Scientific Papers. Series A. Agronomy, Vol. LXV, No. 1, 2022
ISSN 2285-5785; ISSN CD-ROM 2285-5793; ISSN Online 2285-5807; ISSN-L 2285-5785

EVALUATION OF BIOCHAR APPLICATION ON SOIL NUTRIENTS

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Abstract

Field experiments with different levels of application of BC and manure were conducted, according to developed methodology based on literature data. Six variants have been developed: 1) V1- control; 2) V2 - with manure (4t/ ha^{-1}); 3) V3 - with biochar (500 kg/ ha^{-1}); 4) V4 - manure (4 t/ ha^{-1}) + biochar (250 kg/ ha^{-1}); 5) V5 - manure (4 t/ ha^{-1}) + biochar (500 kg/ ha^{-1}); 6) V6 - manure (4 t/ ha^{-1}) + biochar (750 kg/ ha^{-1}) under optimum irrigation. For each of the variants were examined the following indicators in dynamics - climate condition, pH, NPK in soil after harvesting of each crops. The dynamics of yields for zucchini, broccoli, broad bean and leek were evaluate, and the biometric data was collected. The aim was to study the effect of imported carbonized plant residues on the content of essential nutrients in the soil.

Key words*: biochar, manure, soil, nutrition, vegetable.*

INTRODUCTION

Maintaining and increasing soil fertility is a key prerequisite for obtaining high and sustainable yields. Soil fertility is one of the factors that are particularly affected by intensive agriculture. In recent years, in the context of climate change, there is a great interest in studying biochar (BC) use in agriculture (Lehmann, 2007).
As a pyrolysis product containing high organic carbon, biochar is able to improve soil physical, hydraulic and fertility properties, to improve biological activity and reduce pollution (Maftu'ah, 2019).
According to many authors the positive effects of biochar are due to the chemicals and nutrients present that it contains and because of its absorption capacity and the ability to retain nutrients (Hammes and Schmidt, 2009; Lehmann et al., 2011; William & Qureshi, 2015). It also increases the soil organic matter (SOM), which is helpful for the plants (Verheijen et al., 2009). Besides this, it also adjusts the pH of the soil to neutral, which increases the cation exchange capacity level and is beneficial for the growth of the plants. Soil fertility can be improve by amendments applications such as biochar.
Biochar is widely studied in terms of its effect on water-physical properties and soil fertility, but only a small part of the results was obtained from field experiments.
The aim is to study the effect of imported carbonized plant residues on the content of essential nutrients in the soil.

MATERIALS AND METHODS

The experiment was carried out in the experimental field of the University of Forestry Sofia (42° 7′ N, 23° 43′ E). The soil is Fluvisol, slightly stony. This area came under a continental climatic sub region, in a mountain climatic region.
The experiment was set with two amendment - biochar and manure (used as a background). During the spring cultivation, the two ameliorants were incorporated into the soil at 15 cm depth. Six variants were developed:
V1- soil – Control;
V2 - with manure (4 t/ha^{-1});
V3 - with biochar (500 kg/ ha^{-1});
V4 - manure (4 t/ ha^{-1}) + biochar (250 kg/ ha^{-1});
V5 - manure (4 t/ ha^{-1}) + biochar (500 kg/ ha^{-1});
V6 - manure (4 t/ ha^{-1}) + biochar (750 kg/ ha^{-1}).
The experiment was carry out by randomized complete block design with four replicates and protection zones.
During the first year of the experiment, two vegetable crops were selected: zucchini as the first crop cultivation and broccoli as a second one. In the second year, the selected crops were faba beans, first crop, and leeks, the second crop. The selected varieties that were used for

the purpose of the experiment were zucchini, variety Izobilna (as a standard variety for Bulgaria); broccoli is of two varieties: Monty F1, with a 60-day growing season and Corato F1, with a 75-day growing season; broad beans, Super Guadaluche variety, and leek, Starozagorski kamush variety.

Plants were irrigated by a drip irrigation system; the tape drip hose used has the following characteristics: I-Tape 8 mil/distance between drippers 20 cm/5.3 lh. The irrigation rate is 40 mm.

Soil samples for agrochemical analysis were taken by variants at the beginning of vegetation and at the end of the growing season of each crop. Sampling is perform with a soil probe from a depth of 0-30 cm. One medium sample was taken from each section, formed by 10 stitches of the probe diagonally. The soil from all points (from one depth) is mixed in order to homogenize in a larger vessel. An average sample weighing 400-500 g was taken and placed in a packaging bag.

Soil samples is given for laboratory analyses according to approved methods.

Samples of used amendments (biochar and well-decomposed caw manure) have been taken before conducting the experiment.

RESULTS AND DISCUSSIONS

Climatic conditions directly affect the development of plants, and hence the levels of evapotranspiration and nutrient uptake.

Information about the annual amounts of precipitation in the Sofia region, as well as the average monthly temperatures have been collected and analysed. A rainfall security curve has been prepared by year, and the data cover a long period of 31 years (Figure 1). This information is important because rainfall in the autumn - winter period of the previous year is essential for the formation of moisture reserves for the next experimental year.

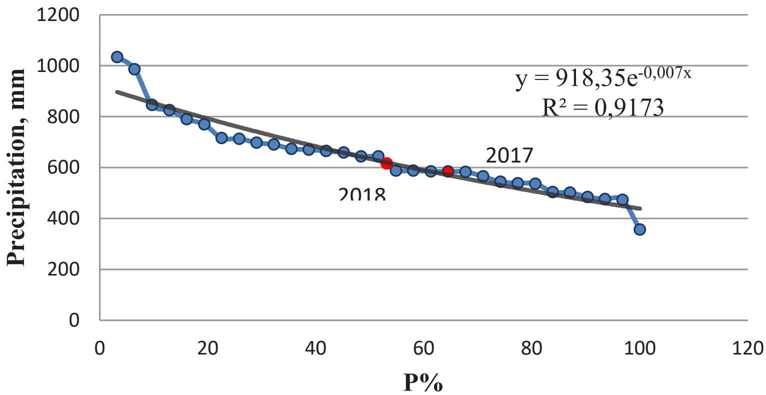

Figure 1. Curve of precipitation for the period 1987-2018

Based on the collected data the extremely wet years with security below 15% are 2013 and 2002, and the dry years with security over 90% are 2000 and 2010.

The experimental year 2017 was characterized by security close to 70%, which defines it as the average year in terms of precipitation.

The second experimental year (2018) was drier, with a security of 53%. The rainfall during the vegetation of the vegetable crops was evenly distributed.

Despite its even distribution, the amount was insufficient to ensure the development of plants, as the necessary water treatment was maintained by a drip irrigation system.

Soil temperature is the function of heat flux in the soil as well as heat exchanges between the soil and atmosphere (Elias et al. 2004). The soil temperature affects pH reaction, cation exchange capacity, and soil mineralization.

The average monthly air temperature over the experimental periods does not exceed 23°C. During the experimental period (April-July, 2017), the weather conditions were favourable for the growth and development of zucchini (Figure 2), with average seasonal temperatures close to normal. Higher temperature values were observed at the beginning of July during broccoli vegetation, with the maximum reported value was 8.6°C.

The reported temperatures were on average + 1.2°C higher in comparison with the data published by National Institute of Hydrology and Meteorology, compared to the norms for the period 1961-1990. The average daily temperatures during the development of broad beans were permanently above 10°C, reaching 20°C in early May. These temperatures were suitable for the development of broad beans and its timely germination. In period of leek vegetation, the average monthly air temperature does not exceeded 23°C. At the end of September, there was a sharp drop in temperature, which dropped from 16°C to 9°C.

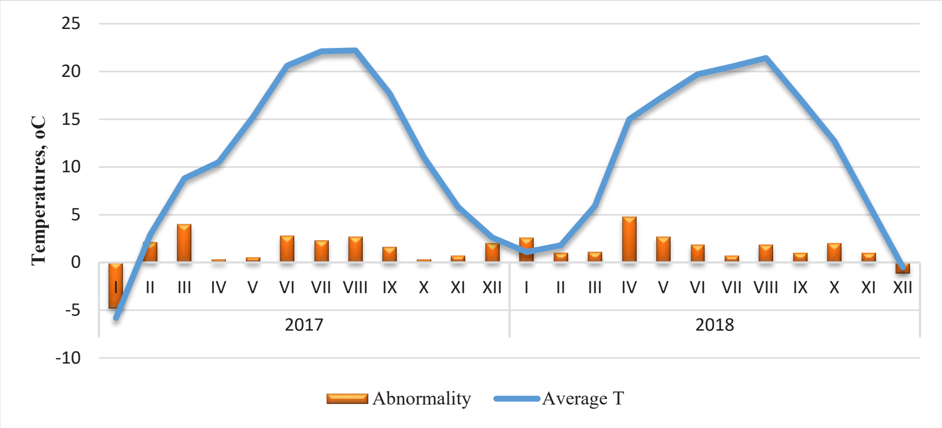

Figure 2. Average monthly temperatures during 2017-2018

The content of basic nutrients, heavy metals and pH was obtained from soil.

The pH reaction was slightly alkaline. The manure contained a high amount of organic carbon, well stored with total N and medium stored with P and K, the values of the mobile forms being approximately equal to the reported total amounts of P-0.89% and K-1.31% (Table 1). The ratio of ammonium to nitrate forms indicates that the mineralization process is not fully complete (NH_4 - 79.9 mg/kg and NO_3-0.9%).

Table 1. Nutrient content of cow manure

Indicator	Unit	Method	Value
pH		BS EN 15933	7.51
Organic C	%	BS EN 13137	16.92
N	%	BS EN 13342	2.06
K	%	BS EN 16170	1.4
P	%	BS EN 16170	1.39
K mobile	%	BS EN 16170	1.31
P mobile	%	BS EN 16170	0.89
NH_3	%	BS EN 16177	0.9
NH_4	mg/kg	BS EN 16177	79.9

The biochar, used to conduct the experiment, was made from wood chips. The pH reaction in the analysed sample from BC was highly alkaline (Table 2).

Table 2. Chemical characteristics of BC obtained from wood chips

pH	EC mS/m	C %	N %	P %	K %	Ca %	Mg %	$CaCo_3$
10.8	45	61.8	0.39	0.22	0.85	2.18	0.23	5.4

It contained a large amount of carbon, which confirms the ability of BC to deposit carbon into the soil, reducing its release into the atmosphere.

The mineral content of NPK was minimal. The presence of $CaCo_3$ was one of the causes of the highly alkaline reaction of the substrate (Table 2).

Soil samples for analysis from the beginning of the experiment and after the end of the vegetation of each crop, showed the influence of ameliorants on the agrochemical composition of the soil.

The sampling depth was consistent with the main root zone of the zucchini.

The soil reaction was slightly alkaline, approaching a depth-neutral layer (Table 3).

Table 3. Agrochemical characteristics of Fluvisol before conducting the experience with zucchini

Depth cm	pH (H_2O)	Humus %	N % Kjeldahle	P_5O mg/100 g	K_2O mg/100 g
0-20	7.3	1.73	0.160	79.2	18.1
20-40	7.2	1.64	0.154	94.81	19.9

Soil data obtained before amendments incorporation, showed a good degree of storage of K_2O, a very high content of P_5O, which increases in depth. The soil was poorly humus with content varying between 1.73% for the arable horizon and 1.64% for the sub arable horizon. The data obtained were characteristic of this soil type.

After the end of zucchini vegetation, the soil samples were taken from a depth of 0-30 cm. It is obvious that the humus content increased in variants with higher BC content in combination with manure (Table 4).

Table 4. Soil analysis after zucchini vegetation end

Variants	pH (H_2O)	Humus (%)	N (%)	P_2O_5 (mg/100 g)	K_2O (mg/100 g)
Var. 1	7.2	1.36	0.165	53.60	10.0
Var. 2	7.3	1.33	0.173	68.45	10.8
Var. 3	7.3	1.30	0.143	51.05	11.0
Var. 4	7.1	1.82	0.189	81.60	14.1
Var. 5	7.3	1.91	0.194	84.32	17.8
Var. 6	7.3	1.90	0.203	81.84	19.3

The reduced content of total N in Var. 3 with biochar, probably was due to the adsorption of NH_3 or organic N onto its surface by cations or anion exchange reactions and the increased immobilization of N, as a consequence of the additional C incorporate in soil with BC. A number of authors investigating BC produced at different pyrolysis temperatures (Yao et al., 2012) reported similar results.

A decrease in P_2O_5 content in variant 3 was observed with BC alone, this is most likely due to the ability of BC to absorb phosphorus and nitrogen anions on its surface. The combined introduction of BC and manure had a positive effect on the potassium content of the soil as the soil storage of K increased from medium to very good. This was probably due to the ability of BC to retain nutrients in the soil directly through the negative charge that develops on its surfaces. "Cations" are positively charged ions, in this case these are nutrients such as calcium (Ca_2+), potassium (K+), magnesium (Mg +) and others. Many authors reported for increasing levels of K in soil after BC application (Cheng et al., 2008; Lentz and Ippolito, 2012). It was considered that plants (Karer et al., 2013) could rapidly absorb available K in the BC composition. However, some researchers have suggested that the high availability of K for plants may not continue beyond the year of application (Steiner et al., 2007).

After harvesting the precursor (zucchini) soil samples were taken for agrochemical analysis, the data are presented in Table 5. These data are the starting point for the broccoli vegetation. To monitor the dynamics of nutrients in the soil, as well as the influence of amendment after the end of the experiment with broccoli, soil samples were taken again. There was an increase in pH by variants, as the medium becomes slightly alkaline. In variant 2, which was only with the application of manure, the pH approached neutral (Table 5).

Table 5. Soil analysis after harvesting the experiment with broccoli 2017

Variants	pH (H_2O)	Hummus (%)	N (%)	P_2O (mg/100 g)	K_2O (mg/100 g)
Var. 1	7.2	1.66	0.174	69.05	10.3
Var. 2	7.1	1.87	0.175	81.68	11.5
Var. 3	7.5	2.02	0.181	86.78	11.9
Var. 4	7.3	1.97	0.189	81.76	14.9
Var. 5	7.4	2.07	0.195	76.87	13.9
Var. 6	7.4	2	0.197	87.12	16.7

The humus content varied between 1.66% for the control variant and 2.7% for variant 5, containing the optimal amount of BC and manure. Over time, mineralization of organic carbon imported with manure occurs, which led to an increase in the humus content compared to the samples after harvesting the precursor. Plant residues after harvesting the previous crop also had an effect.

Total nitrogen increased in variations. In the mobile forms, the ammonia nitrogen is the highest in variant 2, in which only manure is applied in the dose 4 t/da, with the increase of the norm of BC by variants a decrease of the content of NH_4 was observed, which was due to the high porosity of BC which retained positively charged cations on its surface.

In the case of a nitrate form, the opposite trend was observed - the values increased in more variants, ranging from 0.022 to 0.102 mg/kg. The soil was very well stocked with phosphorus, with the highest values reported in variants 6 with an increased rate of BC- 87.12 mg/100 g. Potassium reserves were low to medium, and increased with increasing rates of imported BC.

In the second year of the experiment (2018), broad beans and leeks were grown. The dynamics of the main nutrients in the root layer was monitored. After harvesting the broad bean, the soil reaction was close to neutral, their no significant differences between variants (Table6).

Table 6. Soil analysis after harvesting the experiment with broad beans 2018

Variants	pH (H_2O)	Hummus (%)	N (%)	P_2O (mg/100 g)	K_2O (mg/100 g)
Var. 1	7;1	1.552	0.182	48.4	18.0
Var. 2	7.2	1.690	0.186	58.5	18.4
Var. 3	7.2	1.603	0.188	53.4	16.5
Var. 4	7.2	1.741	0.189	63.6	21.5
Var. 5	7.2	1.845	0.199	76.5	18.7
Var. 6	7.2	1.879	0.210	74.0	19.7

The humus content varied between 1.552% for the control variant and 1.879% for variant 6 containing a larger amount of BC. The carbon content corresponded to that of hummus, ranging from 0.90% to 1.09%. It was noteworthy that the total nitrogen had higher values compared to the samples before planting, which was due to the nitrogen-fixing ability of broad beans. The soil was well stocked with phosphorus, with the highest values reported in variant 5 with increased rate of BC and manure 4 t/da - 76.5 mg/100 g. The phosphorus content decreased after the vegetation of beans, but the trend continued. In variant 6 the K content increased to 19.7 mg/100 g, which was a good reserve for Fluvisol.

Soil samples after the end of the vegetation experiments showed that the soil reaction was kept around neutral to very slightly alkaline (Table. 7).

Table 7. Soil analysis after harvesting the leek experiment 2018

Variants	pH (H_2O)	Hummus (%)	N (%)	P_2O (mg/100g)	K_2O (mg/100g)
Var.1	7.2	1.465	0.176	45.9	16.3
Var.2	7.2	1.345	0.182	58.6	17.2
Var.3	7.2	1.396	0.180	53.4	16.5
Var.4	7.3	1.362	0.185	61.3	18.0
Var.5	7.3	1.500	0.189	58.8	18.6
Var.6	7.2	1.655	0.191	69.3	23.2

After harvesting the experiment, layer-by-layer depletion of phosphorus was observed, however, the storage remained very good. The data showed that leeks exported some of the nutrients, depleting a significant amount of nitrogen fixed by broad beans.

In the variants with a higher BC content combined with manure, the humus content increased. Decreased P_2O content was observed in variant 3 with BC only, most likely due to the ability of BC to absorb phosphorus and nitrogen anions on its surface. Regarding the content of K_2O in the soil, there was a clear tendency to increase with the amount of imported BC. Compared to the initial amount of potassium in the soil before the experiment, variant 6 showed a better supply despite the export of nutrients with plant products.

The production from the selected experimental crops was harvested by variants and replicates. The average yield data show that the tested soil ameliorants have an impact on the yield (Figure 3).

The greatest impact on the yield of zucchini had two options - the self-application of manure and the combination of manure and biochar, with an increased rate of biochar.

The influence of the ameliorants used on the broccoli yield differed between the two varieties. In the variety with short vegetation (Monty F1), the best effect was the option with combined use of the two ameliorants, with a reduced rate of biochar. In the case of the variety with long vegetation (Corato F1), two variants had an impact - with independent use of manure and with combined use of the two ameliorants, with average (standard norm) for the use of biochar.

In the case of beans, the option with self-use of biochar had the best effect on yield.

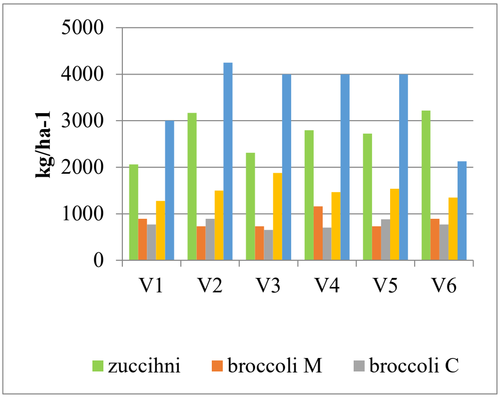

Figure 3. Average yield of experimental crops

Leek yields was best influenced by the option of self-use of manure, followed by the options of self-use of biochar and the combined use of the two ameliorants.

CONCLUSIONS

Based on the experiment the results demonstrate the positive effect of BC on soil organic matter content and water-physical properties.

For variants with higher BC content in combination with manure humus content increases. The reduced content of total N in variant 3 probably is due to the adsorption of NH_3 or organic-N onto its surface by cationic or anion exchange.

The lowest NPK values were reported in variant 1 clear soil and variant 3 with only BC added. In the variants of BC, as the rate of imported carbonated plant residues, the NPK content also increases. The highest N content in the experimental variants is reported in variant 6 (manure 4 t/da + BC 750 kg/da).

It concluded that the addition of carbonized plant residues in combination with organic fertilization could use as a soil improver and as a means of utilization of plant residues in agriculture.

Based on the experiment, the results demonstrate the positive effect of BC on the content of organic matter in the soil and its retention capacity.

In variants with a higher BC content in combination with manure, the humus content increases. The reduced total N content in variant 3 is probably due to the adsorption of NH3 or organic N on its surface by cationic or anionic exchange.

The lowest NPK values were reported in variant 1 non-treated soil and variant 3 with only BC added. In the BC variants, with the increase in the amount of imported carbonized plant residues, the NPK content also increased. The highest N content in the experimental variants wass reported in variant 6 (manure 4 t/da + BC 750 kg/da).

It can be concluded that the addition of carbonized plant residues in combination with organic fertilizers can be used as a soil improver and as a means of utilizing plant residues in agriculture.

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