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Heterogeneity of zeolite combined with biochar properties as a function of sewage sludge composting and production of nutrient-rich compost

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ABSTRACT

In the present study, biochar combined with a higher dosage of zeolite (Z) and biochar (B) alone were applied as additives for dewatered fresh sewage sludge (DFSS) composting using 130-L working volume lab-scale reactors. We first observed that the addition of a mixture of B and Z to DFSS equivalent to 12%B + 10% (Z-1), 15% (Z-2) and 30% (Z-3) zeolite (dry weight basis) worked synergistically as an amendment and increased the composting efficiency compared with a treatment of 12%B alone amended and a control without any amendment. In a composting reactor, the addition of B + Z may serve as a novel approach for improving DFSS composting and the quality of the end product in terms of the temperature, water-holding capacity, CO_2 emissions, electrical conductivity, water-soluble and total macro-nutrient content and phytotoxicity. The results indicated that during the thermophilic phase, dissolved organic carbon, NH_4^+-N and NO_3^--N increased drastically in all biochar amended treatments, whereas considerably low water-soluble nutrients were observed in the control treatment throughout and at the end of the composting. Furthermore, the maturity parameters and dissolved organic carbon (DOC) indicated that compost with 12%B + 15%Z became more mature and humified within 35 days of DFSS composting, with the maturity parameters, such as CO_2 evolution and the concentration of NH_4^+-N in the compost, being within the permissible limits of organic farming in contrast to the control. Furthermore, at the end of composting, the addition of higher dosage of biochar (12%) alone and 12% B + Z lowered the pH by 7.15 to 7.86 and the electrical conductivity by 2.65 to 2.95 mS cm^{-1} as compared to the control, while increased the concentrations of water-soluble nutrients (g kg^{-1}) including available phosphorus, sodium and potassium. In addition, greenhouse experiments demonstrated that the treatment of 150 kg ha^{-1} biochar combined with zeolite and that of 12%B alone improved the yield of Chinese cabbage (*Brassica rapa chinensis* L.). The highest dry weight biomass (1.41 ± 0.12 g/pot) was obtained with 12%B + 15%Z amended compost. Therefore, 12%B + 15%Z can be potentially applied as an amendment to improve DFSS composting.

1. Introduction

One of the most problematic characteristics of human society is its capacity to utilize huge quantities of water for anthropogenic activities and later generate large amounts of waste water, which cause serious environmental problems, such as sewage sludge (SS). In China, more than 129 million tons of municipal wastewater are treated daily in wastewater treatment plants (WWTPs). During this process, over 30 million tons of SS are generated annually as an unavoidable byproduct (National Bureau of Statistics of the People's Republic of China, 2014). The management of huge quantities of biological SS from waste-water treatment plants is an expansive and environmentally sensitive problem in Chinese cities because this waste contains heavy metals (HMs), organic micro-pollutants and pathogens, which have lead to stringent legislation for SS applications (Zhang et al., 2014; Awasthi et al., 2016b).

However, in the last few years, many alternative methods for the ecofriendly disposal of this bio-waste have been proposed, with composting being one of the most promising alternative technologies used to kills pathogens present in these waste materials. Composting has the ability to create a valuable humus-like end product that can be used as a growing medium (Malinska et al.,

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2014; Zhang et al., 2016) or increase soil fertility (Biederman and Harpole, 2013). In fact, it has been documented that the composting of SS (which is significantly rich total nitrogen and high moisture content) together with organic bulking waste materials which high contain carbon and low in moisture content (straw, rice husk, yard waste, sawdust, etc.) can be used to produce sanitized and stabilized end products by adjusting the moisture content (~55%) and carbon-to nitrogen (C/N) ratio (~25). SS mixed with wheat straw, rather than either waste alone, is more suitable for efficient composting (Venglovsky et al., 2005; Zorpas and Loizidou, 2008; Villaseñor et al., 2011; Zhao et al., 2013; Awasthi et al., 2016b).

Biochar is composed of a carbonaceous solid byproduct which formed during bio-energy production through organic biomass pyrolysis or gasification under low oxygen conditions (IBI, 2012). It has appreciable carbon sequestration value and abundant quantities of recalcitrant aromatic ring structures (Zhang et al., 2014) that have a long half-life in soil (Czekala et al., 2016). In the last few years, biochar has been widely used in soil remediation, carbon sequestration, and the mitigation of greenhouse gases (GHGs) (Shrestha et al., 2010; Jindo et al., 2012; Malinska et al., 2014; Sun et al., 2016b), because biochar sequestration and application do not require advanced scientific method. Biochar production is a simple technology and suitable for all developed as well as developing countries, but its optimization and economic feasibility for large-scale production still need to be established (Zhang et al., 2016). The biochar amendment process was applied to the composting of various organic substances by several earlier researchers (Hua et al., 2009; Dias et al., 2010; Steiner et al., 2010; Jindo et al., 2012; Awasthi et al., 2017), who reported a number of additional benefits, such as increased nutrient availability, microbial activity, soil organic matter, and water retention during organic waste composting.

Consequently, biochar can be used as a bulking agent to reduce the bulk density and increase the porosity (Steiner et al., 2010; Sun et al., 2016a), and, as a result, increase the microbial growth and enzymatic activities (Jindo et al., 2012), and reduced the nitrogen loss, CH_4 and N_2O emission (Awasthi et al., 2017), and water-soluble salts (Hua et al., 2009). In addition, Dias et al. (2010) and Zhang et al. (2016) reported that the addition of wood biochar could enhance organic-matter degradation by 73.2% of the initial content when poultry manure was mixed with wood biochar at a proportion of 1:1 (fresh weight basis). In contrast, when sawdust and coffee husk as bulking agents were amended with poultry manure, degradation levels of organic matter of 65.0% and 84.2% were achieved, respectively. A review of the above literatures indicated that the effect of natural additives such as zeolite have been extensively studied on different aspects of the composting process, such as the reduction of ammonia emissions and HMs bioavailability (Villaseñor et al., 2011; Zhao et al., 2013; Zhang et al., 2016), kaoline, bentonite, lime, phosphogypsum and medical stones for nutrient transformation and humification (Li et al., 2012; Fang and Wong, 1999; Gabhane et al., 2012; Zhang et al., 2014; Wang et al., 2016b). In the last few years, biochar has also been widely utilized as amendment for the mitigation of GHGs emission and bioavailability of HMs (Prost et al., 2013; Sánchez-García et al., 2015; Awasthi et al., 2016a). However, Jindo et al. (2012) and Zhang et al. (2016) investigated the effects of a 2–10% (v/v) wood biochar and 5–15% (v/v) wheat straw biochar amendment in poultry manure compost and found a 10% increased in the carbon content in water-extracted humic-like substances and 30% decreased in the dissolved carbon content.

However, knowledge of the effects of biochar combined with natural zeolite on nutrient transformation and compost quality during the SS composting is limited because the efficiency of composting process can observed by the rate of nutrient loss and availability of nutrients. It was with this background that wheat straw biochar mixed with SS-wheat straw to be composted to investigate its role on the biodegradation of organic matter and mitigation of GHGs as well as optimum dosage of biochar (Awasthi et al., 2017). Zeolite is a large group of microporous, hydrated aluminosilicate minerals that has the ability to reduce the various gases emissions and salinity and increased the bioavailability of mineral nutrients during composting (Munthali et al., 2014). However, zeolite alone is not good enough to buffer against the low pH during composting as revealed by several earlier authors (Venglovsky et al., 2005; Zorpas and Loizidou, 2008; Villaseñor et al., 2011; Awasthi et al., 2016b). Hence, we hypothesized that the characteristics of biochar combined with zeolite in the composting process may provide valuable information regarding the evolution of the rate of composting; considerably buffer the composting mass, water-soluble and total nutrient transformation and finally the end product quality. It should however be noted that this study was confined to the physicochemical transformation and end product quality. The objective of present study was to study the nutrient transformation during composting of DFSS with the assistance of biochar combined with a higher dosage of zeolite and compared with biochar alone as well as control treatments. The novelty of this work consists of its use of biochar combined with higher dosage of zeolite for DFSS composting and evaluating the effect of the final compost to Chinese cabbage (*Brassica rapa chinensis* L.) growth to assess the compost toxicity.

2. Materials and methods

2.1. Composting feed stock collection, processing and properties

DFSS was collected from a local municipal wastewater treatment plant (Yangling, Shaanxi Province, China) and wheat straw (WS) was collected from the local agricultural farmer of the university campus. Chopped WS (2–5 cm) was used as a bulking agent to achieve the moisture content (~55%) and C/N ratio ~25, whereas DFSS and WS were mixed at a ratio of 1:1 (dry weight basis). Biochar was purchased from Yangling Pvt. Ltd., Shaanxi Province, China, whereas natural zeolite with a cation exchange capacity of 120–160 meq/100 g and diameter of 3.5–4.0 (Ai) was purchased from Zhejiang Shenshi Mining Industry Co., Ltd, China. The biochar was prepared from wheat straw biomass via slow and dry pyrolysis at a temperature of 500–600 °C at atmospheric pressure for 24 h, which was initiated by the pyrolysis of feedstock from the bottom of the kiln as per Khan et al. (2015). The some basic properties of the biochar are shown in Table 2, and the BET surface area ($421.57\ m^2\ g^{-1}$), the pore volume ($0.2\ cm^3\ g^{-1}$) and the pore size (5.93 nm), S (0.17 ± 0.03%), O (15.8 ± 0.12%) and H (3.05 ± 0.06%), which were determined by standard methods (Mc-Naughton, 1976). The biochar C, H, O, N and S properties were analyzed using Vario EL cube CHNOS element analyzer (Elementar, German). Air-dried wheat-straw biochar was crushed into fine particles and sieved to 2–5 mm and was used as an amendment for the experiment. The basic physicochemical characteristics of the raw materials are listed in Table 2.

2.2. Composting system and experimental design

Composting was carried out in 130-L laboratory scale in-vessel reactors which is filled with 100-L or ~50 kg of fresh DFSS mixed with wheat-straw (1:1 ratio on dry weight basis or ~5:1 ratio of fresh weight basis), and 12% B combined with different dosages of Z [10% (Z-1), 15% (Z-2) and 30% (Z-3) by dry weight of the DFSS] (Table 1). Similarly 100-L mixture of DFSS and WS (that is, without any amendment) were used as a control, whereas a 12%B alone amended treatment served for comparison purposes. In addition,