

Long-term effects of biochar application on the wheat yield and nutrient uptake on Fluvisol

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Abstract

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A field experiment with an indicator wheat crop in 2022 was carried out on Fluvisol, in the experimental field of “Nikola Poushkarov” Institute of Soil Science, Agrotechnologies and Plant Protection, of the village of Tsalapitsa (Plovdiv region). Variants were set with two rates of biochar (5 and 10 t.ha⁻¹) and nitrogen fertiliser (130 and 260 kg.ha⁻¹) in 2019 and 2020, and are left for observation to determine the aftereffect of biochar. The purpose of this study was to assess the yield of wheat, the uptake of macronutrients with biomass and some soil characteristics on the 3rd and 4th year following application of biochar and nitrogen fertilizer. Plant samples were taken in the full maturity phase of wheat in three replications, and the concentrations of N, P, K, Ca and Mg were determined.

The obtained results show that the time of biochar application has a significant effect on the yield of wheat, a higher yield was reported by the variants when biochar was applied at the 3rd year. For the B₍₃₎5N130 and B₍₃₎10N260 variants, the increase was 12% and 13% compared to controls. The data showed that biochar residing in soil at two rates (5 and 10 t/ha) for four years, had no significant effect on wheat yield, growth, macronutrient uptake and soil nutrient content compared to the control variants. However, the more pronounced effect of biochar aftereffect was observed on the physicochemical characteristics (pH, CEC and OC) at the 3rd and 4th year compared to the control in the variants with the lower nitrogen rate and the higher levels of biochar.

Keywords: after-effect of biochar; nitrogen fertilizer; wheat; macroelements

Introduction

The challenges facing agriculture are related not only to identifying effective measures to improve crop production, but also to protect soil fertility against the background of constantly changing climatic conditions. Wheat is the main field crop and is grown on an area of between 10 and 15 million acres in Bulgaria. The most widespread in the country is the so-called winter wheat, which is used for the production of bread grain and fodder. Increasingly visible climate change is putting wheat production to the test, which could drop dramatically. Biochar as a soil amendment produced from organ-

ic feedstock in the pyrolysis process, is one of the promising strategies for protecting and improving vital soil characteristics and agro-ecological technology, necessary for the sustainable development of cultivated plants. Studies have shown that the use of biochar improves physicochemical, water-physical, biological properties and increases yields, as well as being a potential tool for soil carbon sequestration (Bista et al., 2019; Lehmann and Joseh, 2015). In our previous studies, Benkova et al. (2020) found that applying different rates of biochar obtained from different plant materials, lead to an increase in the reserves of mineral nitrogen and available potassium in the soil, pH and total organic carbon values increase on Flu-

visol, but the expected effect on wheat yield is not observed. A meta-analysis of studies evaluating the effects of biochar on soil and plant properties varies widely, depending on the characteristics of both soil and biochar, and on the levels of application (Jiang et al., 2024). They reveal that the effects of biochar application on yield vary between crops, biochar significantly increases wheat yield by an average of 17% in all years except the third year. Most of the current research on the effect of biochar on crop growth and nutrient uptake was examined within a growing season (Mete et al., 2015; Yeboah et al., 2016; Malik et al., 2018). There are fewer studies that look at the impact of biochar in long-term experiments. Studies by Zhang et al. (2020) and Hu et al. (2021) show that one time application of biochar can improve the growth and yield of wheat and maize over four years.

Therefore, it is necessary to study the long-term effect of biochar on crops under different soils and climatic conditions. Our research was conducted on a soil, that is characterized by a light soil texture, a flushed water regime, and was vulnerable to the leaching of nitrate nitrogen. The purpose of this study was to assess the yield of wheat, the uptake of macronutrients with biomass and some soil characteristics on the third and fourth year after application of biochar and nitrogen fertilizer on Fluvisol.

Material and Methods

During vegetation season 2021 and 2022, an experiment with winter wheat without fertilization was conducted on the area of a three-year experiment with maize, in the experimental field of the village of Tsalapitsa (Plovdiv). The soil texture is sandy clay loam, classified as Fluvisol (WRB 2015). The basic properties of the topsoil: pH (H₂O) 6.1, CEC 16.7 cmol.kg⁻¹, soil organic carbon (SOC) 0.68% and total N 0.052%.

Table 1. Scheme of variants

Year of BC application	Variants	BC t.ha ⁻¹	N kg.ha ⁻¹
2019 one time application BC four years ago	K1N130	0	130
	K2N260	0	260
	B ₍₄₎ 5N130	5	130
	B ₍₄₎ 10N130	10	130
	B ₍₄₎ 10N260	5	260
	B ₍₄₎ 5N260	10	260
2020 one time BC application three years ago	B ₍₃₎ 5N130	5	130
	B ₍₃₎ 10N130	10	130
	B ₍₃₎ 5N260	5	260
	B ₍₃₎ 10N260	10	260

Source: Authors' own elaboration

The variants of the grown maize have two doses of biochar (5 and 10 t.ha⁻¹) and two doses of nitrogen fertilizer (130 and 260 kg.ha⁻¹) from the first and second years of the experiment, and are left for monitoring of the aftereffect of biochar (Table 1).

The experiment began in 2019, using a randomized block design with following treatments: K1N130, K2N260 (two controls only with fertilisers), B₍₄₎5N130, B₍₄₎10N130, B₍₄₎10N260 and B₍₄₎5N260. Biochar rates were one-time application in 2019, and 4 new variants were set in 2020 year according to the same scheme: B₍₃₎5N130, B₍₃₎10N130, B₍₃₎10N260 and B₍₃₎5N260. Biochar was produced from oak at a pyrolysis temperature of 450 °C. Biochar properties were: pH (H₂O) 9.7, organic C content 49 %, total N 0.59%, available N 72 mg.kg⁻¹, K 499.6 mg.100⁻¹ g, available P 43.4 mg.100⁻¹ g. Wheat (*Triticum aestivum*, L.) was sown in October. Seeding density ensured 600 germinated seeds per 1 m². The experimental plot area was in three replicates of each variant with 12.5 m². The agrotechnical activities were carried out in accordance to the requirements for cultivation of the tested crop. After harvesting of wheat (early July), plant samples were taken (grain, chaff and straw). The following biometric data were determined for the characterization of plant growth and development: weight of bunches, weight of spikes, count of spikes and height of plants (cm/m²). Absolute dry weight (kg.ha⁻¹) and content of nutrients N, P, K, Na, Ca and Mg (%) were determined in all of the plant samples. The yield of wheat (kg.ha⁻¹) and the export of macro-elements with plant biomass are calculated. Soil samples were taken 0-20 cm depth after harvesting of wheat.

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), calcium and magnesium by ICP-OES. The physicochemical soil properties were determined by the method of Ganey and Arsova (1980). Electrical conductivity was determined in soil: water (1: 5), ISO 11265 : 2002. Soil pH/Eh was measured in a soil: water of 1: 2.5. Total organic carbon (TOC) and composition was determined by the methods of Kononova (1966). Statistical data were analyzed by making use of STATGRAPHICS Centurion XV, one-way ANOVA methods, one-factor variance analysis.

Results and Discussion

Meteorological conditions

Rainfall, temperature and soil moisture are essential to obtain optimal wheat yields. A climatic characteristic of the territory of Tsalapitsa, Plovdiv region for 2022 was presented in Fig. 1.

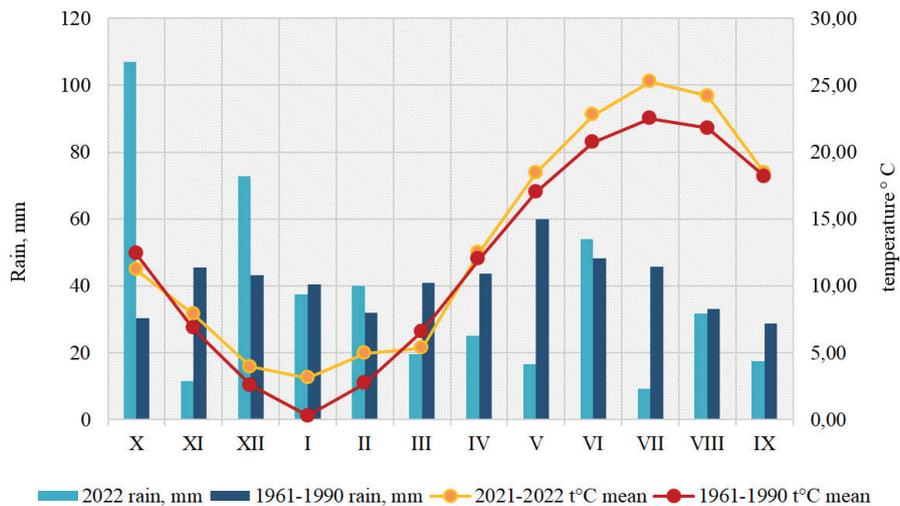


Fig. 1. Average temperature and precipitation for investigation period (2021–2022) compared to the climatic norm (1960–1990)

Source: Authors' own elaboration

The period was characterized by temperatures, higher than the climatic norm. This, as well as the sufficient amount of rainfall in October and December 2021, allowed the germination of wheat and the formation of one levelled crop, which reached the tillering phase in less than a month. Winter was dry and warm, with temperatures much higher than usual. In March, precipitation was almost twice lower than normal. This makes the spring moisture supply unsatisfactory. Spring was warm and dry. In the critical period for wheat in terms of moisture (10.04–10.05), the combination of temperature and moisture was not favourable for it. A higher amount of precipitation was reported only in June 2022. The

amount of precipitation in the summer months is lower than the climatic norm. The observed climatic trends have their impact on the cultivated crop, as they were less favorable with higher recorded temperatures and less rainfall.

Growth parameters

Statistical processing of the data (Table 2) shows that the control with a low rate N (130 kg·ha⁻¹) and the variants B4 (four years after BC application) in the studied biometric indicators form a homogeneous group, i.e. there were no statistically significant differences with 95% confidence. There were differences between the fertilizer variants of

Table 2. Mean values of biometric parameters of wheat

Variants	Weight of bunch, g/m ²		Weight spikes, g/m ²		Count spikes per m ²		Height cm/m ²
K1N130	720	a	444	a	446	a	44.5
K2N260	920	c	600	d	616	bc	49.6
B ₍₃₎ 5N130	760	ab	510	b	480	a	49.8
B ₍₃₎ 10N130	830	bc	540	c	650	c	48.8
B ₍₃₎ 5N260	740	ab	480	ab	630	bc	51.0
B ₍₃₎ 10N260	870	c	620	d	540	b	51.1
B ₍₄₎ 5N130	760	ab	440	a	538	ab	47.6
B ₍₄₎ 10N130	740	ab	480	ab	482	a	50.6
B ₍₄₎ 5N260	750	ab	490	ab	532	ab	51.8
B ₍₄₎ 10N260	740	ab	450	ab	594	bc	48.8
CV	10.03%		13.77%		15.17%		5.99%
SD	78.53		69.60		83.58		2.96
p ≤ 0.05	0.002		0.001		0.004		0.08
LSD 95%	91		68		102		

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.

Source: Authors' own elaboration

the previous crop with the high nitrogen rate (260 kg.ha⁻¹) and the variants three years after the application of BC (B₍₃₎ (B₍₃₎10N260), including the control K2N260 and the remaining variants. It can be noted that the quantity of nitrogen fertilizer and the time of BC application influence the indicators.

Chemical elements content of biomass

The content of the main macronutrients in the cultivated crop (wheat) was presented in Figure 2 and Figure 3. The data given in the tables refer to the period of harvesting of the experiment on plant organs, on which a complete chemical analysis was made.

It was found that the nitrogen content was higher in wheat grain between 1.63 and 2.07 % compared to chaff (0.37–0.87 %) and straw (0.21–0.33 %) in all studied variants. ANOVA of the N content data showed that the 5 homogenous groups were formed with significant differences between them

(LSD ± 0.193, p < 0.05, respectively) (Fig. 2) The nitrogen content in wheat grain was higher in the control variant with the high nitrogen dose K2N260 (1.91 %) and the biochar and high nitrogen dose variants (B₍₃₎5N260, B₍₃₎10N260) after the third year of application. Expected in the variants of the predecessor, fertilizers with the higher N norm (260 kg.ha⁻¹) reported higher amounts of N compared to fertilizers with 130 kg. N.ha⁻¹, and the differences were statistically proven with 95% certainty.

The phosphorus content was also the highest in the grain in a narrow range (0.34–0.37%). Statistical analysis of the P content also showed that 5 homogeneous groups formed, with significant differences between controls and all tested variants (LSD ± 0.044, p < 0.05) (Fig. 2). In the wheat biomass, the tendency of accumulation of potassium in the straw in greater quantity than in the grain of the plants was shown. The potassium content was highest in the straw of all studied variants, and was in the range of 0.65–0.79%. The

Fig. 2. Nitrogen, phosphorous and potassium content (%) in wheat biomass

Source: Authors' own elaboration

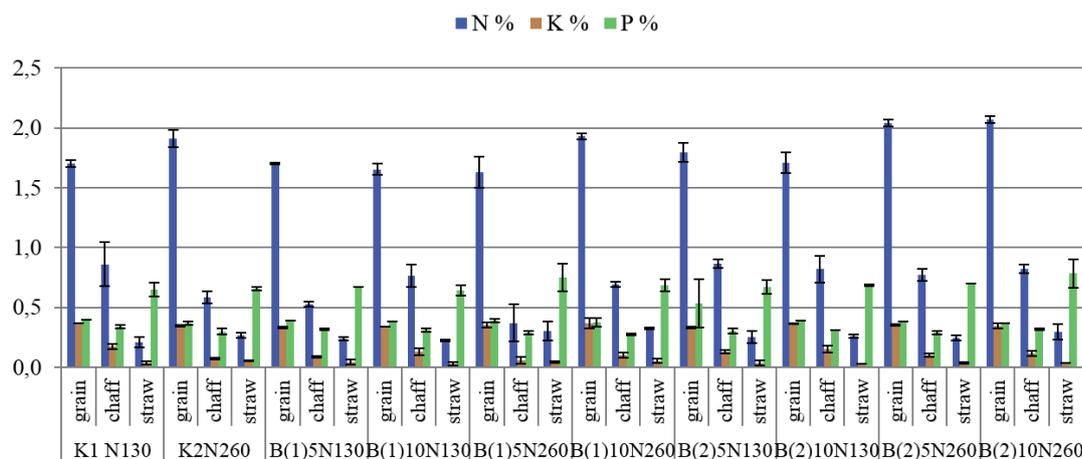


Fig. 3 Calcium and magnesium content (%) in wheat biomass

Source: Authors' own elaboration

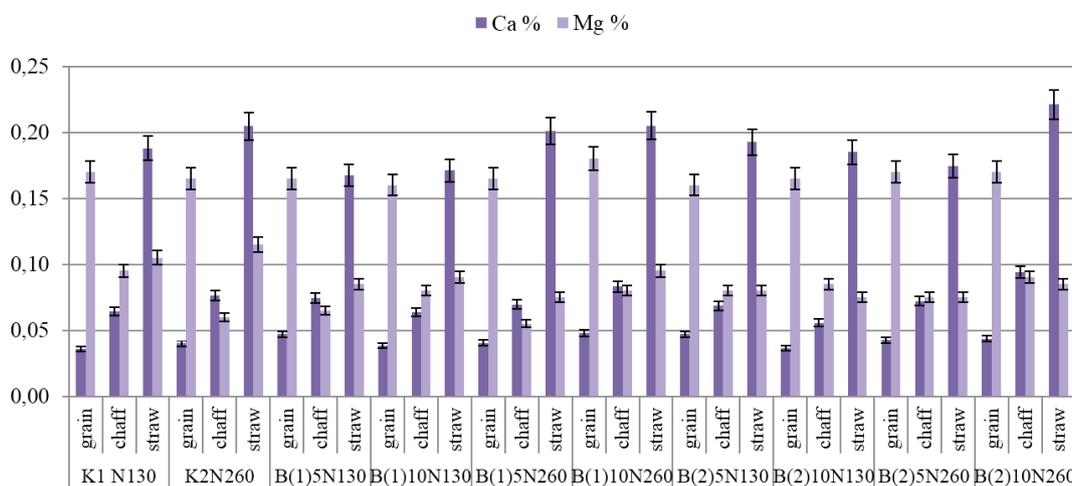


Table 3. Multi-factor ANOVA analysis of variance data for N % and P% content in wheat biomass

Source	Content N			Content P		
	Sum of Squares	P-Value	%	Sum of Squares	P-Value	%
MAIN EFFECTS						
A:BC	0.455491	0.0045	21.11	0.0202417	0.0002	37.21
B:N	0.111005	0.0803	5.15	0.000474074	0.4392	0.87
C:Year	0.942084	0.0000	43.67	0.00106667	0.2499	1.96
INTERACTIONS						
AB				0.0102861	0.0052	18.91
BC	0.021125	0.4335	0.97	0.00326667	0.0506	6.00
RESIDUAL	0.798884		30.03	0.0168		30.88
TOTAL (CORRECTED)	2.15717			0.0543867		

Source: Authors' own elaboration

potassium content data formed 3 homogeneous groups with significant differences between them ($LSD \pm 1.122$, $p < 0.05$) (Fig. 2), according to ANOVA analysis.

Magnesium values decrease from the grain to the straw, and for calcium the highest values are observed in the straw, but their content is relatively stable and no significant differences are observed in the variants of fertilization and introduction of biochar (Fig. 3).

To follow the influence of the studied factors – after application of BC for three and four years (factor C), amount of BC (factor A) and N (factor B) on the content of the elements in the biomass of wheat – a Multi factor analysis was performed. The data were summarized in a Table 3.

The analysis showed that the impact on nitrogen content of biochar applications and the timing of its application was 15% and 39%, respectively. A higher content was reported for variants B3, i.e. when applying BC three years ago. The effect of biochar on nitrogen content four years ago was very weak, as the controls had a higher content. Biochar had an influence on the phosphorus content – 37.21%. The interaction of the two factors (A-the amount of BC imported and B -the time of its application) together was the greatest (18.91%) on the P content, and the total effect of the two factors on the N content was not significant (Table 3).

The obtained data show that the content of the main nutrients in wheat ranges within the limits characteristic of the corresponding crop, and was affected by timing of the biochar application. The N content of the fertilized variants with a high dose of the previous crop (maize) had only a slight increase of 8%. In the study of Benkova et al. (2022), the co-application of nitrogen fertilizer with biochar revealed negligible effect on the N, P, K, Mg and Ca concentration in plant tissues of the previous crop (maize) in the first year. There were significant differences in N content of plants in all treatments compared to controls only in the early plant growth stages. Similar results have been obtained by other

authors (Jones et al., 2012). In other our research, Benkova et al. (2020) found that there is no statistically significant effect of different type and rates biochars application on the content of major macrolelements in the different parts of wheat by variants. In a four-year study on the effect of biochar on wheat growth, nutrient concentrations in straw and grain did not differ depending on biochar applications (Erdal et al., 2024).

On the basis of the determined amount of formed total above-ground biomass and the percentage of elements in it, the export of nitrogen and ash elements and their permanent removal from the field was determined. In wheat, the total biomass ranges from 6038 to 7117 $kg \cdot ha^{-1}$ and exports from 62.26 to 101 $kg \cdot ha^{-1}$ of nitrogen. The lowest biomass was in variant B₍₃₎5N260, and the highest – in variant B₍₃₎10N260, which imported double the amount of nitrogen in corn and biochar three years ago (Table 4). There were no significant differences between the controls and the other variants with biochar applied 3 and 4 years ago, which shows that there was no residual influence of biochar on the total biomass of wheat, only fertilization of the previous crop.

Phosphorus export was relatively low – from 12.52 to 16.56 $kg \cdot ha^{-1}$. The export of potassium with wheat varies from 21.74 to 31.08 $kg \cdot ha^{-1}$. The amount of exported calcium with the total biomass of wheat was low and without differences in the variants, varying between 3.74–5.05 $kg \cdot ha^{-1}$. Magnesium export was 6.91–9.16 $kg \cdot ha^{-1}$. The export of the main macronutrients with the biomass of wheat depends on the reported content in the vegetative organs, but since it varies within narrow limits, exports depend to the greatest extent on the quantities of absolutely dry biomass obtained.

Wheat grain yield

The yield of wheat grain obtained during the experiment in 2022 is presented, ranging between 3285 and 4423 $kg \cdot ha^{-1}$ (Fig.4). Variants B₍₃₎5N130 and B₍₃₎10N260 with biochar in

Table 4. Absolute dry weight and nutrient uptake (kg.ha⁻¹) with wheat, 2022

Variants	Organs	DW	Nutrient uptake (kg.ha ⁻¹)				
		kg.ha ⁻¹	N	P	K	Ca	Mg
K1N130	grain	3554	59.44abc	12.93ab	13.98ab	1.26	5.94
	chaff	190	8.60	1.75	3.40	0.65	0.95
	straw	2760	2.10	0.40	6.50	1.88	1.05
	total	6504	70.14	15.08	23.88	3.78	7.94
K2N260	grain	3384	63.83bc	11.52ab	12.37a	1.34	5.52
	chaff	146	5.85	0.75	3.00	0.76	0.60
	straw	3200	2.65	0.55	6.60	2.05	1.15
	total	6729	72.33	12.82	21.97	4.14	7.27
B ₍₃₎ 5N130	grain	4218	74.22d	13.94bc	21.33d	1.99	6.65
	chaff	164	8.65	1.30	3.05	0.69	0.80
	straw	2500	2.55	0.35	6.70	1.93	0.80
	total	6882	85.42	15.59	31.08	4.60	8.25
B ₍₃₎ 10N130	grain	3714	62.61bc	13.35bc	14.26bc	1.33	6.04
	chaff	165	8.20	1.50	3.10	0.56	0.85
	straw	2900	2.60	0.30	6.85	1.85	0.75
	total	6779	73.41	15.15	24.21	3.74	7.64
B ₍₃₎ 5N260	grain	3321	66.96cd	11.63ab	12.46a	1.40	5.58
	chaff	175	7.75	1.00	2.90	0.72	0.75
	straw	2600	2.45	0.35	7.00	1.75	0.75
	total	6096	77.16	12.98	22.36	3.87	7.08
B ₍₃₎ 10N260	grain	4423	90.27d	15.01c	16.13c	1.90	7.41
	chaff	194	8.25	1.15	3.15	0.94	0.90
	straw	2500	2.95	0.40	7.85	2.21	0.85
	total	7117	101.47	16.56	27.13	5.05	9.16
B ₍₄₎ 5N130	grain	3405	57.05ab	11.22a	13.05a	1.56	5.53
	chaff	122	5.25	0.85	3.15	0.75	0.65
	straw	3200	2.40	0.45	6.70	1.68	0.85
	total	6728	64.70	12.52	22.90	3.98	7.03
B ₍₄₎ 10N130	grain	3659	60.98abc	12.53ab	14.01ab	1.42	5.90
	chaff	161	7.65	1.30	3.10	0.64	0.80
	straw	2600	2.25	0.30	6.40	1.71	0.90
	total	6420	70.88	14.13	23.51	3.76	7.60
B ₍₄₎ 5N260	grain	3285	55.51a	12.08ab	13.26ab	1.38	5.61
	chaff	153	3.70	0.60	2.90	0.70	0.55
	straw	2600	3.05	0.45	7.50	2.01	0.75
	total	6038	62.26	13.13	23.66	4.08	6.91
B ₍₄₎ 10N260	grain	3445	62.53bc	11.98ab	12.14a	1.55	5.83
	chaff	170	6.95	1.05	2.75	0.83	0.80
	straw	2900	3.25	0.55	6.85	2.05	0.95
	total	6516	72.73	13.58	21.74	4.43	7.58

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.

Source: Authors' own elaboration

combination with nitrogen fertiliser showed a significant increase ($p \leq 0,05$) in wheat yield compared to non-biochar controls and other variants. The increase is 12% and 13% compared to the no biochar controls. It was observed that the effect of biochar (B4) on yield decreased after the fourth year, only nitrogen fertilization from the previous crop had an effect.

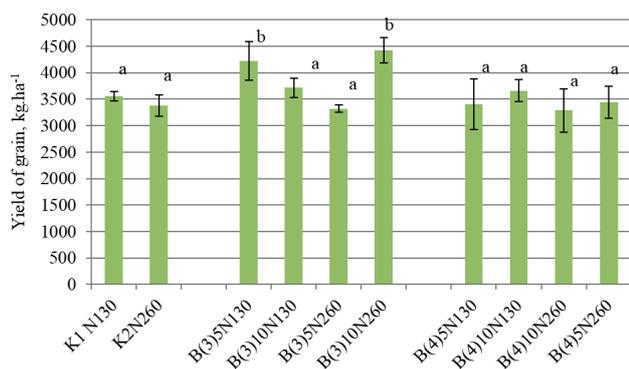


Fig.4. Wheat grain yield (kg. ha⁻¹) at 14% humidity 2022
Source: Authors' own elaboration

A multi-factor analysis was made to evaluate the effect of the factors nitrogen fertilizer, biochar and year on the yield of wheat, depending on the fertilization variants of the previous crop. The factor nitrogen fertilization only had the significant effect (60%) on the yield for 2022, at a confidence level $P \geq 95\%$.

According to data from Agro-statistics of the Ministry of Health, survey "Yields from field crops – harvest 2022", the average yields for the country for wheat grain are 5146 kg.ha⁻¹, and our obtained yields in variants were lower than the average for the country, respectively, 4423 kg.ha⁻¹. This is mainly due to growing the wheat without fertilization and the relatively unfavorable climatic conditions during the experimental year. The positive impact of the amount of biochar on grain yield depends on adequate nitrogen fertilization. In many studies, increased yield was observed when biochar and inorganic fertilizers were applied together. Biochar improves the efficiency of inorganic fertilizers through microbial functions and reduces nutrient loss, thereby making nutrients more accessible to plants (Yeq et al., 2019; Peng et al., 2021). The application of biochar and inorganic fertilizers, especially nitrogen fertilizers in general, provides better nutrient management and crop yield in most soil types.

Agrochemical analysis of the soil after wheat harvest

The results obtained in autumn of 2022, show that there were no significant variant differences in the mineral nitro-

Table 5. Agrochemical characteristic of the soil from the field experiment, after wheat sowing in the autumn of 2022

Variants	Σ N-NH ₄ +NO ₃	P ₂ O ₅	K ₂ O	C
	mg.kg ⁻¹	mg.100g ⁻¹		%
K1N130	10.94	15.41	19.18	0.69
K2N260	10.94	11.75	20.8	0.74
B ₍₃₎ 5N130	9.22	15.53	15.95	0.69
B ₍₃₎ 10N130	9.79	13.76	19.57	0.76
B ₍₃₎ 5N260	12.67	9.62	13.05	0.69
B ₍₃₎ 10N260	12.67	12.68	16.06	0.76
B ₍₄₎ 5N130	12.10	14.68	17.29	0.84
B ₍₄₎ 10N130	11.52	11.33	15.06	0.81
B ₍₄₎ 5N260	11.52	10.92	12.38	0.66
B ₍₄₎ 10N260	8.06	11.22	14.5	0.71

Source: Authors' own elaboration

gen content, which ranges from 8.06 to 12.67 mg.kg⁻¹. This indicates a low supply of this nutrient. Phosphorus values show average storage and also range from 9.62 to 15.41 mg per 100 g⁻¹ soil. The content of mobile potassium varies slightly between 13.05–20.80 mg per 100 g⁻¹ soil (Table 5) without pronounced variant differences. Our results also confirmed that the application of biochar after 3-4 years does not increase the nutrient content of the soil. One of the reasons may be the aging of biochar, which changes its surface functional groups, affecting its specific surface and weakening of the adsorption of macroelements in the soil. On the other hand, biochars do not increase soil nutrients if the soils already have enough nutrients (Erdal et al., 2024).

The results obtained after harvesting the experimental crop, show that higher values of the soil reaction were found in almost all variants compared to the controls (Table 6). Biochar is known to reduce soil acidity from the application of nitrogen fertilizers and thus increase soil fertility. It is interesting to note the more pronounced effect of biochar in variants with lower nitrogen norm and both doses of biochar compared to controls as the pH values increased by 0.2–0.4 units. The highest values of cation-exchange capacity were reported in the post-effect variants B₍₄₎5N130 and B₍₄₎10N130 – 15.3 cmol.kg⁻¹ compared to the other variants studied. The degree of base saturation increases compared to the controls, and this trend was more noticeable in the variants with a lower dose of nitrogen and imported BC in both years. While the total acidity (H_{8,2}), which covers all adsorbed cations with acidic functions, decreases compared to the controls with increasing pH values. For the electrical

Table 6. Soil physicochemical characteristics by variants after harvesting of wheat

Variants	pH	EC Ms/cm	CEC	CEC _{CA}	CEC _A	H _{8.2}	Exch. Al	Ca	Mg	BS %
K1N130	5.7	0.120	14.9	12.4	2.5	2.7	0.3	10.5	1.7	81.88
K2N260	5.7	0.190	14.9	12.4	2.5	2.8	0.3	10.3	1.7	81.21
B ₍₃₎ 5N130	6.0	0.090	15.3	12.7	2.6	2.4	0	11.0	1.9	84.31
B ₍₃₎ 10N130	6.0	0.090	15.3	12.8	2.5	2.3	0	11.2	1.8	84.97
B ₍₃₎ 5N260	5.9	0.310	14.8	12.8	2.0	2.1	0.1	10.8	1.8	85.81
B ₍₃₎ 10N260	5.7	0.150	14.8	12.4	2.4	2.6	0.3	10.4	1.7	82.73
B ₍₄₎ 5N130	5.9	0.080	15.0	12.8	2.2	2.4	0.2	10.8	1.8	84.00
B ₍₄₎ 10N130	6.1	0.130	15.3	12.9	2.4	2.0	0	11.3	2.0	86.93
B ₍₄₎ 5N260	5.8	0.120	15.0	12.7	2.3	2.5	0.2	10.6	1.9	83.33
B ₍₄₎ 10N260	5.8	0.160	15.0	12.8	2.2	2.6	0.3	10.7	1.8	82.67

Source: Authors' own elaboration

conductivity, there were no significant differences in variants ranging from 0.08–0.19 ms/sm.

From the results on total carbon content and organic matter composition (Fig. 5), a slight increase in carbon was observed, with the largest change (0.89 and 0.91 %) in the third year, at low dose N post-effects variants B₍₃₎5N130 and B₍₃₎10N130, and the fourth year variant B₍₄₎5N130. In these variants, the C_{HA}/C_F ratio does not increase and, accordingly, the quality of soil organic matter does not change compared to the controls.

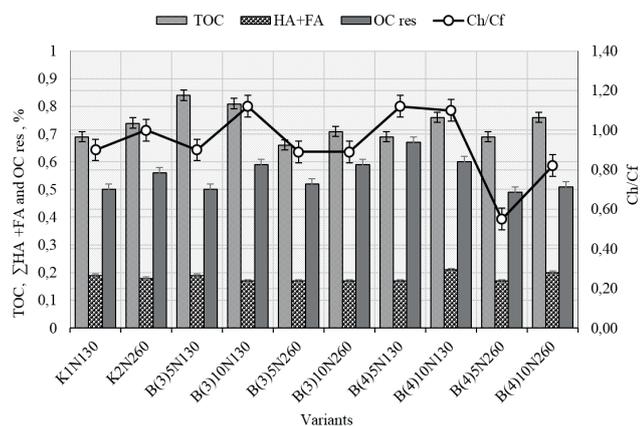


Fig. 5. Content and composition of TOC in Fluvisol by variants

Source: Authors' own elaboration

The impact of biochar application on the agrochemical and physicochemical properties of the soil and, accordingly, on crop yields, may change over time due to the biogeochemical interactions that take place in the soil.

Conclusions

The obtained results conclude that the time of biochar application has a significant effect on the yield of wheat – a higher yield was reported by the variants when biochar was applied in the third year. For the B₍₃₎5N130 and B₍₃₎10N260 variants, the increase was 12% and 13% compared to controls. The data showed that biochar residing in soil at two rates (5 and 10 t.ha⁻¹), for four years, had no significant effect on wheat yield, growth, macronutrient uptake and soil nutrients content compared to the control variants. The nitrogen content in wheat grain was higher in variants with high nitrogen doses and biochar applied three years ago. Biochar's influence on phosphorus content was significant, with the interaction of biochar amount and application timing having the greatest effect. The more pronounced effect of biochar aftereffect was observed on the physicochemical characteristics (pH, CEC and OC) in the third and fourth year compared to the control, in the variants with the lower nitrogen rate and the higher levels of biochar.

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