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Effect of organic amendments on soil characteristics and maize biomass in a greenhouse experiment

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Abstract

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A pot experiment was performed with maize on Fluvisol. The aim of this study was to establish the effect of some soil organic amendments on the chemical properties of Fluvisol and maize biomass. Three organic products were used as ameliorants – biochar, compost of plant residue and sewage sludge and added in increasing amounts (1%, 2.5% and 10%) to the weight of soil. A soil without ameliorants was used as control. The results of the vegetation experiment with maize showed that organic amendments lead to improvement of soil properties. All amendments increased soil pH by 0.2-0.7 units, and the medium (2.5%) and highest rate (10%) of biochar and compost increased CECsa and % base saturation. The study showed that the tested organic amendments increased the ameliorative efficiency of the treatment carried out. The application of compost and sewage sludge resulted in an increase in soil available K and P, but only the addition of compost increased soil available N. The application of the three organic amendments affected plant nutrient accumulation, especially with respect to N and K, when higher rates were added. The highest percentage of the studied elements was observed in the variants with the maximum dose of ameliorants. Biochar had the least impact on maize biomass growth. The compost and the sludge were found to be equally efficient at 10%, resulting in an increase in the maize biomass. It can be concluded that compost had a greater impact on soil chemical properties, available forms of nutrients and maize growth compared to the other two organic amendments.

Keywords: compost; biochar; sewage sludge; biomass; maize; soil characteristics

Introduction

In recent years, the loss and the disturbed balance of soil organic matter as a result of intensive agriculture has been a major cause of soil fertility loss. A variety of soil organic amendments, e.g., animal fertilizers, biochar, compost and sewage sludge are used, extremely rich in organic substances and macro- and microelements which improve soil quality by increasing soil organic matter stocks, growth and diversity of microbial communities and available nutrients (N, P, K, Ca and Mg) (Atanassova et al., 2005; 2006; 2011; 2012; Atanassova & Teoharov, 2009). On the other hand, the safe reutilization of organic waste (composts, animal manures, crop residues), applied as soil ameliorants is also allowed (Gómez – Sagasti et al., 2018).

Despite of the great benefits of organic ameliorants, there are also potential environmental risks due to the danger of having high concentrations of heavy metals, organic pollutants and pathogenic microorganisms in them, as well as causing excess of nutrients in soil (Scotti et al., 2015; García et al., 2017; Semblante et al., 2015; Atanassova et al., 2006; Atanassova et al., 2012; Harizanova et al., 2011). There are different regulations and standards for the quality of composts and sewage sludge applied to agricultural soils in different European countries in line with the implementation of the Directive № 86/278/ EEC. In Bulgarian legislation they are regulated by the „Ordinance on the procedure and method for the recovery of sludge from wastewater treatment through its use in agriculture", of 14 December 2004.

Most studies have focused on the effects of organic amendments on the physical, chemical properties of soils and the resulting crop production. The addition to soil of green residues (Aslam et al., 2014), sewage sludge (Atanassova et al., 2006; Guerrini et al., 2017), biochar (Simeonova et al., 2019; Benkova et al., 2020; Sohi et al., 2010) significantly increase plant growth and crop yield (Hartl & Erchart, 2005), which is mainly due to increased biomass and enhanced activity of soil microorganisms (Lucas et al., 2014). According to other studies, the physical structure of the soil is improved, e.g., density, pore size and stability of aggregates (Scotti et al., 2013), moisture holding capacity (Karami et al., 2012) and the concentration of soluble organic carbon, sulfate and chloride in the soil solution (Simeonova et al., 2019).

Other studies report significant benefits of improving the physico-chemical and chemical properties of soils and the use of composts and sewage sludge (Marinova et al., 2012; Kolchakov et al., 2016; Zlatareva et al., 2018). An assessment of the influence of soil organic ameliorants (biochar, compost, sewage sludge, textile industry sludge, etc.) on the physical, chemical and biological properties of two soil types (Fluvisol and Haplic Vertisol) was made in a preliminary model experiment (Hristova et al., 2021; Perfanova et al., 2020). The results obtained serve as the basis for the present study.

The aim of the study was to establish the effectiveness of some soil organic amendments on the chemical properties of Fluvisol and maize biomass in the conditions of a pot experiment.

Materials and Methods

A pot experiment was performed with maize on Fluvisol for three months (May – July 2020), consistent with the results of preliminary incubation experiment (Hristova et al., 2021). The Alluvial-meadow soil according to the classification of soils in Bulgaria is defined as *Eutric Fluvisol* – FLeu (FAO, 2015). It is characterized by a weakly acidic to neutral reaction, with a low content of total nitrogen, organic matter and mineral nitrogen, low cation exchange capacity, and low supply of available phosphorus and potassium. The electrical conductivity is also low, as a result of which the amount of water-soluble salts is very small (Table 1).

The organic materials used as ameliorants were biochar, compost of plant residues and sewage sludge. They were added in increasing amounts (1%, 2.5% and 10%) to the weight of the soil. The ameliorant treatments were the following:

- Control – initial soil (Soil);
- 1% biochar by soil weight (BC1);
- 1% compost by soil weight (C1);
- 1% sewage sludge by soil weight (SS1);
- 2.5% biochar by soil weight (BC2.5);
- 2.5 % compost by soil weight (C2.5);
- 2.5 % sewage sludge by soil weight (SS2.5);
- 10% biochar by soil weight (BC10);
- 10% compost by soil weight (C10);
- 10% sewage sludge by soil weight (SS10).

After 30 days of composting of the materials at 70% of the field capacity in three replications with 2 kg soil per pot were sown 3 corn seeds. The physico-chemical properties of the soil (pH, cation exchange capacity, exch. Al, exch. Ca and Mg) were determined by the method of Ganev & Arsova (1980). Analysis of the total forms of heavy metals was performed by decomposition with "aqua regia" (ISO 11466:1995). Mineral nitrogen and available P and K were assessed following the methods of (Kjeldahl & Ivanov, 1984). The maize was grown and harvested at 45 days. After harvesting, the content of macronutrients (N, K and P %) was analyzed and their plant uptake was determined. The nitrogen content in plant samples was determined by wet combustion by the Ginzburg method, and potassium and phosphorus by ash analysis (Peterburgskii, 1986). Before setting the experiment, chemical and agrochemical characteristics of the ameliorants – biochar, compost and sludge, were analyzed (Table 2). Statistical data were performed by using One-way ANOVA method from the package Stat graphics, Centurion 15.

Results and Discussion

The data of the chemical and agrochemical analyses of ameliorants (Table 1) showed that the total and mobile forms of nitrogen were the highest in the sewage sludge, 3.23% and 247.1 mg/kg, respectively. The availability of K and P is generally higher in most compost than the availability of N (Harrison et al., 2008). In our study, the highest content

Table 1. Physicochemical properties of the soil.

	pH (H_2O)	EC	CEC	Ca	Mg	BS	OM	∑ $N\text{-}NH_4$+NO_3	P_2O_5	K_2O
		$mS.cm^{-1}$	$cmol.kg^{-1}$			%	%	$mg.kg^{-1}$	$mg.100\ g^{-1}$	
Soil	6.05	0.101	16.5	10.8	1.7	73.94	1.25	19.6	12.7	19.4

Table 2. Chemical characteristics of the soil ameliorants (means)

Parameters		Biochar	Compost	Sewage sludge
pH/H_2O		7.9	8.7	6.8
EC	mS. cm^{-1}	0.13	1.6	0.55
CEC	cmol.kg^{-1}	10.9	44.7	51.6
Ca exch.	cmol.kg^{-1}	7.8	40	35
Mg exch.	cmol.kg^{-1}	3.1	4.5	9.6
base saturation (% BS)	%	100	99.6	86.4
C	%	31.7	14	14.6
N	%	0.36	1.18	3.23
C / N		88.1	11.8	4.52
∑ N-NH_4+NO_3	mg.kg^{-1}	47.2	61	247
P_2O_5	mg.100g^{-1}	15.2	156	261
K_2O	mg.100g^{-1}	427	1289	181
Cu	mg.kg^{-1}	3	43	361
Zn	mg.kg^{-1}	5	124	1631
Pb	mg.kg^{-1}	5	17	28
As	mg.kg^{-1}	0	18.2	14.8
Cr	mg.kg^{-1}	0	9	45
Co	mg.kg^{-1}	0.13	5.06	4.89
Cd	mg.kg^{-1}	0.84	1.88	3.39
Ni	mg.kg^{-1}	0	0.00	11.1
Se	mg.kg^{-1}	0.0	16.5	1.3
Hg	mg.kg^{-1}	0.94	0.00	2.12
Al	mg.kg^{-1}	27	5655	8047
Fe	mg.kg^{-1}	51	82 785	4157
Mn	mg.kg^{-1}	173	408	348

of mobile potassium was observed in compost, which was mainly produced from plant and food residues. The available forms of phosphorus were found to be higher in the sludge and compost. The higher content of exchanged Ca and Mg determines the high sorption capacity of compost and sewage sludge. The content of organic carbon is highest in biochar, but our preliminary research shows that carbon is in a stable /residual/ form, difficult to decompose and mineralize. There are differences in the total content of heavy metals in the soil organic additions. According to Hudcová et al. (2019), more than 50% of the produced sewage sludge is used in agricultural soils in Bulgaria (data from 2015). The concentration of copper and zinc in the sludge is the highest, but they did not exceed the national regulation standards (Regulation, 2004). In the compost total heavy metal contents did not exceed maximum permissible levels (MPL), in accordance with Table A1-3 in Annex № 1 of the Regulation for the treatment of biowaste (Regulation, 2017).

The agrochemical analyses of the Alluvial-meadow soil (Figure 1) showed that the addition of compost and sewage sludge increased the plant available phosphorus and potassium. The highest level of mobile phosphorus is realized by composting the soil with sludge which reaches up to 100 mg P_2O_5/100g soil, followed by the compost.

The amount of mobile potassium also increased with the application of the three amendments compared to unamended soil. This is due to the higher content of K of the organic components (Table 2).

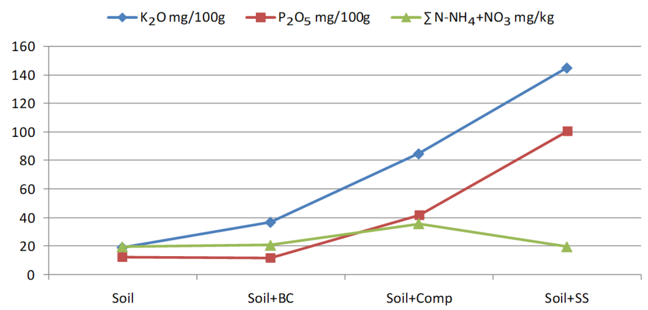

Fig. 1. Agrochemical properties of Fluvisol and added amendments –biochar, compost and sewage sludge

The significant amounts of available forms of phosphorus and potassium in the soil can cause depression in yield of plants, because they exceed the values of the average thresholds of these elements in the soil. In our previous study (Simeonova et al., 2019) on Alluvial-meadow soil, it was found that the applied biochar affects the available K, as well as increases its stock in soil by variants (37 – 43 K_2O/100g). In the research work of Zlatareva et al. (2018), using 11% compost and various compost mixtures, the K content reached 87 and 183 mg K_2O/100 g of soil, respectively. The amount of soil mineral nitrogen increased only at compost addition compare to the other nutrients. The different organic materials have different N release patterns depend on the interactions between the material, the crop and the environmental conditions (Hue & Silva, 2000). The application of biochar can reduce the available nitrogen for plants, which is due to nitrogen immobilization (Liu et al., 2018; Werner et al., 2018). Plant residue compost can increase the nitrogen retention in the soil system by stimulating plant uptake and microbial immobilization (Steiner et al., 2008).

Table 3 shows the physico-chemical parameters of the Alludial-meadow soil at the end of the experiment. In all the variants was found a pH increase compared to the control due to the alkaline reaction of the added organic ameliorants.

There was an increase in pH (H2O) values, with the 10% biochar, compost and sludge treatments increasing to 7.1, 7.0 and 6. 8, respectively, compared to the control (pH 6. 3). The increase in soil pH is related to the reaction of the strongly acidic positions (CEC_{SA}), with its hydrogen ions being replaced by exchangeable bases. In the control variant CEC_{SA} was 11.5 cmol.kg^{-1} and increases in the variants with addition of 10% biochar and compost to 12.4 cmol.kg^{-1} and 13.6 cmol.kg^{-1}, respectively. The soil analyses showed that the soil exchange capacity was hardly changes. The variation is mainly at the expense of the strongly acidic positions, reducing the total acidity ($H_{8,2}$) especially in the variants with 10% biochar and compost added. In the treatment of 10 % compost, the greatest reduction in total acidity to 1.8 cmol.kg^{-1} was recorded compared to the control variant, where it was 4.2 cmol.kg^{-1}. That was at the expense of the exchangeable bases (Ca), which increased from 10.9 cmol.kg^{-1} to 12.7 cmol.kg^{-1} in the 10% compost variant. The bases interact with the weakly acidic positions (CEC_a) and from 5.2 cmol.kg^{-1}, it decreased to 3.0 cmol.kg^{-1} in the variant with 10% compost. The degree of base saturation increases, and this trend is more noticeable in the variants with medium and high dose of biochar and compost.

The results (Fig. 2) showed that increasing the percentage of ameliorants increases the biomass of maize, with the exception of the variant with biochar. When the least amount of ameliorant was applied, the maize biomass increased only in with sludge (SS1) and compost (C1) variants. The addition of biochar at all levels (B1, B2.5 and B10) had no effect and no significant difference with the control. The addition of the medium (2.5%) and the largest amount of the ameliorant (10%), again showed a significant increase (LSD 0.536, $p < 0.05$) in biomass in the sludge and compost compared to the control. The greatest positive effect was shown for the variant C10 where biomass increased by about 76 % compared to control. The value of 10% SS variant was statistically different ($p < 0.05$) from C10 variant with an average 4-5 fold increase in crop biomass in both variants. The increase in plant biomass due to the use of sewage sludge and compost has been reported in numerous studies (Vaca et al., 2011; Elsalam et al., 2021). The supply of nutrients in the form of N, K and P as well as trace elements and organic matter from

Table 3. Physico-chemical characteristics of the investigated soil with increasing rates of organic ameliorants after the end of the experiment

Variants	pH/ H_2O	EC	CEC	CEC_{SA}	CEC_A	Total acidity $H_{8.2}$	Exch.Al	Exch. Ca	Exch Mg	BS
		mS/cm	cmol.kg^{-1}							%
Soil	6.3	0.07	16.5	11.5	5.2	4.2	0	10.9	1.8	74.55
BC 1	6.5	0.07	16.4	11.5	4.9	3.8	0	10.8	1.8	76.83
Com1	6.5	0.07	16.5	12.3	4.2	3.9	0	11.2	1.8	76.36
SS1	6.4	0.07	16.5	11.3	5.2	4.1	0	10.4	2.0	75.15
BC2.5	6.7	0.08	16.1	12.1	4.0	3.4	0	10.8	1.8	78.88
Com 2.5	6.6	0.09	16.6	12.7	3.9	3.3	0	11.3	2.0	80.12
SS2.5	6.6	0.09	16.6	11.6	5.0	4.3	0	10.6	2.0	73.50
BC10	7.1	0.10	16.0	12.4	3.6	2.8	0	10.8	1.9	82.50
Com10	7.0	0.18	16.6	13.6	3.0	1.8	0	12.7	2.1	89.16
SS10	6.8	0.11	17.0	10.8	6.2	4.5	0	10.6	2.2	73.50

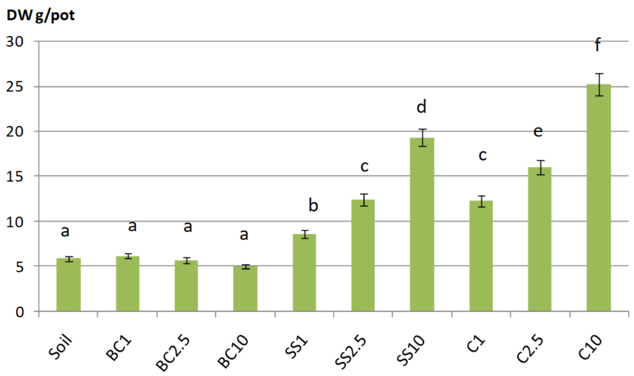

Fig. 2. Dry biomass (g/pot) by variants (a, b – means followed by the same symbol are not significantly different at P < 0.05 level)

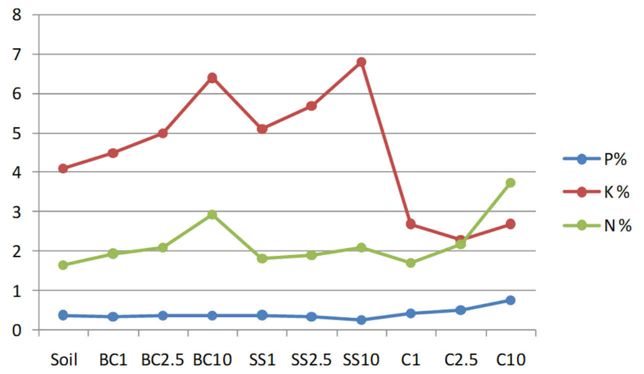

Fig. 3. Content of nitrogen (%), potassium (%) and phosphorous (%) in biomass of maize

the decomposition of compost and sludge is the likely cause of the observed positive effect on dry matter

The macronutrients in the plant biomass were also analysed. The nitrogen content in the plants ranged from 1.65% to 3.74%, with the highest content in plant biomass recorded in the maximum rate (10%) biochar and compost treatments. The data showed that the content of potassium varied from 2.30 to 6.80% in the plant biomass. Compared to the control variant, the content of K was the highest in the variants with the maximum of biochar and sludge dose. This result indicated that biochar effect as a soil conditioner modifies the soil chemical properties and leads to increased uptake of soil nutrients N and K. There was some decrease in the content of this element in all variants in the compost, despite the high amount of exchangeable potassium in the ameliorant itself (1289 mg/100 g). It was likely that potassium was not taken up by plants, suggesting that the K ion can be easily replaced in the soil solution by Ca and Mg cations or lost by leaching. The values of P content in the plant biomass for all treatments were the lowest of the other elements and ranged within a narrow range of 0. 26 – 0.76 %. Most plants need from 0.2 to 0.5% P on a dry matter basis for normal growth (Hue & Silva, 2000). The phosphorus content of plants decreased in the variants as the percentage of sewage sludge increases. It was evident that plant available P from sewage sludge was in a poorly available form and was fixed by the soil, resulting in low phosphorus content in plants.

Based on the amount of dry biomass of maize and the average nutrient content of the maize, their export by variants was determined (Table 3). The obtained results for the nitrogen uptake by the crop were consistent with the increase of the maize biomass with the increase of the dose of ameliorants.

The highest amount of dry biomass in all variants of the experiment was reported in the variant with 10% compost, respectively, uptake of nitrogen was the highest in this variant. The lowest amount of biomass and, consequently, the lowest nitrogen uptake was observed in the control and the biochar variants. Uptake of potassium was the highest in the 2.5 and 10% sludge variants. There was a very good correlation between plant biomass and uptake of nitrogen ($R = 0.92$, $p < 0.0002$) and phosphorus ($R = 0.87$, $p < 0.0009$), and a weaker correlation between biomass and uptake of potassium ($R = 0.67$, $p < 0.03$). The highest uptake of P was found in the compost treatment and can be explained by the better mineralization of the material as well as its higher availability to plants.

When the same amendments were tested in a model experiment, compost from biodegradable waste and sewage sludge also had the most favourable effect on the development of soil microorganisms in the studied soil (Perfanova et al., 2020). Hristova et al. (2021) reported that transforma-

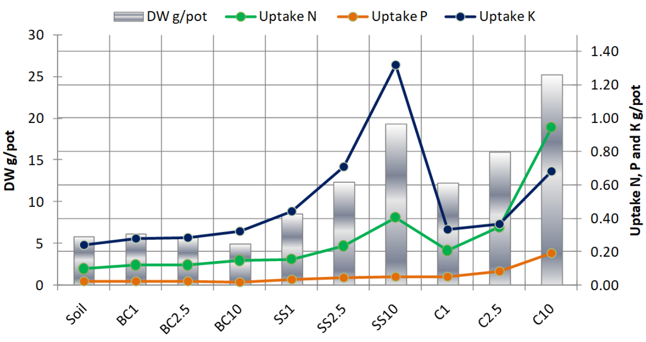

Fig. 4. Biomass of maize (DW/pot) and nutrients of uptake

tions occurred in the content and composition of soil organic matter when the different ameliorants were mixed with with Alluvial-meadow soil of Tsalapitsa, Plovdiv.

Conclusions

The results of the vegetation experiment with maize showed that organic amendments lead to improve of soil properties. All amendments increased soil pH by 0.2-0.7 units, and the medium (2.5%) and highest rate (10%) of biochar and compost increased CEC sa and % base saturation. The study showed that the tested organic amendments increased the ameliorative efficiency of the treatment carried out. The application of compost and sewage sludge resulted in an increase in soil available K and P, but only the addition of compost increased soil available N. The application of the three organic amendments affected plant nutrient accumulation, especially with respect to N and K, when higher rates were added. The highest percentage of the studied elements was observed in the variants with the maximum dose of meliorants. Biochar had the least impact on maize biomass growth. The compost and the sludge were found to be equally efficient at 10%, resulting in an increase in the maize biomass. It can be concluded that compost had a greater impact on soil chemical properties, available forms of nutrients and maize growth compared to the other two organic amendments.

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