STUDY ON THE INFLUENCE OF BIOCHAR ON PHYSICO-CHEMICAL PROPERTIES OF SOIL

[1]Nikola POLÁŠKOVÁ, [1]Michal KALINA, [1]Šárka SOVOVÁ, [2]Jiří SMILEK

[1]First author: Brno University of Technology, Faculty of Chemistry, Materials Research Centre, Brno, Czech Republic, EU, Nikola.Polaskova@vut.cz

[2]Corresponding author: Brno University of Technology, Faculty of Chemistry, Materials Research Centre, Brno, Czech Republic, EU, smilek@fch.vut.cz

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Abstract

The paper is focused on assessment of the influence of biochar on the soil physico-chemical properties (specific gravity, bulk density, porosity, water retention capacity and maximum water holding capacity, oxidizable carbon content, total nitrogen content, phosphorus, potassium and magnesium content). The selected and examined soil types were: cambisol, fluvisol, chernozem and regosol. There were two types of biochar used for analysis – NovoTerra and Sonnenerde. Soil samples were dried to constant weight and adjusted to grain-size fraction under 2 mm, respectively 0.25 mm. The oxidizable carbon content was measured by oxidation using a mixture of potassium dichromate and sulphuric acid (Walkley-Black method), the total nitrogen content was measured by Kjeldahl method and P, K and Mg content was measured using Mehlich 3 extraction and ICP-OES spectrometer. The results show that biochar has a significant influence on soil characteristics depending on the type of biochar and soil we use for biochar application.

Keywords: Biochar, soil, cambisol, chernozem, fluvisol, regosol

1. INTRODUCTION

Biochar is a solid product of thermal decomposition of organic material with limited oxygen access at relatively low temperatures (300-700 °C) [1]. This process is called pyrolysis. Biochar is a material rich in carbon, nitrogen (in the form of nitrite, nitrate and ammonium ions), Mg, K, Na and P content, which are nutrients that are necessary for plant growth [2]. The main advantages of biochar are the ability to positively affect water retention [2], to retain substances due to its micropores and large surface area (therefore it can protect environment from contaminants) [3]. It can also play a role in fighting climate changes – it is quite stable in a long term and it can take part in sequestering carbon from the atmosphere [4]. Due to number of advantages biochar is applicable in agriculture as an auxiliary soil and plant substance to increase soil quality and fertility. The application of biochar into soil leads to decrease of its acidity, increase of cation exchange capacity and water holding capacity, therefore it is suitable environment for microbes [5].

Another fertilizer option is for example foliar application of fertilizers and biostimulants, which complements standard root fertilizer treatments [6]. In combination with the biochar application, it could be an effective method of improving the soil properties and increasing the uptake of nutrients by the plant at the same time.

As mentioned, biochar is a product of biomass pyrolysis. We can define biomass as an organic matter, especially plant-based biomass (spent peat, woody green waste, tree bark, applewood, flax shives, spent coffee grounds etc.) [7], but animal-based biomass (e.g. insect frass or chicken manure) can also be used [7,8]. The properties of biochar do not depend only on source biomass, but also on the production conditions – highest treatment temperature, pyrolysis time, heating rate, pressure or post treatment [9]. Generally, biochar as a material consists of aromatic compounds, which cause an increase of its stability in soil. By measuring molar ratio of oxygen and carbon we are able to estimate half-life of biochar. If the ratio is O: C < 0.2, the minimum half-life is about 1,000 years. This ratio can be influenced by production temperature [10].

Generally, there is number of properties and characteristics which are evaluated and measured, e.g. soil reactions, available P content, K, Mg and Ca content, but also micronutrients content (B, Cu, Fe, Mn, Zn and other heavy metals) and soil organic matter. Results show the decrease of high-quality agricultural soil in the Czech Republic [11], therefore it is important to deal with this issue. The main goal of this study is to compare soils before and after biochar application. The effect of biochar on modified and unmodified soil is studied in soil which is planted with corn plants. After 100 days the analysis of soil (and the biochar [12]) was performed.

2. MATERIALS AND METHODS

2.1. Samples

Four types of soil were selected for this study – cambisol, fluvisol, chernozem and regosol. These soils represent soils of the Czech Republic. Cambisol was collected from Náměšť nad Oslavou (28. 5. 2020), fluvisol was collected from Iváň (28. 5. 2020), chernozem was collected from Žabčice u Brna (28. 5. 2020) and regosol was collected from Pánov (28. 5. 2020). Samples were collected from topsoil (0-20 cm below surface).

Two types of biochar were selected for this study – NovoTerra (NovoCarbo GmbH, the source biomass was residual softwood wood chips) and Sonnenerde (Sonnenerde GmbH, the source biomass was grain husks, sunflower husks and fruit sludge).

One kg of soil and 20 g of biochar in the polypropylene bags was weighed into the pots. Corn was planted in the soil and the growing process took about 100 days. After the cultivation, the biochar and the plants were removed from the soil and the analysis of the soil was performed. All samples were dried at 105 °C for 3 days, homogenised and passed through a 2mm sieve before further analysis.

2.2. Determination of specific gravity ρ_s, bulk density ρ_d and porosity *P*

For specific gravity, labeled pycnometer with stopper was weighed. Then it was filled with distilled water and weighed again. The soil sample was added into the pycnometer to a quarter of its height and weighed. The pycnometer with soil was filled with distilled water to a half of its height and heated on the stove to boiling. After cooling down the pycnometer with soil sample and water was fully filled with adjusted distilled water (water in beaker was heated to boiling and then covered with watch glass beaker cover and cooled down) and weighed together with the stopper. Specific gravity was calculated according to the equation (1).

$$\rho_s = \frac{m_1}{m_1 + m_2 - m_3} \cdot \left(\rho_l - \rho_g\right) + \rho_g \tag{1}$$

where:

m_1 – the mass of the sample dried to a constant weight (g)
m_2 – the mass of the pycnometer filled with distilled water (g)
m_3 – the mass of the pycnometer with boiled sample and distilled water (g)
ρ_l – the density of water (g·cm^{-3})
ρ_g – the density of air (g·cm^{-3})
ρ_s – the specific gravity (g·cm^{-3})

For bulk density, weighed sample was added into a graduated cylinder. Bulk density was calculated according to the equation (2).

$$\rho_d = \frac{m_{sample}}{V} \tag{2}$$

where:

m_{sample} – the mass of the sample added into a graduated cylinder (g)
V – the volume of the sample added into a graduated cylinder (cm^3)
ρ_d – the bulk density (g·cm^{-3})

For porosity determination the following equation (3) was used:

$$P = \frac{\rho_s - \rho_d}{\rho_s} \cdot 100 \quad (3)$$

where:

ρ_s – the specific gravity ($g \cdot cm^{-3}$)
ρ_d – the bulk density ($g \cdot cm^{-3}$)
P – the porosity (%)

2.3. Determination of maximum water holding capacity MWHC and water retention capacity WRC

For maximum water holding capacity the soil sample was weighed and added into plastic bottles. Sample was excessively saturated with water. Opened bottle was reversed and put on 4x folded filter paper. After 1 hour of suction the filter paper was changed. After 1 hour the sample was weighed. Maximum water holding capacity was calculated according to the equation (4).

$$\mathrm{MWHC} = \frac{a - b}{a} \cdot 100 \quad (4)$$

where:

a – the mass of the sample after 2 hours of suction (g)
b – the mass of the sample dried to a constant weight (g)
MWHC – maximum water holding capacity (%)

For retention water capacity the suction of water was continued for another 22 hours, then the sample was weighed.

$$\mathrm{WRC} = \frac{c - b}{c} \cdot 100 \quad (5)$$

where:

b – the mass of the sample dried to a constant weight (g)
c – the mass of the sample after 24 hours of suction (g)
WRC – water retention capacity (%)

2.4. Determination of oxidizable carbon content C_{ox}

For oxidizable carbon content the sample was passed through a 0.25mm sieve and weighed (approximately 0.1 g). The sample, 5 ml of $K_2Cr_2O_7$ solution and 7.5 ml of H_2SO_4 was added into a beaker, covered with Petri dish and heated in dryer at 135 °C for 30 min. After cooling down, the solution with the sample was quantitatively added into the 100ml volumetric flask and fully filled with demineralized water. After 60 min of suspension, sedimentation the solution was centrifugated at 3,500 rpm for 10 min. For making of calibration solutions there was used a glucose. Glucose solutions was prepared by adding specific amount of glucose into the 100ml volumetric flask and the flask was fully filled with $K_2Cr_2O_7$ solution. These glucose solutions were oxidized the same way as sample solution (without another addition of $K_2Cr_2O_7$ solution). Then the absorbance of calibration solutions and sample solutions was measured at the wavelength 585 nm.

2.5. Determination of total nitrogen content N_{tot}

For total nitrogen content the sample was weighed (approximately 0.2-1.0 g). The sample and 4 ml of mixture of salicylic acid and sulfuric acid was mixed and let to react overnight. Then 0.5 g of copper(II) thiosulfate pentahydrate was added to a sample and cautiously heated until the foaming stopped. The mixture was cooled down. Then 1.1 g of catalyst (mixture of K_2SO_4, $CuSO_4 \cdot 5H_2O$ and TiO_2) was added to the mixture and the mixture was heated at 360-400 °C for 2 h until clarification. After cooling down, 20 ml of demineralized water was added to the mixture. The mixture was added into a distillation flask. 5 ml of H_3BO_3 was added into receiving flask and 20 ml of NaOH solution was added into distillation flask continuously during distillation. After distilling 40 ml of distillate, 2-3 drops od mixed indicator was added to distillate and titrated with HCl.

2.6. Determination of P, K and Mg content

For P, K and Mg content determination, 10 g of sample and 100 ml of extraction solution (Mehlich 3) was added into a PE bottle and the mixture was extracted on a rotary shaker for 10 min. After the extraction the mixture was centrifugated at 4,000 rpm for 5 min. Calibration standard solutions for P, K and Mg content determination was prepared at different concentrations. Mixed calibration standard solution was prepared by adding different amounts of standard solution and 20 ml of concentrated extraction solution (Mehlich 3) into a 100ml PE volumetric flask and the flask was fully filled with distilled water. An auxiliary calibration standard solution was prepared by adding different amounts of standard solution into a 100ml PE volumetric flask and the flask was fully filled with distilled water. Then 50, 25 and 10 ml of the auxiliary calibration standard solution was added into 3 100ml PE volumetric flasks. 20 ml of concentrated extraction solution (Mehlich 3) was added into each flask and the flasks were fully filled with distilled water. All solutions (the set of calibration solutions and the set of sample solutions) were measured on ICP-OES spectrometer.

3. RESULTS AND DISCUSSION

3.1. The influence of biochar on physical properties of soil

The resulting values of physical properties of soil are shown in **Table 1**. The specific gravity is increased in all types of soil after NovoTerra biochar application, on the contrary Sonnenerde biochar increased the specific gravity only in cambisol. Depending on the results of the carbon content after the biochar application (see **Figure 1**), it can be assumed that the Sonnenerde biochar compared to the NovoTerra biochar increased the carbon content, so much that it decreased the specific gravity, which is dependent on the carbon content.

Table 1 Physical properties of soil before and after biochar application – ρ_s is the specific gravity (g·cm^{-3}), ρ_d is the bulk density (g·cm^{-3}), *P* is the porosity (%), MWHC is the maximum water holding capacity (%) and WRC is the water retention capacity (%); C is cambisol, F is fluvisol, CH is chernozem, R is regosol, N is NovoTerra biochar and S is Sonnenerde biochar.

Sample	ρ_s (g·cm^{-3})	ρ_d (g·cm^{-3})	*P* (%)	MWHC (%)	WRC (%)
C	2.39±0.05	1.01±0.01	57.7±1.9	17.9±0.9	15.7±0.6
C+N	2.41±0.05	0.96±0.01	60.1±1.7	23.4±0.4	20.1±1.9
C+S	2.44±0.04	0.86±0.03	64.8±0.5	18.4±1.9	15.4±1.2
F	2.35±0.04	1.09±0.03	53.7±1.1	14.9±0.9	12.8±0.6
F+N	2.37±0.06	1.13±0.03	52.1±2.0	15.7±1.4	12.9±0.7
F+S	2.33±0.01	1.05±0.06	55.2±1.9	15.2±1.0	13.5±0.6
CH	2.53±0.04	1.21±0.05	52.2±1.3	19.3±0.3	17.7±1.3
CH+N	2.56±0.04	1.31±0.05	48.8±1.1	19.4±1.7	17.7±3.0
CH+S	2.52±0.01	1.24±0.07	51.0±3.0	16.1±4.0	17.1±1.4
R	2.41±0.05	1.44±0.03	40.0±2.0	13.2±0.8	10.0±0.7
R+N	2.42±0.07	1.42±0.04	41.1±0.7	18.8±1.3	18.0±1.3
R+S	2.28±0.04	1.42±0.07	37.9±4.0	15.2±2.0	11.2±1.2

In the case of bulk density, Sonnenerde repeatedly reduced the resulting value of this parameter, because it was able to increase the carbon content of the sample more than NovoTerra biochar. Even in this case, the bulk density is dependent on the carbon content (see **Figure 1**). The bulk density describing soil compaction has an influence on other physical properties such as porosity or water retention capacity, which also correlates.

A more significant increase in porosity occurred in the case of cambisol. This increase can be explained by the fact that the increased carbon content and other supplied minerals from the biochar caused that the plants had a larger root system, which aerated the soil more and thus created more pores. For both mentioned water capacities, we again encounter the fact that the carbon content correlates with the increased water retention capacity (according to the results).

3.2. The influence of biochar on chemical properties of soil

The effect of biochar on the oxidizable carbon content is shown in **Figure 1**. In general, there was an increase in the carbon content after the biochar application. However, it is worth noting that Sonnenerde biochar was more effective than NovoTerra biochar. This can be explained by the fact that NovoTerra biochar was made from biomass with a higher content of more stable organic matter, which was more difficult to release into the soil than in the case of Sonnenerde biochar.

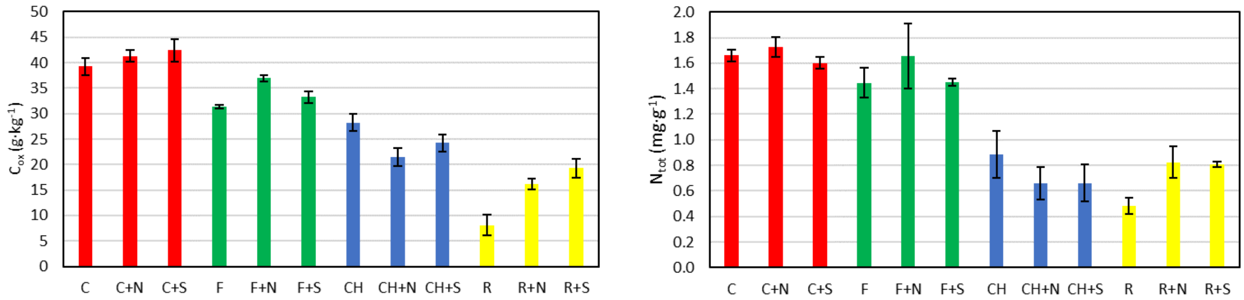

Figure 1 Oxidizable carbon content C_{ox} (left) and N_{ox} (right) in soil before and after biochar application

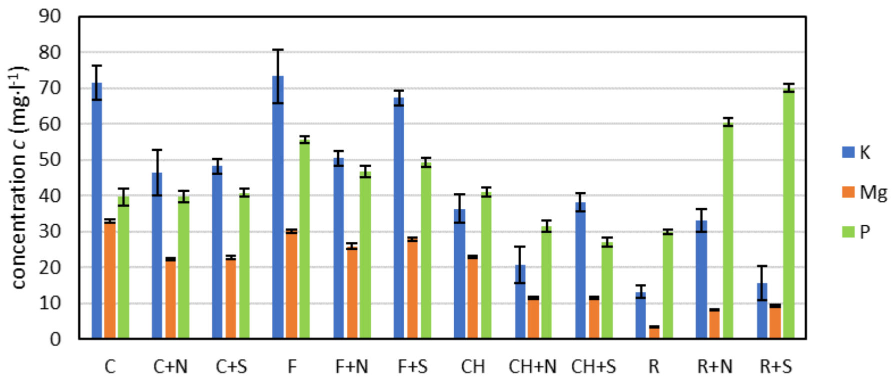

Figure 2 P, Mg and K content in soil before and after biochar application

In the case of cambisol and fluvisol, there was no significant influence on total nitrogen content after biochar application (**Figure 1**). NovoTerra biochar seems to be more efficient to increase the N_{tot} content, while Sonnenerde biochar did not significantly affect it. Chernozem showed a decrease in the total nitrogen content in the case of use of both biochars and regosol showed an increase in N_{tot} content in both cases.

In the **Figure 2**, there is shown the decrease in the P and Mg content after biochar application in the case of cambisol, fluvisol and chernozem. Regosol showed an increase in both mentioned parameters. Furthermore, it can be observed that there were no changes in the P content in the case of cambisol after biochar application. The increase in the case of fluvisol was not significant. Chernozem showed significant reduction in P content, while Sonnenerde biochar had a greater influence on this result. On the other hand, there was a very significant increase in the P content of the regosol and the Sonnenerde biochar had a greater influence on this increase again.

4. CONCLUSION

Generally, it is not easy to describe the effects of biochar on soil properties because of the complexity of the subject of this study. The influence of biochar very much depends on the type of biochar and also on the type of soil. There is an increase of C_{ox} and N_{tot} content after biochar application to the soil. The influence of biochar on P, Mg and K content in soil after biochar application varies depending on the type of soil.

Biochar is more effective in the case of low-quality soils (in this study, this type was represented by regosol). In the case of high-quality soils (cambisol and fluvisol), biochar is not so efficient and the influence is not so obvious. In the future, there is a need for long-term experiments and studies that include the effect of field conditions (larger scale, applications in agriculture, economic review – cost and crop yield, etc.).

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