there is a slight decrease. The application of N to the soil reduces the carbon content of organic matter due to a decrease in the C:N ratio (Yan et al. 2007) and probably mobilization of DOC due to increased microbial activity. But in all the cases the type of humus changes from fulvic-humate to humate compared to the variants during the experiment. The application of nitrogen in combination with biochar does not lead to significant changes in the total carbon content, but generally improves the humus condition of soil after corn harvesting: in all variants the type of humus changes to fulvic-humate or humate, increase in humic acids and a decrease in fulvic acids (increase in the Ch/Cf ratio).

The increase in the values of these indicators is associated with the improvement of the hydro-physical and physicochemical soil properties and there is no risk of mobilization of organic matter. The most favorable humus condition in terms of soil is the variant with low content of BC and nitrogen B_2 (B5N130). The addition of BC to the soil generally favors the process of humic acids formation. Similar results were obtained by Juriga et al. (2018). The higher rate of BC (20 t·ha^{-1}) used by them has a stronger effect on the C content in soil than the lower rate (10 t·ha^{-1}). The amount of C in soil also increases when using the combination of BC with 240 kg N·ha^{-1}.

Dry biomass

Regarding the accumulated dry biomass (Fig. 3) in all six variants of the experiment its value is highest in the phase 'Milky-wax ripeness', as the main amount is formed by the cobs. In variant B_5 the high rate of fertilization (N260) and the low rate of biochar (BC5) were applied. In all studied phases this variant belongs to the same homogeneous group with B_6 and there are no significant differences between them. In the variant B_2 (B5N130) it can be seen that in all the three phases the dry biomass (respectively 2592, 8438 and 17,768 kg·ha^{-1}) is quite high and proven to be equal to that of B_5 (2585, 9723 and 18,914 kg·ha^{-1}). There are no statistically significant differences between the biomass of B_2 and B_6 in '10–12th leaf' phase, which can be explained by the fact that the variant B_2 has the best ratio between nitrogen fertilizer and biochar. The lowest quantity of absolutely dry biomass is reported in the variants without biochar B_1, However, in the third phase, the biomass of the non-biochar variants is higher than those of variant B_3 (B10N130). These results show that, except the applied higher nitrogen norms in combination with BC, the combinations of low doses biochar in variant B_2 (B5N130) also affects the formation of higher biomass.

Statistical analysis was performed using ANOVA multi-factor analysis of variance, in order to assess the effect of nitrogen fertilizer and biochar on the dry biomass accumulation by phases of maize development (Fig. 4). The results show that both factors (biochar and N fertilizer) have a significant effect on the biomass

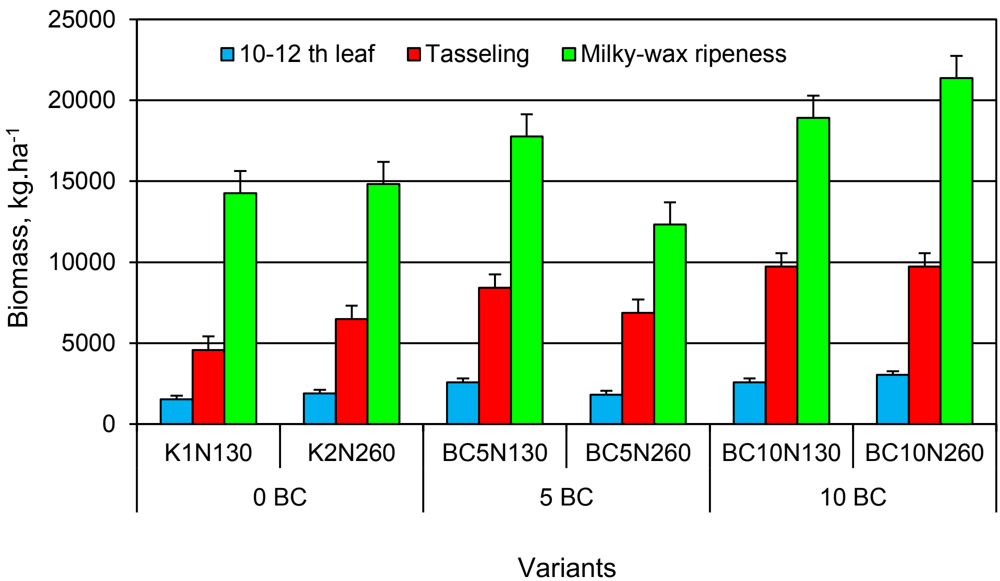

Fig. 3. Total maize biomass in stages of development.

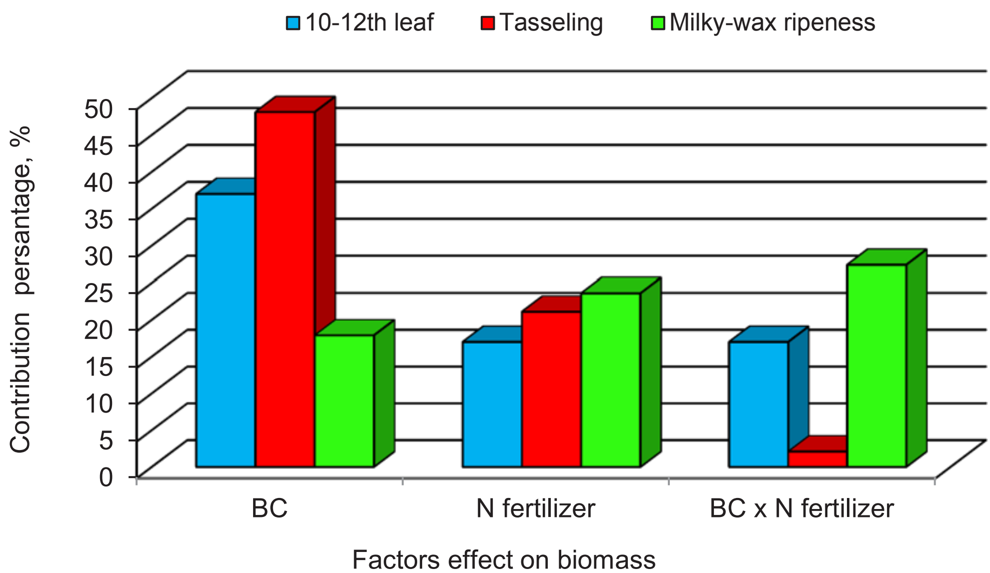

Fig. 4. Component contribution of biochar, N fertilizer, and biochar in combination with nitrogen fertilizer to maize biomass.

accumulation during different stages of maize growth. During 'Milky-wax ripeness', fertilization factor (B:N) contributes most to the variability of dry biomass – 23 %. The factor biochar (A:BC) has a significant effect in '10–12th leaf' (37 %) and 'Tasseling' (48 %). Combination of biochar and N fertilizer contributed over 27.4 % in 'Milky-wax ripeness'. In the 'Tasseling' stage the contribution of both factors on the variation of biomass is statistically insignificant (2.1 %).

In all the studied phases and all tested variants with biochar, the obtained biomass has higher values compared to the control (except for variant B_3 in the last phase). In the variants with nitrogen fertilizer rate of 130 kg·ha^{-1} (B_2, B_3) the plants biomass from the variant B_2 is higher. There are no significant differences between B_2 and B_5. This proves that biochar and N fertilizer, applied together have a beneficial effect on the accumulation of total biomass in maize. As optimal in this respect can be mentioned variant B_2, which has a lower rate of nitrogen fertilizer and yet the biomass is only 114 kg less, compared to the variant with higher nitrogen rate and the same amount of biochar (B_5) (Fig. 3). The reason for this is the ability of biochar to retain nutrients (in particular nitrogen) in the root zone, preventing it from leaching.

Conclusions

The results showed that treatments with biochar in the presence of N fertilizer significantly increased biomass in maize ($p \leq 0.05$) compared to the variants with fertilizer addition only. Greater positive effect of biochar application was observed in the combination of low-rate BC (5 t·ha^{-1}) and low-rate fertilizer (130 kg·ha^{-1}) on crop biomass in different growing stages compared to the controls and the variant with high N and low BC rates (increases were

+24 % and +44 %, respectively). Slight increases in pH, organic carbon and cation exchange capacity in the variants with both rates of biochar and low level of mineral fertilization were observed in the Fluvisol. The application of wood biochar in combination with low nitrogen fertilizer is more effective, because it improves the physicochemical status of soil (increases pH, basic cations and increase of cation exchange capacity) compared to the use of a nitrogen fertilizers only.

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References

Akolgo G., Kemausuor F., Awafo E., Amankwah E., Atta-Darkwa T., Essandoh E., Bart-Plange A., Maia C. 2020. Biochar as a Soil Amendment Tool: Effects on Soil Properties and Yield of Maize and Cabbage in Brong-Ahafo Region, Ghana. Open Journal of Soil Science 10: 91–108. DOI: 10.4236/ojss.2020.103005

Al-Wabel M.I., Hussain Q., Usman A.R.A., Ahmad M., Abduljabbar A., Sallam A.S., Ok Y.S. 2018. Impact of biochar properties on soil conditions and agricultural sustainability: a review. Land Degrad Dev 29: 2124–2161. https://doi.org/10.1002/ldr.2829

Cornelissen G., Martinsen V., Shitumbanuma V., Alling V., Breedveld G.D., Rutherford D.W., Sparrevik M., Hale S.E., Obia A., Mulder J. 2013. Biochar Effect on Maize Yield and Soil Characteristics in Five Conservation Farming Sites in Zambia. Agronomy 3(2): 256–274. https://doi.org/10.3390/agronomy3020256

Filcheva E., Tsadilas C. 2002. Influence of clinptilolite and compost on soil properties. Communications in Soil Science and Plant Analysis 33(3&4): 595–607.

Ganev S. 1990. Modern soil chemistry. Science and Art, Sofia. 371 p. (in Bulgarian).

Ganev S., Arsova A. 1980. Methods for determining the strongly acidic and the slightly acidic cation exchange in soil. Soil Science and Agrochemistry 15(3): 22–33 (in Bulgarian).

Gao S., Hoffman-Krull K., Bidwell A.L., DeLuca T.H. 2016. Locally produced wood biochar increases nutrient retention and availability in agricultural soils of the San Juan Islands, USA. Agriculture, Ecosystems and Environment 233: 43–54. https://doi.org/10.1016/j.agee.2016.08.028

Glaser B., Wiedner K, Seelig S., Schmidt H., Gerber H. 2015. Biochar organic fertilizers from natural resources as substitute for mineral fertilizers. Agronomy for Sustainable Development, Springer Verlag/EDP Sciences/INRA 35(2): 667–678. Available at: https://hal.archives-ouvertes.fr/hal-01284285/file/13593_2014_Article_251.pdf

Hussian M., Farooq M., Nawaaz A., Sadi A.M., Salaiman Z.M., Algmandi S.S., Amyara U., Ok Y.S., Siddique K.H.M. 2016. Biochar for crop production: potential benefits and risks. Journal of Soils and Sediments 17: 685–716.

Islami T., Guritno B., Basuki N., Suryanto A. 2011. Maize Yield and Associated Soil Quality Changes in Cassava + Maize Intercropping System After 3 Years of Biochar Application. Journal of Agriculture and Food Technology 1(7): 112–115.

Ivanov P. 1984. New Acetate-lactate Method for Determination of Available Forms of P and K in Soil. Soil Science and Agrochemistry 19(4): 88–98 (in Bulgarian).

Jeffery S., Abalos D., Prodana M., Bastos A., Groenigen J., Hungate B., Verheijen F. 2017. Biochar boosts tropical but not temperate crop yields. Environmental Research Letters 12(5), 053001. https://doi.org/10.1088/1748-9326/aa67bd

Jones D.L., Rousk J., Rousk J., Edwards-Jones G., DeLuca T.H., Murphy D. 2012. Biochar-mediated changes in soil quality and plant growth in a three-year field trial. Soil Biology & Biochemistry 45: 113–124. https://doi.org/10.1016/j.soilbio.2011.10.012

Juriga M., Šimanský V., Horák J., Kondrlová E., Igaz D., Polláková N., Buchkina N., Balashov E. 2018. The Effect of Different Rates of Biochar and Biochar in Combination with N Fertilizer on the Parameters of Soil Organic Matter and Soil Structure. Journal of Ecological Engineering 19(6): 153–161. https://doi.org/10.12911/22998993/92894

Karer J., Wimmer B., Zehetner F., Kloss S., Soja G. 2013. Biochar application to temperate soils: effects on nutrient uptake and crop yield under field conditions. Agricultural and Food Science 22(4): 390–403. Available at: https://journal.fi/afs/article/view/8155/6659

Kloss S., Zehetner F., Dellantonio A., Hamid R., Ottner F., Liedtke V., Schwanninger M., Gerzabek M.H., Soja G. 2012. Characterization of slow pyrolysis biochars: Effects of feedstocks and pyrolysis temperature on biochar properties. Journal of Environmental Quality 41(4): 990–1000. Available at: https://acsess.onlinelibrary.wiley.com/doi/abs/10.2134/jeq2011.0070

Kononova M. 1966. Soil Organic Matter: its nature, its role in soil formation and in soil fertility. 2nd edition. Oxford: Pergamon Press. 544 p.

Lehmann J., Gaunt J., Rondon M. 2006. Bio-char sequestration in terrestrial ecosystems – a review. Mitigation and Adaptation Strategies for Global Change 11(2): 395–419.

Methods of Soil Analysis 1982. Part 2. Chemical and microbiological properties. II edition, Page A.L., Miller R.H., and Keeney D.R. (Eds), ASA and SSSA, Madison, Wisconsin, USA. 1159 p.

Muhammad N., Hussain M., Ullah W. 2018. Biochar for sustainable soil and environment: a comprehensive review. Arabian Journal of Geosciences 11(731): 1–14. https://doi.org/10.1007/s12517-018-4074-5

Mukhina M., Rizhiya Y., Buchkina P., Balashov V. 2019. Changes in soil conditions after application of biochar. Conference Series: Earth and Environmental Science 368(1), 012037. Available at: https://iopscience.iop.org/article/10.1088/1755-1315/368/1/012037

Mukome F.N.D., Parikh S.J. 2015. Chemical, physi-cal and surface characterization of biochar. In: Ok Y.S., Uchimiya M.S., Chang S.X., Blan N. (Eds), Biochar: production, characterization and application. CRC Press/Taylor and Francis Group: 400–407.

Nelissen V., Ruysschaert G., Manka'Abusi D., D'Hose T., De Beuf K., Al-Barri B., Cornelis W., Boeckx P. 2015. Impact of a woody biochar on properties of a sandy loam soil and spring barley during a two-year field experiment. European Journal of Agronomy 62: 65–78. http://dx.doi.org/10.1016/j.eja.2014.09.006

Novak J.M., Spokas K.A., Cantrell K.B., Ro K.S., Watts D.W., Glaz B., Busscher W.J., Hunt P.G. 2014. Effects of biochars and hydrochars produced from lignocellulosic and animal manure on fertility of a Mollisol and Entisol. Soil Use Manage 30: 175–181. https://doi.org/10.1111/sum.12113

Oladele S.O., Adeyemo A.J., Awodun M.A. 2019. Influence of rice husk biochar and inorganic fertilizer on soil nutrients availability and rain-fed rice yield in two contrasting soils. Geoderma 336: 1–11.

Orlov D.S. 1985. Soil chemistry. Moscow State University. 376. p.

Purakayastha T.J., Kumari S., Pathak H. 2015. Characterisation, stability, and microbial effect of four biochars produced crop residues. Geoderma 239–240: 293–303. http://dx.doi.org/10.1016/j.geoderma.2014.11.009

Paz-Ferreiro J., Méndez A., Am T., Cerdà A., Gasco G. 2014. Preface: Environmental Benefits of Biochar. Solid Earth 5: 1301–1303. https://doi.org/10.5194/se-5-1301-2014

Schulz H., Dunst G., Glaser B. 2013. Positive effects of composted biochar on plant growth and soil fertility. Agronomy for Sustainable Development 33(4): 817–827. Available at: https://hal.archives-ouvertes.fr/hal-01201399/document

Sohi S.P., Krull E., Lopez-Capel E., Bol R. 2010. A review of biochar and its use and function in soil. Advances in Agronomy 105: 47–82. DOI: 10.1016/S0065-2113(10)05002-9

Sukartono, Utomo W.H., Kusuma Z., Nugroho W.H. 2011. Soil fertility status, nutrient uptake, and maize (*Zea mays* L.) yield following biochar and cattle manure application on sandy soils of Lombok, Indonesia. Journal of Tropical Agriculture 49(1–2): 47–52.

Xu G., Sun J., Shao H., Chang S.X. 2014. Biochar had effects on phosphorus sorption and desorption in three soils with differing acidity. Ecological Engineering 62: 54–60. https://doi.org/10.1016/j. ecoleng.2013.10.027

Yan D., Wang D., Yang L. 2007. Long-term effectof chemical fertilizer, straw, and manure on labile organic matter fractions in a paddy soil. Biology and Fertility of Soils 44: 93–101. DOI: 10.1007/s00374-007-0183-0