Changes in soil conditions after application of biochar

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Abstract. Biochar is a carbonized, stable product obtained by pyrolysis. Due to its structure, chemical composition and characteristics biochar can change soil properties over a long period. To study the effect of woody biochar on loamy sand Spodosol, a small-scale field experiment was conducted. Following treatments were used in the experiment: soil-control, soil with biochar at a rate of 5 t ha⁻¹, soil with nitrogen fertilizer at a rate of 90 kgN ha⁻¹ and soil with combined application of biochar and N fertilizer. Application of biochar increased water-holding capacity of the soil in the range of plant-available water by 7%, in average, increased soil moisture 1.13-1.19 times, reduced the soil bulk density by 5% and led to a short-term increase in soil pH.

1. Introduction
Biochar is produced by pyrolysis of agricultural and forestry waste at an elevated temperature of 300-900 °C in an oxygen-free environment. The main characteristic of biochar is a high content of stable carbon resistant to decay [1]. Biochar use as a soil ameliorant can help to improve soil characteristics while reducing CO₂ concentration in the atmosphere due to carbon sequestration in the soil for a long period [2]. Owing to its porous structure biochar can change soil physical properties – moisture content, soil bulk density, water holding capacity, pore size and their location in the soil, etc. [3]. Feedstock and pyrolysis conditions (temperature, processing time, etc.) have a significant impact on the biochar properties and, therefore, on its influence on soil parameters and plant growth.

Since wooden based char is the most produced biochar in Russia it was chosen for the study. The impact of wooden biochar on loamy sand Spodosol in a small-plot field experiment was investigated. It was hypothesized that biochar will enhance soil water holding capacity and moisture content as well as reduce soil bulk density.

2. Materials and methods
The small-plot field experiment was conducted on loamy sand Spodosol, at the Menkovo Experimental Station of the Agrophysical Research Institute (Gatchina district, Leningrad region, 59°34′22″ N 30°01′55″ E) during one growing season (May-September). The investigated biochar was produced by fast pyrolysis at a temperature of 550 °C from wooden residues (alder, birch, aspen). The biochar had high carbon (78.6%) content and low hydrogen (5.2%) and nitrogen (0.3%) content. The ameliorant had neutral reaction (pH = 7.0) and was characterized by high porosity (81%). The biochar was incorporated into a 0-10 cm soil depth. Potato (Solanum tuberosum L.) was grown on the experimental plot.

The following treatments were studied: soil untreated control (C), soil with biochar (B) at the rate of 5 t ha⁻¹, soil with nitrogen fertilizer (N) at the rate of 90 kg N ha⁻¹, soil with biochar and fertilizer (B+N). Soil samples were taken each 14 days and then analyzed for the following indicators: soil moisture
content, soil bulk density and pH. Soil moisture content was measured by gravimetric method [4]. To determine the soil bulk density core method was used [5]. Soil pH was analysed in air-dried soil samples and measured in 1n KCl solution using pH meter with a glass electrode. A soil:solution ratio of 1:2.5 was chosen.

Laboratory experiment was conducted to determine soil water-holding capacity. The following treatments were studied: untreated control soil (C) and soil with biochar (B) at the rate of 9.02 g kg\(^{-1}\) soil. The pressure plate apparatus was used to analyze the soil water-holding capacity [6]. Water retention curve was a relationship between the soil water potential and volumetric water content [7].

Statistical data processing was carried out using the Statistics 5.0 software package.

3. Results and discussion

3.1. Water holding capacity
The water retention curves for the soil with and without biochar are presented in the figure 1.

![Figure 1. Water retention curves for loamy sand Spodosol with (B) at the rate of 4.51 g kg\(^{-1}\) soil and without (C) biochar. pF – decimal logarithm of the pressure, W – soil moisture content.](image)

Significant (p <0.05) changes in the soil water content after biochar application were observed at the pressures above -10 kPa (pF = 2). Soil water content in this range of soil water potential was on average 1.07 times higher in the treatment with biochar than in the control. This potential corresponds to the soil plant available water providing plants with moisture and nutrients. Being porous product with a high surface area biochar can retain soil moisture on its surface thereby increasing the soil water holding capacity (WHC) [8, 9]. Glaser et al. [10] and Novak et al. [11] in their studies also observed increase in soil WHC in soils enriched with biochar. Enhanced water retention in soil may lead to improved soil aggregation while decreasing soil erosion [12].

3.2. Moisture content
Soil moisture is one of the factors that have a great impact on plant growth and nutrients uptake. During the growing season the soil samples were analyzed for moisture content. The dynamics of the soil water content is presented in figure 2.

Soil moisture content depended on weather conditions during the growing season: air temperature and precipitation. The maximum moisture content was observed in the treatments with biochar. Its application increased soil moisture content 1.13-1.19 times compared to C and N treatments.
Application of nitrogen fertilizer did not lead to any significant changes in the soil moisture compared to C treatment.

![Graph showing soil moisture content in loamy sand Spodosol during the growing season 2015.](image)

**Figure 2.** Dynamics of soil moisture content in loamy sand Spodosol during the growing season 2015. C – untreated control, B – biochar, N – N-fertilizer, B+N – biochar + N-fertiliser, W – soil moisture content.

R. Gondim et al., [13] and K. Kammann et al., [14] in their studies showed that biochar, being a porous product, can absorb and retain water in the pores, thereby increasing water retention and soil moisture content.

### 3.3. Soil bulk density

The bulk density of the soil varied during the growing season (figure 3).

![Graph showing bulk density of loamy sand Spodosol during the growing season 2015.](image)

**Figure 3.** Dynamics of loamy sand Spodosol bulk density during the growing season 2015. C – untreated control, B – biochar, N – N-fertilizer, B+N – biochar + N-fertiliser.

Compaction of loamy sand Spodosol during the growing season was observed. After soil cultivation, in the middle of July, the decline in the soil bulk density (SBD) was registered. Maximum values of
SBD were detected in the C and N treatments. The introduction of biochar lead to a significant decrease (p < 0.05) in the soil bulk density, compared with the C and N treatments. Laird et al. [15] in a laboratory experiment on fine-loamy soil with biochar found similar results with SBD increase over the time due to the soil compaction but less in the treatments with biochar. Owing to its lower bulk density biochar through the mixing with soil may decrease soil bulk density.

3.4. Soil pH
Microbiological processes in the soil, weather conditions and introduction of soil ameliorants affect soil pH. The dynamics of the loamy sand Spodosol pH during the growing season is presented in figure 4.

![Figure 4. pH dynamics in loamy sand Spodosol during the growing season 2015. C – untreated control, B – biochar, N – N-fertilizer, B+N – biochar + N-fertiliser.](image)

Loamy sand Spodosol was characterized by lightly acidic reaction. During the experiment it ranged from 6.4 to 6.8. Application of biochar into the soil lead to significant (p<0.05) increase in soil pH during the first 7 weeks of the experiment, by 0.2-0.9 units, with the maximum equal to 7.1, on the 5th week. Later, in the B treatment, soil pH decreased to a minimum value of 6.5, close to the C treatment. Biochar may change soil pH due to soluble functional groups that can interact with the soil environment [16]. Similar results were observed in the experiments of Yamato [17] and Carter with colleagues [18]. In the soil with N treatment there was a significant (p <0.05) decrease in the soil pH at the beginning of the experiment, compared with the C treatment, to a minimum value of 6.2. In the B+N treatment, soil pH during the first 5 weeks of the experiment was significantly (p <0.05) higher than in the C treatment. Later a significant decrease in pH was observed, and by the end of the experiment soil pH in the B+N treatment was lower than in the C treatment but the difference was not significant. Biochar could absorb N from fertilizers, thus, reducing soil acidification at the start of the experiment. However, with time slow release of N from the biochar could cause decrease of the soil pH.

4. Conclusions
Wooden biochar applied to the loamy sand Spodosol at the rate 5 t ha⁻¹ resulted in positive changes in the soil physical properties. The biochar increased the soil water holding capacity in the interval of plant available water by an average of 7 %. Moreover, during the experiment treatments with biochar and biochar with nitrogen fertilizer resulted in higher soil moisture content (on average 1.13-1.19 times).

Soil compaction during the experiment was observed in all treatments. However, in the treatments with biochar soil bulk density was significantly lower.
Application of the biochar to loamy sand Spodosol leads to an increase of soil pH at the beginning of the experiment owing to alkaline nature of the biochar.

The hypothesis that biochar due to its porous structure and high surface area will enhance soil water holding capacity and moisture content as well as reduce soil bulk density has been supported. It is necessary to investigate biochar impact on the soil properties in the longer term.

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