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Effect of poultry litter biochar on soil enzymatic activity, ecotoxicity and plant growth

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ABSTRACT

Diversity of technological conditions and of raw materials from which biochar is produced is the reason why its soil application may have a varied effect on chemical and biological properties of soil and soil ecotoxicity. The aim of this study was to evaluate the effect of the addition of poultry litter (5.00 t DM ha^{-1}) and biochar obtained from this material in doses of 2.25 t and 5 t DM ha^{-1} on soil enzymatic activity, soil ecotoxicity and grass crop yield (pasture grass mix). The research was carried out under field conditions. No significant effect of biochar amendment on soil enzymatic activity was observed. The biochar-amended soil was low-toxic to *Vibrio fischeri* and non-toxic to *Heterocypris incongruens*. Application of poultry litter biochar in doses of 2.25 t and 5 t DM ha^{-1} contributed to an increase in plant biomass production by 32% and 30%, respectively compared to the control (C). Biochar had more adverse effect on soil enzymatic activity and grass crop yield than non-converted poultry litter, but it significantly reduced soil toxicity to *H. incongruens* and *V. fischeri*.

1. Introduction

The growing interest in the subject of biochar is connected not only with its application, but also with conditions of the processes and substrates which are used to obtain this material (Stavi and Lal, 2012). Increasingly, biochar is produced using substrates of different origin and with different physical and chemical properties, such as agricultural and forest biomass, sewage sludge, or by-products from animal production and processing, including from poultry breeding and slaughter. Poultry production is one of the biggest and fastest developing branches of the agri-food industry in the world, generating considerable amounts of waste of which recycling creates a lot of problems. An alternative practice that allows for effective use of nutrients present in this type of materials is to convert them into biochar (Inal et al., 2015a,b). This process may bring not only measurable advantages for the environment, but can also constitute a solution to frequently disputable questions of managing this type of materials (Jindo et al., 2012; Arthur et al., 2015).

Despite the fact that the use of organic waste as fertiliser has been practiced all over the world for many years, there is still necessity to assess their potential effect on soil chemical and biological properties. Environmental concerns connected with the utilisation and environmental management of poultry litter arise mainly from its varied chemical composition, including: contents of water, macronutrients (particularly of nitrogen and phosphorus), trace elements, and unstable organic matter (Bhoi and Mishra, 2012; Arthur et al., 2015). That is why more and more attention is drawn to the proper processing of these materials and their proper management.

Scientists are interested in biochar, as it is a material that improves soil properties (Arthur et al., 2015). A lot of research results indicate that this material may increase the content of soil organic matter, and particularly, of extractable organic carbon. It may increase the biomass of soil microorganisms and stimulate their enzymatic activity (Akça and Namlı, 2014; Lehmann and Joseph, 2015). Beneficial effects of biochar application to soil arise mainly from the improvement of soil physical, chemical and biological properties, which over time determine soil fertility and productivity. It is assumed that, for agricultural purposes, the temperature of material pyrolysis should be approx. 300 °C, since the resulting biochars feature, among others, higher cation exchange capacity and increased content of carbon compounds (Song and Guo, 2012; Hale et al., 2012). Additionally, biochars produced at a temperature above 300 °C contain a much smaller quantity of aliphatic carbon compounds and functional groups, which may significantly reduce the effectiveness of these materials in improving soil quality (Al-Wabel et al., 2013).

According to Steinbeiss et al. (2009) and Lehmann and Joseph (2015), biochar introduced into soil creates a favourable habitat for

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microorganisms, mainly as a result of improved soil porosity. On the other hand, Spokas et al. (2011) draw attention to the possibility of the occurrence of a negative reaction of microorganisms to the biochar application to soil, which, in their opinion, is caused by unfavourable ratios of C/N and O/C. The process of microbiological decomposition of exogenous organic matter (EOM) introduced into soil, including biochar, would not be possible if it were not for specific biocatalysts, i.e. enzymes, produced by soil microorganisms. Soil enzymes catalyse consecutive stages of biodegradation of different substrates, leading to their decomposition. Climatic and habitat conditions are, of course, very important determinants of the intensity of these processes.

The activity of soil enzymes, which are catalysts of organic matter decomposition, is strictly correlated with soil physical and chemical properties (Kussainova et al., 2013), structure of populations of soil microorganisms (Nielsen et al., 2014), vegetation (McCormack et al., 2013), or with the occurrence of various anthropogenic factors (Lehmann and Joseph, 2015). The complexity of factors which influence soil biology is vast, particularly under field conditions. Therefore, assessment of soil ecotoxicity and soil enzymatic activity constitutes a necessary step towards comprehensive discovery and understanding of key processes that link populations of microorganisms and dynamics of trace elements as a result of biochar application (Ameloot et al., 2013a).

Enzymatic tests (Ouyang et al., 2014) and ecotoxicological tests (Oleszczuk et al., 2014) are effective indicators of soil quality. However, these tests are not easy to interpret because there are two contradictory effects at work at the same time. On one hand, external organic matter added to the soil acts synergistically on soil microorganisms, and thereby increases their enzymatic activity. On the other hand, organic and inorganic pollutants which are present in such materials can have an inhibiting (antagonistic) effect on microorganisms (Domene et al., 2014).

The conducted research aimed at assessing the effect of poultry litter amendment, before and after thermal conversion, on the enzymatic activity and ecotoxicity of a loamy sand soil as well as on grass crop yield.

2. Material and research methods

2.1. Poultry litter and its thermal conversion process

The biochar used was produced from poultry litter and adequately prepared (drying at 70 °C, milling in a laboratory mill). Thermal conversion was conducted at a station designed for gasification of biomass, under a limited supply of air (1–2%) (IBI 2012). The rate of heating the combustion chamber was 10 °C min^{-1}. Temperature inside the combustion chamber was 300 °C, and exposure time was 15 min. In the long term, exposure of organic material to heat stabilises active forms of C and has a positive effect on the formation of surface functional groups. The pyrolysis time and temperature were established on the basis of own preliminary examinations and results reported in the literature (Al-Wabel et al., 2013; Gondek et al., 2014).

In order to characterise the chemical composition of the poultry litter before and after thermal conversion, dry matter content was determined after drying the materials at 105 °C for 12 h (Jindo et al., 2012). Next, the materials were ground in a laboratory mill and subjected to chemical analyses. The content of total carbon and nitrogen was determined on the vario MAX cube CNS analyser (manufactured by Elementar) (Elementar Analysensysteme, 2013). In order to determine the total content of macroelements and trace elements, organic material samples (0.5 g dry matter) were placed in Teflon vessels, and treated with 6 cm^3 of concentrated HNO_3 (Suprapur 65%) and 2 cm^3 of H_2O_2. Subsequently, the materials were mineralised in a closed system using Multiwave 3000 microwave oven manufactured by AntonPaar. After mineralisation, the samples were quantitatively transferred to 25 cm^3 flasks by rinsing the vessels with hot water. After cooling, the flasks were made up to volume with redistilled water, their contents mixed, and the contents of macroelements and trace elements determined by inductively coupled plasma optical emission spectrometry (ICP-OES) using Perkin Elmer Optima 7300 DV (Oleszczuk et al., 2007). For quality control of the metal analysis, a certified reference material (Certificate No. NCS DC 73348 – China National Analysis Center for Iron & Steel) and internal laboratory sample were added to each analytical run. The measured total P, K, Cd, Cr, Ni, Cu, Pb and Zn concentrations in these samples were always within 88–121% of the certified reference values. Specific surface area of organic materials, as well as pore volume and diameter were determined using the multifunction accelerated surface area and porosimetry analyser ASAP 2010 (Micrometics, USA). Specific surface area was determined by physical adsorption of nitrogen at liquid nitrogen temperature (77 K) from the Brunauer-Emmet-Teller (BET) equation. Prior to measurement (BET), the studied samples were subjected to desorption at 105 °C in vacuum and rinsed with pure helium. Sample degassing time was 16 h. The surface degassing state was controlled in automatic mode (Barret et al., 1951).

2.2. Micro-plot tests and collecting the research material

Micro-plot tests were conducted in 2014 on arable land located in southern Poland (50° 08,404′ N; 19° 85,362′ E). The soil from the experimental area was classified as typical Eutric Cambisols with the granulometric composition of loamy sand (FAO World Reference Base for Soil Resources (WRB 1998)). The experiment comprised 5 experimental treatments carried out in 3 replications, set up in randomised block design. The area of one plot was 1 m^2. The experiment involved poultry litter (PL) application to soil before thermal conversion (5.00 t DM ha^{-1}), and after thermal conversion in two doses of 2.25 t DM ha^{-1} (PLB I) and 5 t DM ha^{-1} (PLB II)). Two reference treatments were also included: the control treatment without fertilization (C) and a treatment in which only fertilization with mineral fertilisers (MF) was applied. Due to the necessity to create comparable conditions, mineral fertilisers (100 kg N ha^{-1}, 40 kg P ha^{-1} and 120 kg K ha^{-1}) were applied. The dose of phosphorus was applied once under first crop in the form of enriched triple superphosphate. Potassium was applied in the form of potassium salt, and nitrogen in the form of ammonium nitrate. Doses of potassium and nitrogen, with the assumption of harvesting three swaths, were divided into three equal parts. The poultry litter was mixed, before and after thermal conversion, with the soil top layer (0–10 cm), and then a pasture grass mix was sown using 60 kg ha^{-1} of seeds.

After the vegetation was harvested, soil samples were collected from each plot from the 0–10 cm soil layer (7 months after application of organic materials) using a stainless steel sampler. In the soil samples dried and 1 mm sieved, chemical and physicochemical analyses were conducted. Enzymatic activity and ecotoxicity of the soil were determined in fresh soil samples.

2.3. Determinations in the soil

The following properties were determined in soil samples dried at room temperature and 1 mm sieved: pH by potentiometric method in soil and water suspension and in suspension of the soil and 1 mol dm^{-3} KCl solution (soil: solution = 1: 2.5); electrolytic conductivity (EC) by conductometer; and contents of total nitrogen and carbon was determined on the vario MAX cube CNS analyser (manufactured by Elementar) (Elementar Analysensysteme, 2013). The contents of selected trace elements were determined after