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Effects of co-composted maize, sewage sludge, and biochar mixtures on hydrological and physical qualities of sandy soil

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ABSTRACT

The agronomic utilization of compost has some benefits to soil. Compost increase soil nutrients, and soil organic matter content; thus, it has a positive effect on biological, physical, and chemical properties of the soil. During the composting process, different feedstocks such as plant wastes, sewage sludge, and biochar are used. Biochar has great potential to improve the quality of compost. This paper reports the effects of different compost rates and feedstock types of biochar on water retention characteristics of sandy soil in a standard natural turfgrass root zone.

Using soil with the texture of loamy sand, a pot experiment was established. The following mixtures of feedstocks were used in this study: compost of maize straw (MS), compost with sewage sludge (MS + SS), and compost of mixture of maize straw, sewage sludge, and biochar (MS + SS + BC). Mixtures of compost additives and soil were prepared at 0.5% (R05), 1% (R1), 2% (R2), and 4% (R4).

Compared to untreated soil, the physical properties of the sandy soil were significantly improved with the application of compost. The basic physical parameters of the soil, such as bulk density and total porosity, depended mainly on the rate of the biochar additive. The differential porosity of the soil was affected by both compost rate and feedstock type. For compost with sewage sludge, the highest content of large pores with diameters above 500 μm was observed, and this was achieved with biochar addition. Addition of the compost also significantly increased the volume of pores with diameters below 50 μm compared to the untreated control soil. The water retention properties of the soil were improved with the compost application and were dependent on the rate of compost and the type of feedstock. The lowest value of available water content (AWC) was obtained for soil with maize straw compost. The addition of sewage sludge or biochar during the composting process resulted in an increase in AWC in the soil. The best combination of compost rates and feedstock types is maize compost with both sewage sludge and biochar at a rate of 4%.

1. Introduction

Composting organic bio-wastes and applying them as organic fertilizers has become increasingly popular in Europe. The agronomic utilization of compost has some benefits to soil. Compost increase soil nutrients, and soil organic matter content; thus, compost application has a positive effect on biological, physical, and chemical properties of the soil (Aggelides and Londra, 2000; Hargreaves et al., 2008).

Because of the high macronutrient (e.g., nitrogen, phosphorus, calcium, and sulfur), micronutrient (e.g., copper and zinc) and organic matter contents, municipal sewage sludge (SS) is recognized as a source of valuable fertilizer. However, SS also contains contaminants such as heavy metals, organic pollutants or pathogens, which may lead to environmental or health risks (Bartl et al., 2002; Mosquera–Losada et al., 2010), and this can limit the direct application of sewage sludge to soil fertilization.

Therefore, SS should be composted before its application. Composting is one of the more acceptable and economically feasible technologies for recycling SS (Villasenor et al., 2011). Composting SS helps with waste management, and it appears to be an appropriate soil conditioner due to a high content of stable, humified organic matter (He et al., 2011; Sevilla–Perea and Mingorance, 2015; Yuan et al., 2016).

However, because of a high moisture content that affects the

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dynamics of the composting process, SS is composted alone. Furthermore, a low C/N ratio is not beneficial to the progress of composting because it causes volatilization of a large amount of ammonia (Li et al., 2013; Wang et al., 2014; Kulikowska, 2016). During composting, small particles of SS cause poor gas permeability (Zhao et al., 2016). Thus, SS should be mixed with dry organic material in order to adjust the moisture content and C/N ratio (e.g., straw or wood chips), as well as to improve the gas permeability and reduce the nitrogen losses (Awasthi et al., 2016; Meng et al., 2017). The co-composting of SS reduces the contamination with pathogenic microorganisms, improves stability, and contributes to a lowering of the availability of metals in amended soils (Smith, 2009; Alvarenga et al., 2015).

However, researchers are constantly searching for other soil additives to improve both the process and the final compost quality. Biochar, the solid product of biomass pyrolysis, seems to be a very promising soil amendment and compost component. During the past decade, biochar has been considered a valuable product that results in soil improvement and carbon sequestration that may mitigate climate change (Peake et al., 2014). Biochars are described as produced from organic feedstocks heterogeneous materials that vary in their chemical and physical properties. This variability depends not only on the parameters involved in pyrolysis but also on the materials used to produce biochar (Gundale and DeLuca, 2006; Atkinson et al., 2010). As a soil additive, biochar has been shown to affect the physical, chemical, and biological properties of the soil (Lehmann et al., 2011; Mukherjee and Lal, 2013; Herath et al., 2013). Nutrient availability (N and P) in the soil may be enhanced by adding biochar because of a higher cation adsorption (Liang et al., 2006) or because of an increased pH in acidic soils (Van Zwieten et al., 2010). Lehmann et al. (2011) reported that the application of biochar affects the activity of soil fauna and microorganisms. However, these effects depend on biochar characteristics, doses, and soil properties (Jha et al., 2010). Głąb et al. (2016) in a previous study reported that biochar improved the physical properties of sandy soil. By adding biochar, the macroporosity and mesoporosity of the soil were significantly increased, thus improving aeration and water availability for plant roots (Herath et al., 2013). This characteristic of biochar is ascribed to its highly porous structure and large surface area (Atkinson et al., 2010). However, other studies have reported no impact. Jeffery et al. (2015) found no significant effects of biochar application on sandy soil water retention. Hardie et al. (2014) observed similar results with no improvement in soil moisture or water retention characteristics.

Some advantages of biochar application have also been recognized during the composting process. Biochar reduces gaseous emissions including ammonia, carbon dioxide, and other greenhouse gasses (Malińska et al., 2014; Steiner et al., 2011). It improves the quality of composts by reducing nitrogen losses and by reducing the mobility of heavy metals (Dias et al., 2010; Chen et al., 2010; Jindo et al., 2012; Zhang et al., 2014). Biochar has an impact on composting dynamics by causing a faster decomposition of organic matter, and by increasing the porosity and the water holding capacity (Czekała et al., 2016).

In coarse-textured soils, the application of organic fertilizers, especially compost, is particularly important. Sandy soil is widely used at sport facilities with natural turfgrass. A typical soil profile under sport turfgrass contains a sand-enriched rootzone on top of a coarse-textured sand or gravel. The principal motivation of using a high sand-content rootzone is to improve the mechanical properties of the turf surface and to resist soil compaction from frequent foot traffic. This contradicts the main function of the rootzone, which is to store water and nutrients (McCoy and McCoy, 2009). Coarse-structured soil with low clay content is characterized by a lack of water retention and nutrient-holding capacity necessary for healthy turf growth (Nasta et al., 2009). One of the solutions is to increase the soil organic matter content by adding organic materials such as sphagnum peat moss or compost, including composted sewage sludge (Rawls et al., 2003; Bigelow et al., 2004; Cheng et al., 2007). This increases the amount of available moisture in the rootzone, thus permitting longer intervals between irrigations (Shao-Hua et al., 2012; Andry et al., 2012). However, reports on the effects of organic matter on soil hydraulic properties are sometimes contradictory. Danalatos et al. (1994) did not find any effect of organic matter content on water retention. A risk exists that the organic substances in the soil and their biodegrading products may induce water repellency (Scott, 2000; McKissock et al., 2000).

We hypothesize that a compost of maize straw and sewage sludge with a biochar additive influences the soil pore system, but this influence can be modified by adjusting compost components and application rate. The objective of this study was to determine the effect of different compost rates and feedstock types of compost on sandy soil water retention characteristics in a standard natural turfgrass rootzone.

2. Materials and methods

2.1. Sample preparation

In this experiment, the following three feedstocks were used to produce compost: maize straw (MS), sewage sludge (SS), and biochar (BC). SS used in this study came from a municipal wastewater treatment plant (mechanical and biological system) located in the Małopolska Province (southern Poland). Before the sampling, sewage sludge was subjected to oxygen stabilization in separate open chambers in which continuous aeration was performed at ambient temperature. The aeration process lasted for 5 days. Then, sewage sludge was dewatered using a settling centrifuge.

Biochar was produced from willow (*Salix viminalis* L.). The plant material was pyrolyzed in an electrical laboratory furnace at a temperature of 350 °C for 15 min with limited air access (International Biochar Initiative, 2014). Time and temperature were set according to Lu et al. (2013), Mendez et al. (2013) and Domene et al. (2015). The rate of the furnace heating was 10 °C min^{-1}. Then, the biochar was removed from the furnace and cooled in a desiccator.

The following mixtures of feedstocks were used in this study: maize straw (MS), maize straw with sewage sludge (MS + SS) and maize straw, sewage sludge and biochar (MS + SS + BC). The proportions of the components used in individual treatments were (by weight of dry matter): MS:SS – 1:0.15; MS:SS:BC – 1:0.15:0.1. These proportions of feedstock in the mixtures correspond to a C/N ratio of 30. The feedstock was composted for 140 days from May to the end of September 2015. The process was carried out in 1.2 × 1.0 × 0.8 m bioreactors with perforated bottoms to allow active aeration. The moisture of the composted material was equilibrated to 60% by weight. Aeration of the biomass was performed in cycles 6 times a day; air was flown through the bioreactor at a rate of 15 dm^3 per min for 60 min. The biomass was manually shifted every 10 days. Laboratory bioreactors were sheltered against precipitation, but they were exposed to outside temperatures and sunlight. The basic chemical characteristics of the composts are presented in Table 1.

According to the ASTM F2396–04 and DIN 18035–4 standards, soil

Table 1
Chemical properties of tested composts made of maize straw (MS), sewage sludge (SS) and biochar (BC). Standard deviations in parentheses.

Parameter	Units	MS	MS + SS	MS + SS + BC
Dry matter	g kg^{-1}	705 (9)	745 (10)	642 (7)
Ash	g kg^{-1}	209 (2)	296 (3)	288 (4)
pH H_2O		7.89 (0.79)	7.96 (0.80)	7.60 (0.76)
Electrical conductivity	μS cm^{-1}	6.78 (0.70)	4.86 (0.49)	4.64 (0.46)
C	g kg^{-1}	406 (3)	365 (4)	382 (32)
N	g kg^{-1}	31.8 (0.7)	39.4 (1.9)	33.2 (2.8)
P	g kg^{-1}	11.2 (0.7)	18.1 (0.4)	14.4 (0.3)
K	g kg^{-1}	35.9 (2.3)	28.3 (1.0)	22.0 (0.2)
Ca	g kg^{-1}	11.4 (0.6)	26.0 (0.5)	28.3 (2.1)
Mg	g kg^{-1}	6.10 (0.33)	7.85 (0.23)	6.60 (0.15)