Impact of Biochar on Soil Grain Size

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Abstract. Degradation of arable soils reduces their productivity and worsens the problem of global food security. One of the ways to prevent this phenomenon is the possibility of using biochar. Its addition to soil improves water, biochemical and mechanical properties. This has been proven in many research works. The purpose of the research described in the article is to determine the dose of biochar to be used in a heavy soil cultivated field in order to improve its grain size. The tests were carried out for 10 different doses of biochar in relation to the control field. After the end of the growing season, soil samples were taken for laboratory tests in order to determine the granulometric composition of the soil. Studies have shown that the addition of biochar changes the grain structure of the soil.

1. Introduction

The current tendency to use biochar as a soil modifying substance is based on discoveries in the Amazon region, where local farming practices lead to black soil, called 'terra preta to Indio' [1,2]. This soil is characterized by increased fertility and quality, which is why it is classified as anthropogenic soils. Biochar used for soil fertilization has the ability to absorb and store water, which helps to counteract and protect the soil against climate change [2].

Studies on the applicability of biochar as an improver of degraded soils properties have shown that it is strictly dependent on the biomass used for production, the production process and the temperature at which it is produced [3]. The most important factor determining the properties of biochar is the temperature during production. Pyrolysis temperatures higher than 500°C result in the formation of biochar with a carbon content above 80%, while the carbon content in samples generated at temperatures of 400÷500°C is 60÷80%. In the case of low-temperature processes (up to 350°C), carbon content does not exceed 60% [4,5]. The nitrogen and sulfur content in biochar decreases with increasing temperature, and their highest loss is recorded at production temperatures of 300÷600°C. When applying temperatures above 550°C, biochars with a large specific surface area (about 400 m²·g⁻¹), high ash content and high degradation resistance are obtained [4-6]. At pyrolysis temperatures below 550°C, biofields with more oxygen-containing functional groups are obtained, leading to an amorphous carbon matrix which promotes nutrients retention [4,6,7]. Excessive amorphy of biocarbon negatively affects its hydrophilicity, which impedes a contact of particles with the environment [8,9]. Increased biochar production process temperatures are also conducive to its alkalinization [5].
The use of biocarbon improves physical and water properties of the soil, by modifying water retention, changing porosity and pore structure in the soil [10-14]. An addition of biochar has a positive effect on the water-air system in the soil and its cultivation parameters. This trend is not correlated with the sort or type of soil and the properties of the biochar used [7,12-14]. In the literature on the subject, most commonly are analyzed degraded acidic soils, that have a large share of a fraction with a particle size greater than 0.2 mm. In these soils, the addition of biochar increases the concentration of organic carbon, increases the specific surface area, improves microporosity and increases water accessibility for plants [15-17]. A properly selected dose of biochar converts macro- and mesopores into micropores, which positively affects its physical parameters [17].

The purpose of the work was to determine the effect of different doses of biochar on the change in grain size composition of cultivated soil.

2. Material and methods
The experiment was established on the experimental field belonging to the University of Agriculture in Krakow. The soil used for research is a brown soil made from Jurassic limestones. To determine the effect of biochar on soil grain composition, 10 experiments were established with biochar content in the range of 1÷100 Mg·ha⁻¹ and 1 control plot (marked with the symbol 0).

The scope of the research included laboratory analysis of soil and soil samples with the addition of biochar, taken with soil auger, in accordance with PN-R-04031: 1997. During the field work, a total of 11 drillings were made (1 per experimental plot), each 30 cm deep.

In order to measure size of grains from sedimentary material samples, the method of Casagrande's areometric technique modified by Prószyński was used, which is used to determine soil graining. In this method, the percentage fraction <0.1 mm in the soil sample is determined. Fractions greater than 0.1 mm are separated on sieves of defined mesh diameter. Areometric methods consist in measuring the density of soil suspension during sedimentation of soil particles at a constant temperature. The Prószyński hydrometer is used to measure density, the scale of which, based on the difference of two consecutive readings, allows to determine the percentage of the fraction, settling to the bottom of the cylinder in the time separating these two readings. The sedimentation times of individual fractions depend on the temperature of the solution and the size of the grains. Considering these relationships Prószyński developed 14 tables characterizing various grain size groups. Boards differ in the percentage share of fractions below 0.02 mm. In order to select the appropriate table, an approximate grain size analysis should be performed in the 10-minute sedimentation time. From the difference in readings on the hydrometer immersed in the soil suspension and in the comparative solution, the content of floatable parts is determined. Then, select the appropriate table and make five density measurements to obtain the exact size of grains from the soil sample under investigation by PN-ISO 11277:2005 and [18].

3. Results and discussion
Calculations of water permeability of soil samples were based on grain size analysis (fig. 1). The conducted grain size studies revealed the presence of the gravel fraction (Φ >2.0 mm) at an average level of 2.0±0.59%. This fraction includes the fragments of the parent rock (limestones and flint spatter). The most numerous fraction in the examined samples was the sand fraction (Φ 2.0÷0.05 mm). Its share is in the range of 56.7÷60.0%. The use of biochar addition caused a quantitative increase of this fraction on average by 2.2% in relation to the blank sample.
Analyzing the data presented on Fig. 1, it cannot be unequivocally indicated that the observed variability is due to the addition of biochar. The silt fraction (Φ 0.05–0.002 mm) in the blank test accounted for approx. 50% of the sand fraction mass. The addition of biochar caused a reduction in the amount of grains of this fraction from 1.4 to 7%. The largest fractional loss was recorded for the dose of biochar in the amount of 50 Mg·ha⁻¹, and the lowest for the dose of 100 Mg·ha⁻¹. The last type of fraction - responsible for water retention in the soil - is clay (Φ <0.002 mm). In the analyzed soil its content is at the level of 10.5%. The addition of biochar into the soil caused the division of plots into two groups. The first one corresponds to doses of 30, 40 and 100 Mg·ha⁻¹, which caused a decrease in the content of these particles while increasing the presence of sand fraction. In the second group doses of biochar were used at levels 1, 5, 20, 50 and 60 Mg·ha⁻¹ which caused an increase in the clay fraction in the soil. Biochar doses in the range of 10 and 80 Mg·ha⁻¹ did not cause a significant difference in the clay fraction content.

When analyzing the data presented on figures 1 and 2, it is not possible to clearly indicate the effect of the addition of biochar on the retention properties of the cultivated soil. This is due to the application of a material with non-homogeneous grain composition, in which all the discussed fractions are found, with the exception of the fraction with a grain diameter of more than 2 mm. The above-mentioned studies also indicate a problem in the selection of biochar dose, because in the case of soils with a high content of silt and clay, further reduction of water permeability will cause problems in the beginning of spring crop.

4. Conclusions
These dependencies are described in Ajaya's publications [17,19]. These teams investigated the variability of soil porosity caused by the addition of biochar. As a result, they received an increase of water accessibility for plants up to 230% compared to the initial value of the soil and its longer retention. The study of using biochar sandy soils with regard to the improvement of retention was also carried out by Burrell [10], who received similar results.
In the literature one can also find negative effects of using biochar as a material that improves water retention in soil. This is due to the hydrophobicity of the biochar, which is correlated with the temperature of its production. This property causes a negative capillary pressure during periods of drought. The occurrence of this phenomenon may result in the blockage of pores in which water is stored, which will result in the increase of water erosion at intense rainfall [8,20,21].

Summing up the presented experimental results, it can be concluded that the optimal dose of biochar that should be used to improve soil retention is 60 Mg·ha⁻¹. This dose may be suitable for soil grains similar to the soil under test. In other cases, appropriateness of the biochar use as an improvement of field retention should be considered. The conducted experiment also indicates that in order to improve water properties, the underflow of the silt or clay fraction should be replenished in the soil, and consequently biochar with an appropriate grain size should be used.

Acknowledgment(s)
The publication was financed by the National Centre for Research and Development under the strategic program “Natural environment, agriculture and forestry” BIOSTRATEG III (BIOSTRATEG3/345940/7/NCBR/2017).

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