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Effect of biochar application on the physical properties of Haplic Podzol

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A R T I C L E I N F O

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A B S T R A C T

The paper presents the results of a study on the effect of biochar application to soil on the basic physical properties of Haplic Podzol. In a six-year (2010–2015) field experiment, the physical properties of biochar-amended Haplic Podzol originating from glaciofluvial fine-grained loamy sand (LS) were studied. The experiment was carried out on three plots with an area of 5.0 m^2 each. Biochar produced from wheat straw in the process of pyrolysis at 650 °C was applied to the soil in the following rates: treatment A – 45.0 Mg ha^{-1}, treatment B – 30.0 Mg ha^{-1} and treatment C – Control (soil without the addition of biochar). Biochar was applied to the soil (April 2011) and mixed with the soil surface layer (0–10 m). Soil samples, their natural structure preserved intact, were collected six times (sampling dates 0-V), once a year, during the vegetation season – after harvest (2nd decade of August). Soil samples were taken from layers: 0–10 cm, 10–20 cm and 20–30 cm, in six replicates, using 100 cm^3 metal cylinders. The following physical properties of the soil were determined: particle density (PD), bulk density (BD), total porosity (TP), field air capacity at the potential of −15.5 kPa (content of macropores with $\Phi > 20$ μm – FAC), air permeability at the potential of −15.5 kPa (FAP), water content at sampling (SM), field water capacity (at −15.5 kPa) (FC), available water content (AWC), unavailable water content (UWC), and the ratio FC/TP was calculated. Analysis of the results indicated a positive effect of biochar application on most of the studied physical properties. Compared to soil without biochar addition, soil compaction was lower, there was an improvement in the soil air properties (FAC and FAP) and an increase in water available to plants (AWC). It should be emphasized, however, that the effect of biochar was short-lived, and also limited in depth as it related mainly to the layer of 0–10 cm. The positive effect of biochar on the soil properties was observable mainly at sampling dates I and II. Starting from sampling date III, the differences noted in the values of the soil properties under study gradually diminished, and at sampling date V they virtually disappeared. The statistical evaluation of the results confirmed the observed impact of biochar on the soil, its range and stability. It demonstrated that the effect of biochar on the soil is positive but short-lasting, as starting with the second year after biochar application (sampling date II) its decrease was noted.

1. Introduction

Contemporary intensive agriculture without proper care for the soil condition may result in its degradation (Blum, 1998; Dexter, 2004a,b,c; Karlen et al., 1997; Lal, 1998; Polish Committee for Standardization, 2001a; Pranagal, 2009). Knowledge on the constantly increasing area of soils with various forms of degradation (Lal, 2008), and awareness of the need for rectification of that state, are present in numerous research works. New agromeliorative techniques are being developed. Among other approaches, they consist in the application of various additives to soil. Those are materials with both organic and mineral character (Ajayi et al., 2016; Pranagal et al., 2002; Skowrońska et al., 2002).

In Poland such materials most frequently are the following: sewage sludge, compost produced from municipal waste, lignite, or waste rockwool (Baran et al., 2008; Krzywy et al., 2002; et al., 2007; Maciejewska and Kwiatkowska, 2007; Paluszek, 2009a,b). The environmental effects of biochar application to soil are also the subject of research (Kuśmierz and Oleszczuk, 2014; Oleszczuk et al., 2014b), as well as the possibility of fermented sludge application to soil (Stefaniuk et al., 2015; Różyło et al., 2015).

Current EU regulations (Council Directive EC, 1999) impose the obligation of systematic increase of the amounts of utilized wastes. In this situation attempts are undertaken to improve the quality of arable soils through the use of various waste materials. In many cases cereal

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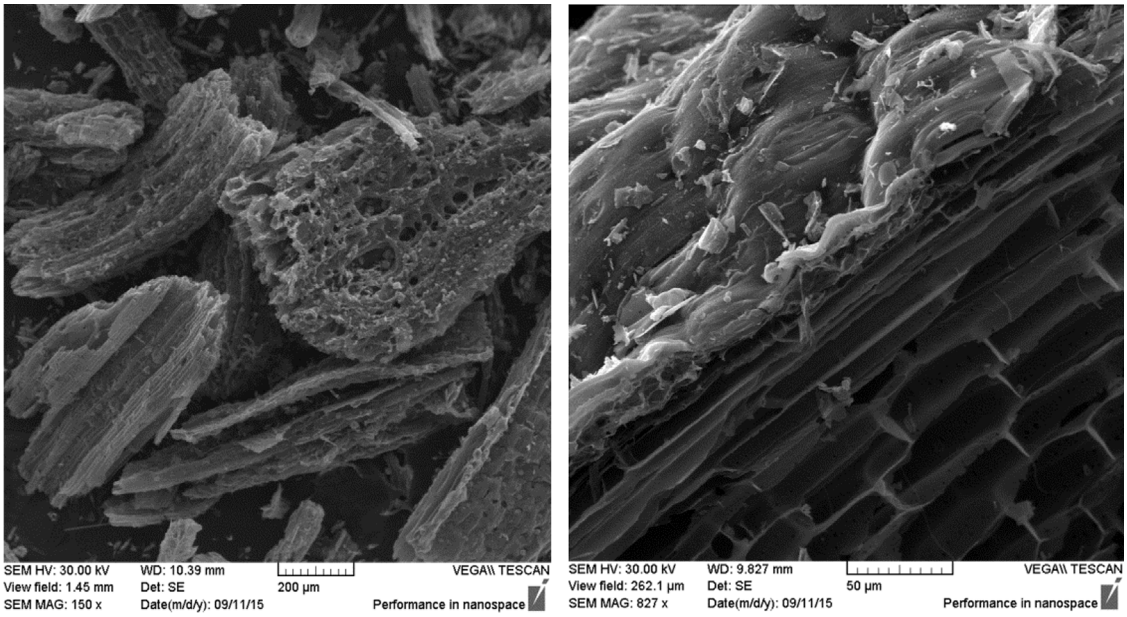

Fig 1. SEM pictures of biochar used in the field experiment.

straw is a useless by-product and often treated as a waste. Therefore, one of the methods of its utilization can be the application to soil after prior thermal conversion into biochar.

Biochar displays very good sorptive properties, and it is also resistant to chemical agents and to biochemical degradation. The properties of biochar are determined primarily by the original material (e.g. feed stock) and the conditions of pyrolysis, especially the maximum temperature of combustion (Morales et al., 2015). Applied to soil, biochar can be used for the protection and/or purification of selected elements of the environment (Ennis et al., 2011; Joseph et al., 2009; Karhu et al., 2011; Novak and Busscher, 2013). Among other aspects, it allows the immobilization of carbon dioxide in soil and, in consequence, a reduction of its emission to the atmosphere (Conte, 2014). In experiments with biochars produced from biomass obtained from areas contaminated with heavy metals no elevated levels of any potentially toxic element (e.g. Pb or Cd) were noted (Evangelou et al., 2014). They volatilize in the course of biochar production, especially at high temperatures (700 °C and above). In addition, no unfavorable effects on soil microorganisms were observed. The properties of biochar allow also its application for phytostabilization of soils (Edenborn et al., 2015; Inbar et al., 2015), and for the stabilization of sewage sludge. Oleszczuk et al. (2014a) demonstrated that biochar added to sewage sludge at various doses reduced the content of dissolved PAHs. Another positive effect of an addition of biochar to soil on which various pesticides were applied was demonstrated by Oleszczuk et al. (2014b). The biological activity of such a soil was higher in relation to most enzymes, compared to soil with no biochar content.

The literature provides some interesting results concerning the use of biochar in the environment. Kuśmierz and Oleszczuk (2014) demonstrated that soils in the immediate vicinity of biomass combustion furnaces are the most contaminated with PAHs, while the biochar produced has much lower levels of contamination. The researchers concluded that the source of soil contamination is the production of biochars in a given area (Oleszczuk et al., 2014c). According to estimated values of ILCRs, the risk of cancer resulting from contact with contaminated soils can be assessed as at least high. It should be noted that apart from the risk of cancer in people employed in the production and transport of biochar, the material affects also other elements of the environment (Kuśmierz and Oleszczuk, 2014). A study by Ahmad et al. (2014) demonstrated that biochar can increase the mobility of certain metals (e.g. Cu and As) in soil. Increased mobility of arsenic in soils with an addition of biochar from biomass contaminated with heavy metals was noted also by Hartley et al. (2009).

Another important aspect of biochar addition to soil can be the change of its physical properties. It should be emphasized that the physical status of soil (e.g. density, air-water properties, distribution and patency of soil pores) plays an important role (Blum, 1998; Bronick and Lal, 2005; Dexter, 2004a,b,c; Reynolds et al., 2002), as it determines the conditions under which chemical reactions, biochemical transformations and microbiological processes take place (e.g. processes of oxidation and reduction, values of redox potential, transfer or immobilization of pollutants in soil) (Pranagal, 2011). Research on the subject conducted so far showed that an addition of biochar caused an increase of soil ability to retain water available for plants (AWC), a reduction of soil bulk density and an increase of total porosity, as well as enhanced stability of soil aggregates (Abel et al., 2013; Ajayi et al., 2016; Herath et al., 2013; Laird et al., 2010; Nelissen et al., 2015; Omondi et al., 2016).

The objective of this study was to determine the effect of biochar application to soil on the basic physical properties of Haplic Podzol (IUSS Working Group WRB, 2006), and the durability of the effect of one-time application of biochar to the soil.

2. Materials and methods

2.1. Study area and sampling

The field experiment was conducted under the climate conditions of south-east Poland. The six-year (2010–2015) study on the physical properties of Haplic Podzol (IUSS Working Group WRB, 2006) originating from glaciofluvial fine-grained loamy sand (LS) was conducted at the Experimental Agricultural Station in Bezek – 51°12′N; 23°16′E (macro-region of Polesie Wołyńskie, mezzo-region of Pagóry Chełmskie). The particle size distribution (Polish Society of Soil Science (PSSS), 2009) of the arable layer of this soil was as follows: 2.0–0.5 mm fraction 9%; 0.5–0.25 mm fraction 24%; 0.25–0.05 mm fraction 39%; 0.05–0.002 mm fraction 26% and < 0.002 mm fraction 2%. Total organic carbon content TOC = 5.3 g kg^{-1}; pH_{KCl} = 4.9; $CaCO_3$ trace amounts. In the field experiment biochar produced from waste biomass – winter wheat straw – was used. It was produced through pyrolysis conducted at a very low oxygen level (1–2%) and at a combustion temperature of maximum 650 °C. The biochar was produced by