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The effect of precomposted sewage sludge mixture amended with biochar on the growth and reproduction of *Eisenia fetida* during laboratory vermicomposting

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ABSTRACT

The obtained results showed that the addition of biochar to the mixture of sewage sludge and wheat straw prior to composting facilitated the growth and reproduction of *Eisenia fetida* during laboratory vermicomposting of this mixture. After 4 weeks of vermicomposting the average number of produced cocoons in the mixtures amended with biochar increased by 13% for SS + ST + 4%B and 66% for SS + ST + 8%B. Also, the number of juvenile earthworms was higher in the mixtures amended with biochar. However, the total weight of earthworms declined with the depletion of organic matter after 18 weeks of the experiment. Amending sewage sludge mixtures with biochar for vermicomposting resulted in higher reproduction rates, and thus could allow faster and more efficient conversion of sewage sludge into vermicompost.

1. Introduction

In recent years the interest in the application of vermicomposting for organic waste management has been rapidly increasing and vermicomposting as a method for treating organic waste (including sewage sludge) has been extensively studied by many researchers worldwide (Begum and HariKrishna, 2010; Yadav and Garg, 2011; Nayak et al., 2013; Kharrazi et al., 2014; Hanc and Chadimova, 2014; Suthar and Gairola, 2014; Lalander et al., 2015; Abbasi et al., 2015). Due to increasing quantities of municipal sewage sludge generated in Poland in recent years (CSO, 2014) and introduction of new regulations on sewage sludge management there is a need for alternative methods for converting municipal sewage sludge into value added product. Vermicomposting of sewage sludge could be one of these methods (Khwairakpam and Bhargava, 2009; Azizi et al., 2011; Fu et al., 2015).

Vermicomposting is defined as a decomposition process that allows conversion of organic waste by worms and microorganisms into stable humus-like material referred to as vermicompost (Khwairakpam and Bhargava, 2009; Garg et al., 2012). This method shows a number of advantages and benefits for cost-effective and sustainable utilization of sewage sludge from municipal wastewater treatment plants. The evaluation of vermicomposting process is based on the following indicators, i.e. survival rate, biomass production (i.e. weight gain) and reproduction (i.e. number of cocoons, juvenile and adult earthworms), conversion rate of waste to vermicompost and properties of obtained vermicomposts (Garg et al., 2012). The activity of earthworms, and thus the efficiency of sewage sludge vermicomposting, can be limited by different contaminants present in this material, e.g. heavy metals or pharmaceuticals, and thus inhibit the activity of earthworms. Therefore, vermicomposting of sewage sludge requires pretreatment and addition of selected materials to provide favorable conditions for earthworms. Literature provides examples of studies on the effects of various amendments added to composting mixtures of sewage sludge in order to reduce the negative effect of contaminants on the activity of earthworms. Sewage sludge was mixed with a wide range of materials such as garden waste, food waste, bulking materials (e.g. straw, sawdust, hay, pine bark, mature vermicompost, paper mulch, water hyacinth *Eichhornia crassipes*), anaerobically digested biogas plant slurry, rabbit manure, vinasse biowaste, sugarcane trash, etc. (Haimi and Hupta, 1986; Ndegwa and Thompson, 2000; Garg et al., 2006; Molina et al., 2013; Begum and HariKrishna, 2010; Hait and Tare, 2012; Garg et al., 2012; Malińska et al., 2004; Malińska and Zabochnicka-Świątek, 2013). Also, selected

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immobilizing amendments such as fly ash, phosphatic rock, etc. can be added to sewage sludge for reducing mobility and bioavailability of heavy metals (Wang et al., 2013). Other potential amendments for vermicomposting of sewage sludge include biochar. Biochar is a charcoal like material obtained from pyrolysis of different types of biomass feedstock that is composed of relatively recalcitrant carbon, liable or leachable carbon and ash. It shows high stability and sorption properties, and thus retention of water, nutrients, and other compounds. Different types of biochar contain macro and micronutrients, and therefore can be valuable sources of nutrients for soil microorganisms, and soil macrofauna such as earthworms (Lehmann et al., 2011). However, depending on biomass feedstock and pyrolysis parameters biochar can also contain some toxic compounds such as furans, dioxins, heavy metals, polycyclic aromatic hydrocarbons and polychlorinated biphenols. Biochar can be used for a great number of applications that also include composting and vermicomposting (Czekała et al., 2016; Schmidt, 2012). Steiner et al. (2011) investigated biochar as a bulking agent for composting of poultry manure. Due to its properties biochar can be applied as an amendment to waste mixtures treated with vermicomposting. It is speculated that the addition of biochar to composting mixtures can have a beneficial effect on the process of vermicomposting by facilitating the growth and reproduction of earthworms, and thus more efficient conversion of waste to vermicompost, and improving the properties of obtained vermicomposts. According to the literature the effects of various types of biochar on the activity of earthworms are not known. However, Leisch et al. (2010) investigated the impact of two different biochars (pine chip and poultry litter char) at five application rates (0, 22.5, 45, 67.5 and 90 Mg ha^{-1}) on growth and survival rate of *Eisenia fetida* in artificial soil. They found that the highest two application rates of poultry litter biochar resulted in 100% mortality and weight loss. This was mostly due to the fact that poultry litter biochar showed high pH (10.3) and contained toxic compounds such as As, Zn, Cu, Fe and Al. Also high Na and Mg content resulted in high salinity. The examples of studies on the effect of biochar on growth and reproduction of *E. fetida* during vermicomposting of sewage sludge were not found in the literature. We hypothesize that the amendment of sewage sludge and wheat straw mixtures with biochar has a beneficial effect on earthworms reproduction and biomass production, and thus could contribute to more efficient conversion of sewage sludge into vermicompost. According to the literature this could be due to a number of factors including immobilization of heavy metals present in sewage sludge by biochar, improvement of total porosity and water holding capacity, and provision of macro and microelements.

Therefore, appropriate organic by-product management is needed to achieve an optimal use and valorization of such materials. Concerning horticulture, potential targets to be studied are: fertilization, organic amendment, biostimulants against plant stress and production of growing media (Polo et al., 2006; Cáceres and Marfà, 2013).

The overall goal of this article is to present the results obtained from a 25-week study on the activity of *E. fetida* during laboratory vermicomposting of precomposed sewage sludge mixed with straw and amended with biochar. The scope of the study included: (1) physical and chemical characteristics of substrates, (2) 2-week laboratory composting of sewage sludge mixed with straw and amended with biochar in a set of composting bioreactors, (3) 25-week laboratory vermicomposting of pre-composted mixture of sewage sludge, wheat straw with biochar, (4) the analysis of *E. fetida* activity based on survival rate, total weight, cocoon production, number of juvenile earthworms, and (5) physical and chemical characteristics of the obtained vermicompost.

2. Material and methods

2.1. Materials

2.1.1. Raw materials

Materials used in the experiment included sewage sludge, wheat straw and biochar. Sewage sludge (dewatered and anaerobically stabilized) was sampled from a municipal wastewater treatment plant (Częstochowa, Poland). Wheat straw was collected from a local farm, air-dried and cut into 4–5 cm length. The properties of sewage sludge (SS) and wheat straw (ST) are presented in Table 1. Biochar was obtained from a commercial manufacturer (Poland). It was produced from willow woodchips in temperature of 350 °C. Biochar was crushed in a laboratory jaw crusher (LAB-01-65, EKOLAB) and sieved to size <2 mm. Moisture content (MC) was 4.9% (on fresh weight), ash content was 7.4% (on dry weight) and pH of 7.06. Biochar was tested for C, N, S, H (Leco analysis) and macro and microelements (atomic absorption spectrometry). The content of total N, C, H and S in biochar was 0.36% d.m, 83.21% d.m, 3.08% d.m, 0.03% d.m, respectively. Organic carbon was 51.4 (on dry weight). The average concentration of selected macronutrients i.e. Ca, K, Mg and P was 6300 mg/kg d.m, 1500 mg/kg d.m, 720 mg/kg d.m and 438 mg/kg d.m, respectively. The average concentration of heavy metals in biochar was following: Pb – 1.9 mg/kg d.m, Cd – 0.5 mg/kg d.m, Cu – 7.7 mg/kg d.m, Ni – 2.8 mg/kg d.m, Zn – 8 mg/kg d.m, Cr – 0.04 mg/kg d.m and also Hg – 0.023 mg/kg d.m, and did not exceed the thresholds stipulated by the *European Biochar Certificate* for safe application of biochar to soils (EBC, 2015).

2.1.2. Initial mixtures

Sewage sludge (SS) was mixed with wheat straw (ST) (20 kg of sewage sludge and 0.5 kg of wheat straw) and amended with 4% and 8% of biochar (B) (wet weight). The ratios of these materials in the mixtures were following: SS + ST + 0%B – 1:0.03:0 (1:0.12:0 dry weight), SS + ST + 4%B – 1:0.03:0.04 (1:0.12:0.19 dry weight), SS + ST + 8%B – 1:0.03:0.08 (1:0.12:0.39 dry weight).

2.2. Experimental set-up

2.2.1. Composting

All initial mixtures were composted in 40 L laboratory composting reactors with forced aeration for 14 days, and then used for vermicomposting. Composting was monitored by daily measurements of temperature (data not presented here) and samples were taken on day 0, 7 and 14 (Malińska et al., 2014). Composting prior to vermicomposting allows stabilization and mass reduction of waste and also inactivation of pathogenic microorganisms (Nair et al., 2006).

2.2.2. Vermicomposting

The obtained composts were then vermicomposted. The vermicomposting system consisted of the 2.5 L plastic boxes with

Table 1
Characteristics of raw materials.

	SS	ST
MC, %	79.7 ± 0.1	5.2 ± 0.2
OM, %	60.7 ± 0.1	95.6 ± 0.3
Corg, %	33.7	53.1
Ash, %	39.3 ± 0.1	4.4 ± 0.3
N, %	3.10	0.22
C/N	11:1	241:1
pH	7.68	5.79

MC – moisture content (wet weight), OM – organic matter content (dry weight), SS – sewage sludge, ST – wheat straw.