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The effect of Fluvisol applied biochar on wheat yield and nutrient uptake

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Abstract

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In recent years, the effect of biochar for improving soil fertility, reducing the use of mineral fertilizers, increasing crop yields and the quality of the production has been reported. The aim of the present study is to make an agronomic assessment of the impact of biochar on wheat yield, nutrient uptake and some soil properties. A field experiment with wheat was carried out on a Fluvisol in the experimental field of the Institute of soil science agrotechnologies and plant protection (ISSAPP) at Tsalapitsa village (Plovdiv). The impact of biochar on the wheat yield and some soil properties was studied. The applied biochar has a significant effect on wheat yield in variant BC4 but doesn't influence the content of the main nutrients. There is no statistically significant effect of biochar application on the content of major macroelements in the different parts of wheat by variants. Only insignificant decrease in the content of nitrogen was found in all the organs compared to the control. The highest elements uptake is observed in the variant BC2 (4 $t.ha^{-1}$), where the highest rate of biochar was applied which has the greatest impact on soil characteristics and mineral nutrition and elements uptake.

Keywords: biochar; wheat; yield; chemical content; nutrient uptake

Introduction

In recent years, the effect of biochar to improve soil fertility, reduce the use of mineral fertilizers, increase the yields and the crop quality, and to protect the ground water and atmosphere of pollution has been reported. This product obtained by pyrolysis of plant residues shows contradictory properties but some trends for the influence of biochar on the yield of agricultural crop and soil properties are clearly outlined.

Worldwide, various data have been reported for the past 15 years (Major et al., 2010, Park et al., 2011; Vaccari et al., 2011; Schulz & Glaser, 2012; Zhao & Joseph, 2015). The research on the effect of biochar on wheat yield shows that different combinations of biochar and mineral fertilizers increase the yield by 18% compared to the control and by 48% at a dose of 1.5 t / ha of biochar and mineral fertilizers (Solaiman et al., 2010). According to Blackwell et al. (2010), applying biochar is the most effective in terms of increasing grain yield of wheat compared to control when it is applied at rate of 1 t/ha along with 50 kg/ha of phosphorous fertilizer. Very few studies have been carried out in Bulgaria to study biochar obtained by treatment of various plant residues and its effect on soil properties and on the quantity and quality of crop yields (Molla et al., 2013; Stoimenov et al., 2015; Kercheva et al., 2018). In our previous studies (Petkova et al., 2018) it was found that biochar applied at the same rates used in this study had a stimulating effect on the soil microflora and the CO_2-production and the bacterial amounts were positively affected to the greatest extent. Recently innovative research carried out by Atanassova et al. 2020 revealed that the surface horizons of the biochar amended Fluvisol (3t/ha) contained alkanes < C_{24} with even over odd predominance (EOP) and carbon preference index (CPI) of 10.6, which indicates anthropogenic sources and/or predominant microbial contribution to soil organic matter.

The aim of the present study is to make agronomic assessment of the impact of biochar on the wheat yield, nutrients uptake and some soil properties of a long-time fertilizer treated Fluvisol.

Materials and Methods

A field experiment with wheat was carried out on a Fluvisol at the experimental field of Tsalapitsa village (Plovdiv). The soil is characterized by slightly acidic reaction (pH_{H_2O}- 5.4-5.8), cation exchange capacity (CEC) = 16.5 cmol kg^{-1}; low humus content (0.78%), mineral nitrogen – 16.1 $mg.kg^{-1}$, available K and P (28.2 mg $K_2O.100g^{-1}$ and 10.6 mg $P_2O_5.100g^{-1}$).

In the experiment with wheat, the following variants are studied: BC0 – control without biochar; BC3 – variant with biochar applyed in 2016, produced by pyrolysis of rice straw (2 $t.ha^{-1}$); BC4 – variant with biochar applyed in 2017, obtained by pyrolysis of oak bark at 500°C (3 $t.ha^{-1}$). In order to determine the effect of biochar on soil properties, soil samples are taken from previous years: BC1 – variant with biochar applied in 2013, produced by pyrolysis of maize plant residues at 500°C (1.8 $t.ha^{-1}$) and BC2 – variant with biochar applied in 2014, obtained by pyrolysis of plant maize residues at 500°C (4 $t.ha^{-1}$). Background fertilization was applied: 10 kg $N.da^{-1}$ (carbamide), 12 kg P da^{-1} (triple superphosphate) and 10 kg $K.da^{-1}$ (potassium sulfate). The agrotechnical activities were carried out in accordance to the requirements for cultivation of the tested crop.

After harvesting of wheat, plant samples were taken (grain, chaff and straw). The following biometric data were determined for the characterization of plant growth and development: number of classes, weight of classes, straw and bunch (g) and grain yield ($kg.da^{-1}$). Absolute dry weight (kg. da^{-1}) and content of nutrients N, P, K, Na, Ca and Mg (%) were determined in all the plant samples. The total nitrogen content in plant samples was determined by Ginzburg's wet digestion method and phosphorus, potassium, sodium, calcium and magnesium by ash analysis. Nitrogen distillation was accomplished by the Keldahl method. Phosphorus was determined colorimetrically by molybdenum blue, and potassium and sodium by flame photometer, calcium and magnesium by Perkin Elmer atomic absorption spectrophotometer. The main agrochemical parameters of the soil were analyzed by the following methods: nitrogen (N) – by the method of Bremner, (1965), available phosphorus and potassium (P and K) – by the oxalate-lactate method of Ivanov, (1984). Soil organic matter was measure following Tjurin's method (acid-dichromate digestion, 120°C, 45 min in a thermostat, catalyst Ag_2SO_4) and Kononova- Belchicova's method (Kononova, 1966). Statistical data were analyzed by making use of STATGRAPHICS Centurion XV, one-way Anova methods, one-factor variance analysis.

Results and Discussion

For obtaining optimal yields of wheat the main climatic factors are precipitation, temperature and soil moisture (Figure 1).

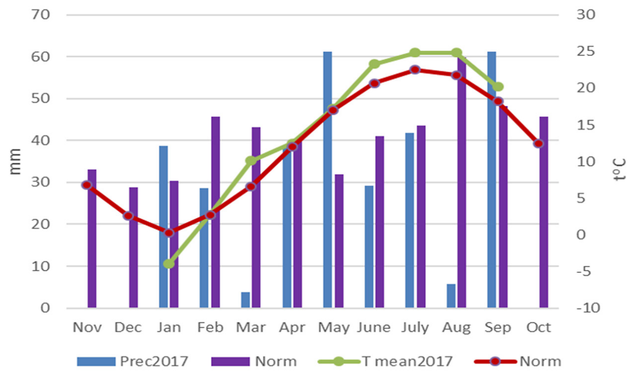

Fig. 1. Average temperature and rainfall for the period Nov. 2016 – Sert. 2017 compared to the climatic norm (1960-1990)

Air temperatures during the winter period were higher than the climatic norm and rainfall was relatively sufficient. The higher air temperatures than the climatic norm during the winter period and relatively sufficient rainfall provide suitable conditions for the sowing of crop. Very good are the climatic conditions in the critical period of humidity during the vigorous growth, spindle and formation of the class – the amount of precipitation is ~ 83 mm. The most important is precipitation during the period April – June, when the generative organs are formed and the grain is poured. For this period the rainfall is ~120 mm.

In Table 1 it is shown that the values of all biometric parameters are highest in the variant with biochar applied in 2017 year (BC4). Differences are significant at a confidence level of 95% between the number of classes of BC4 and the control variant without biochar (BC0), the variant with biochar added to the soil in 2013 (BC1) and the variant with biochar applied in 2016 (BC3). The straw weight showed differences between the control and the biochar variant of 2014 (BC2). With respect to class weight, differences at the same confidence level between the control variant and BC4 and between the BC3 and BC4 variants are significant. Figure 2 shows the yield of wheat by variants. The biometric data indicate that the yield of BC4 is the highest (Figure 2).

Table 1. Average values of the biometric parameters of wheat

Variant	Weight, g			Number of classes	% to control (without BC)		
	bunch	straw	class		Weight straw	Weight class	Number of classes
BC0	1 047 a	386 a	660 a	458666 a	100	100	100
BC1(2013)	1147 a	453 ab	693 ab	458666 a	117	105	100
BC2(2014)	1367 a	533 b	833 ab	538666 ab	138	126	117
BC3(2016)	1080 a	426 ab	653 a	442666 a	110	99	97
BC4(2017)	1367 a	500 ab	866 b	713333 b	129	131	156
SD		77	131	141718			
CV %		16	17	27			
LSD 5%		118	199	205484			

(**a,b** – means in the same column followed by the same symbol are not significantly different at $P < 0.05$ level based on test one – way Anova test.)

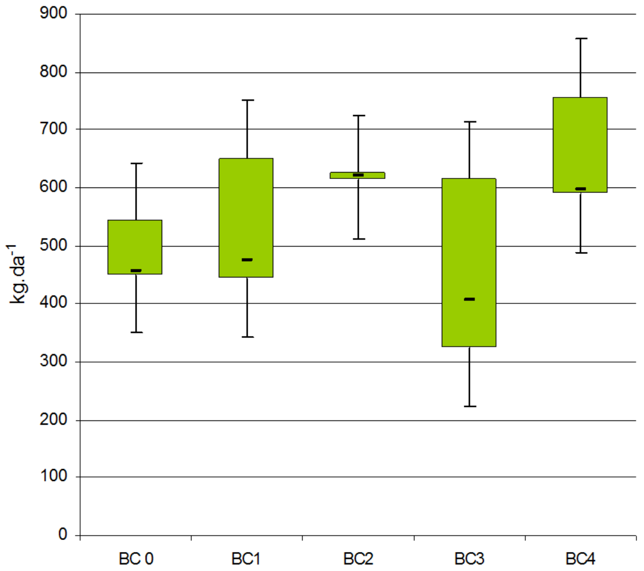

Fig. 2. Wheat yield (kg.da^{-1}) by variants (every box represent five statistical values: median, minimum and maximum values and 25/75 quartiles)

The yield of BC2 is with a very small and insignificant difference between data values, followed by BC1.

The lowest is the yield of wheat for the variant with applied rice straw (BC3). There are significant differences at a 95% confidence level between the yield of BC3 and the yield of BC4 with applied biochar in 2017. This may be due to the fact that in 2016 there was lack of sufficient biomass for pyrolysis and biochar was introduced into the soil in small amounts only 2 t.ha^{-1}.The most probable reason for the higher yield of the variant with biochar added in 2017 (BC4) are the very good weather conditions during the growing season, corresponding to the bio-ecological requirements of the crop and the higher rate of biochar applied.

Chemical elements content in the wheat biomass

The content of main macroelements in the organs of wheat (grain, chaff and straw) is presented in Table 2. In the variants with biochar added there was insignificant reduction of N content in all organs compared to the control with the exception of the BC1 variant. In other research (Sika, 2012; Gaskin et al., 2008; Lehmann et al., 2003; Rondon et al., 2007) it has been also reported that lower N content in plants was established in biochar treated soils. The highest is the nitrogen content in wheat grain between 1.18 and 1.38. There are no significant differences in the content of the studied macro elements P, K, Na, Ca and Mg. The phosphorus content is almost unchanged between variants, but difference is observed between the grain and the straw. It should be noted that nitrogen and phosphorus contents there are insignificantly different between variants (Table 2).

The potassium content is higher in straw (0.7-1.23%) compared to grain (0.4-0.46%). The added biochar in BC4 has a significant effect on wheat yield but does not have a significant influence on the content of the main nutrients. Magnesium values decreased from grain to straw, and for calcium the opposite trend was observed – the highest values were found in straw.

Uptake of macro elements by crop biomass

Uptake of macro element by the biomass of the crop is an important factor when studying the balance of nutrients in the soil-plant system and monitoring the effects of biochar on plant production.

The total biomass ranged from 919 to 1190 kg.da^{-1} and it exports from 8.76 to 10.64 kg. da^{-1} nitrogen (Table 3). The higher are the amounts of nitrogen uptake by biomass in variants BC1 and BC2, where biochar (cornstalks) is added in 2013 and 2014 and the post-effect of the ameliorant is probably observed.

Table 2. Macroelement content (%) in vegetative organs of wheat

Variants	Gen. organs	Macroelements %											
		N	± SD	P	±SD	K	±SD	Na	±SD	Ca	±SD	Mg	±SD
Bo	grain	1.28	0.10	0.38	0.04	0.41	0.01	0.002	0	0.03	0.01	0.12	0.01
	chaff	0.88	0.06	0.23	0.02	0.52	0.06	0.002	0.001	0.04	0.01	0.06	0.01
	straw	0.51	0.08	0.07	0.03	0.70	0.03	0.005	0	0.18	0.01	0.06	0.01
BC1	grain	1.38	0.12	0.38	0.01	0.40	0.01	0.005	0.001	0.03	0.00	0.12	0.01
	chaff	0.56	0.09	0.18	0.02	0.52	0.01	0.004	0.001	0.06	0.02	0.05	0.01
	straw	0.58	0.10	0.06	0.01	1.23	0.08	0.010	0.001	0.26	0	0.05	0.01
BC2	grain	1.26	0.15	0.40	0.03	0.40	0.01	0.003	0.001	0.03	0	0.12	0.01
	chaff	0.61	0.20	0.19	0.05	0.46	0.05	0.004	0.001	0.04	0.01	0.05	0.01
	straw	0.50	0.18	0.05	0.35	1.12	0.03	0.007	0.001	0.24	0	0.06	0.09
BC3	grain	1.18	0.20	0.41	0.02	0.41	0.01	0.004	0.001	0.02	0.01	0.12	0.01
	chaff	0.60	0.19	0.21	0.09	0.49	0.03	0.003	0.001	0.05	0.01	0.04	0.01
	straw	0.63	0.19	0.06	0.05	0.75	0.02	0.010	0.001	0.17	0	0.05	0.01
BC4	grain	1.18	0.07	0.40	0.02	0.42	0.01	0.003	0.001	0.03	0	0.12	0.01
	chaff	0.63	0.09	0.19	0.03	0.43	0.02	0.004	0.002	0.04	0.01	0.06	0.02
	straw	ND		ND		ND		ND		ND		ND	

Table 3. Macroelements uptake (kg.da^{-1}) by wheat biomass

Variant	Gen. organs	Dry weight, кg.da^{-1}	Uptake of macroelements, kg.da^{-1}					
			N	P	K	Na	Ca	Mg
B0	grain	483	6.23 a	1.85 a	1.97ab	0.010a	0.16ab	0.60ab
	chaff	80	0.69	0.18	0.42	0.002	0.03	0.05
	straw	453	2.31	0.32	3.17	0.023	0.83	0.25
	total	**1016**	**9.23**	**2.35**	**5.56**	**0.034**	**1.02**	**0.90**
BC1	grain	523	7.28 a	1.97 a	2.11ab	0.024b	0.16ab	0.61ab
	chaff	106	0.62	0.19	0.55	0.004	0.06	0.06
	straw	501	2.57	0.27	5.45	0.044	1.16	0.23
	total	**1131**	**10.47**	**2.43**	**8.11**	**0.072**	**1.38**	**0.90**
BC2	grain	619	7.8 a	2.46 a	2.5 ab	0.019ab	0.19b	0.72ab
	chaff	128	0.79	0.25	0.59	0.005	0.06	0.07
	straw	443	2.05	0.20	4.59	0.029	0.98	0.23
	total	**1190**	**10.64**	**2.91**	**7.68**	**0.052**	**1.23**	**1.02**
BC3	grain	448	5.22 a	1.85 a	1.86 a	0.018ab	0.11a	0.52a
	chaff	61	0.38	0.13	0.30	0.002	0.03	0.03
	straw	410	3.16	0.30	3.76	0.050	0.83	0.24
	total	**919**	**8.76**	**2.28**	**5.92**	**0.070**	**0.97**	**0.78**
BC4	grain	647	7.6 a	2.62 a	2.70 b	0.017ab	0.19b	0.80b
	chaff	120	0.75	0.23	0.52	0.005	0.04	0.07
	straw		ND	ND	ND	ND	ND	ND
	total							

a,b – means in the same column followed by the same symbol are not significantly different at $P < 0.05$ level

The amount of phosphorus uptake by the biomass ranged in very narrow limits (from 2.28 to 2.91 kg.da^{-1}), which indicates that biochar has no effect on the phosphorus uptake by plants. Potassium uptake in wheat varies from 5.56 to 8.11 kg.da^{-1} reflecting the increase in the amount of accumulation of absolutely dry biomass depending on the variants with biochar. Calcium, magnesium and sodium are removed from the field in significantly lower quantities. The highest is calcium uptake (0.97-1.38 kg.da^{-1}) compared to the other two macroelements (Figure 3).

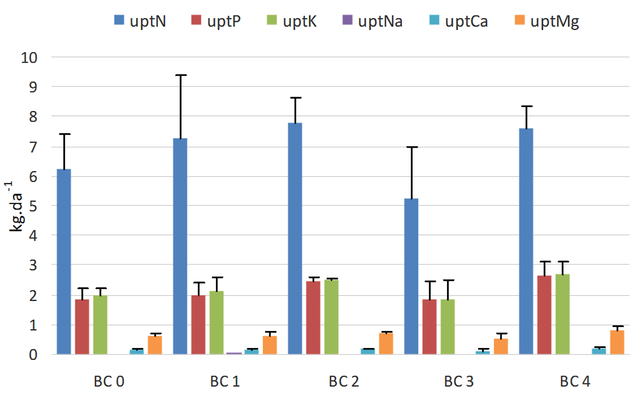

Fig. 3. Nutrient uptake (kg.da^{-1}) by wheat grain

The differences between variants are not clearly expressed, but the nitrogen and phosphorus uptake are higher in grain than in straw, without significant differences between the variants. Potassium uptake in straw is higher than in grain, but significant differences between the tested variants BC3 and BC4 are observed only when uptake by grain is considered. Statistically significant differences of the uptake of Ca by grain are reported between the variants BC3 and BC4, and between BC2 and BC3. It can be concluded that the highest chemical element uptake is observed in the variant BC2, where the highest rate is applied and probably has the greatest effect on the soil characteristics, and hence the influence on the mineral nutrition and elements uptake. Also, it should be noted that higher macro-element uptake by wheat grain and chaff is observed in the variant BC4, as compared to the control and variant BC3.

Agrochemical analysis of soil after harvesting of wheat

The data for pH values of the Fluvisol (Figure 4) after wheat cultivation showed a certain increase in pH (by 0.3-0.4 pH units), depending on the biochar application. This is more evident in the BC3 and BC4 variants as compared to the control (BC0). The Fluvisol is characterized by low humus content, which in the control variant BC0 is 0.65%. The addition of biochar in increasing quantities during different years leads to increase of carbon content in soil. Its content is highest in the last year, probably due to the material used to produce biochar oak peel. In a study by Brewer et al. (2009), biochar obtained by wood has been found to have higher C content and lower ash content than biochar derived from plant residues of corn and grass.

The data show an increase in mineral nitrogen content in soil, depending on the quantities of biochar added during the years which reach 49 mg.kg^{-1}. As a whole, mineral nitrogen is present in small contents (0.2–1.0%) in biochar (Chan & Xu, 2009). In Figures 4 and 5, it is shown that the application of biochar increases the pH and the total soil organic matter content and affects the available K, increasing its stock in soil in the variants,

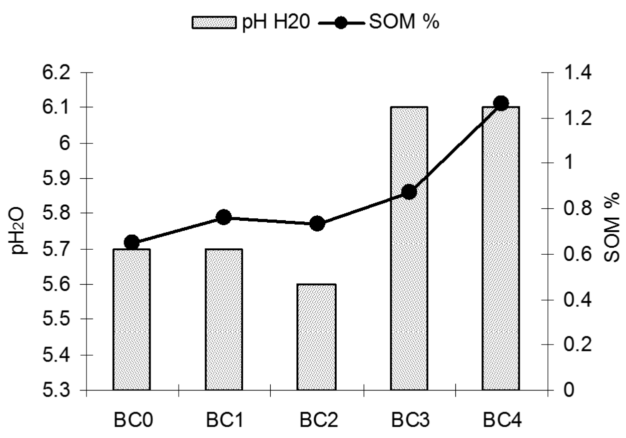

Fig. 4. Soil pH values and soil organic matter content (%) following wheat harvesting

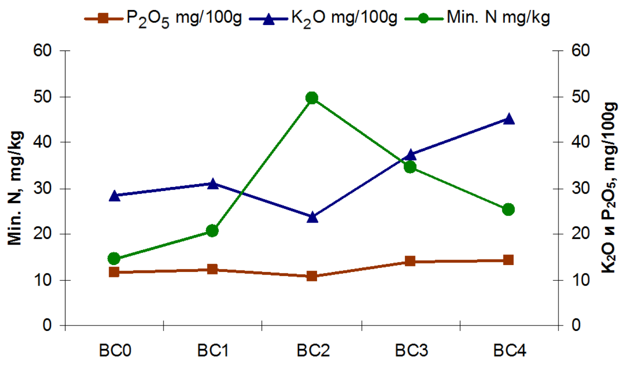

Fig. 5. Content of phosphorus, potassium and mineral nitrogen in soil after wheat production

except in variant BC2, where K_2O (23.7 mg.100^{-1}g) is lower than the control variant. The data obtained for the available phosphorus content did not show major changes compared to the control variant, but this is probably due to the different origin of biochar.

Conclusions

The applied biochar has a significant effect on wheat yield in the variant BC4 with addition of biochar obtained by oak bark (3 t.ha^{-1}) but doesn't influence the content of main nutrients. Although the effect of biochar of different plant origin was evaluated, we can state the following findings: (1) there is no statistically significant effect of biochar application on the content of major macroelements in the different parts of wheat by variants. The reasons for the high yields are probably the following: (i) higher rates of biochar applied and (ii) The favorable weather conditions during the growing season of the cultivated crop, corresponding to the bio-environmental requirements. (2) Only insignificant decrease in the content of nitrogen was found in all the organs compared to the control. (3) The highest elements uptake is observed in the variant BC2 (4 t.ha^{-1}), where the highest rate of biochar was applied which has the greatest impact on soil characteristics and mineral nutrition and elements uptake.

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