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The use of biochar-amended composting to improve the humification and degradation of sewage sludge

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HIGHLIGHTS

- Biochar accelerated the humification progress of sludge organics.
- Biochar increased oxygen uptake rates of sewage sludge during aerobic degradation.
- SEM showed the porosity of the sludge surface increased with 12–18% biochar amended.

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ABSTRACT

Wood biochar (6%, 12% and 18% of fresh sludge weight) adding to a sludge-and-straw composting system was investigated to assess the potential of biochar as a composting amendment. Organic degradation efficiency, temporal humification profile of the water-extractable organic fraction and solid organic matter, through spectroscopic, microscopic and elementary analysis were monitored. Fluorescent excitation and emission matrix indicated that concentrations of aqueous fulvic-acid-like and humic-acid-like compounds were, respectively, 13–26% and 15–30% higher in the biochar-amended treatments, than those in the control without biochar-amended. On the first day of sludge aerobic incubation, the presence of biochar resulted in increased oxygen uptake rates of 21–37% due to its higher nano-porosity and surface area. SEM indicated that, in the biochar-amended sludge, the dense microstructure on the sludge surface disintegrated into fragments with organic fraction degraded and water lost. Results indicated that 12–18% w/w addition of wood biochar to sludge composting was recommended.

1. Introduction

Due to its putrescible characteristics and the continuous and increasing quantities of its generation, sewage sludge has become a major cause for environmental concern. Composting, a traditional process used for sludge treatment, involves the recycling of nutrients and their re-use, as a biofertilizer for land application. Biochar is comprised of carbonaceous matter, formed during biomass pyrolysis (Luque et al., 2012). It contains abundant quantities of recalcitrant aromatic ring structures (Zhang et al., 2014) that have a long half-life in the soil (Fischer and Glaser, 2012). Biochar is widely used to facilitate soil amendment, thus improving soil properties (Schmidt and Noack, 2000; Kramer et al., 2004; Liang et al., 2010; Shrestha et al., 2010; Lehmann et al., 2011; Deal et al., 2012; Schulz and Glaser, 2012). This amendment process has also been applied to the composting of organic substances (Hua et al., 2009; Dias et al., 2010; Steiner et al., 2010; Jindo et al., 2012a).

A number of additional benefits are also associated with the use of biochar for the amendment for organics composting. The use of biochar as a bulking agent can result in decreasing bulk density and increasing aeration conditions (Steiner et al., 2010), improving microbial growth and microbial respiration rates (Jindo et al., 2012a), as well as enhancing the absorption of gaseous NH_3 and water-soluble NH_4^+ (Hua et al., 2009; Steiner et al., 2011). Dias et al. (2010) achieved an organic-matter degradation of 73.2% of the initial content when poultry manure was mixed with wood biochar in a proportion of 1:1 (fresh weight: w/w). When sawdust and coffee husk were amended with poultry manure, organic matter degradation levels of 65.0% and 84.2% were, achieved, respectively. A review of the above literatures indicated that the amount of biochar added to organics composting ranged from 2%

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to 50% of the total organics weight. However, knowledge of the effects of biochar on compost humification is limited. Jindo et al. (2012b), who assessed the effects of a 2% (v/v) wood biochar addition to poultry manure compost, found a 10% increase in carbon content in water extracted humic-like substances and a 30% decrease in the water-soluble carbon content. It should however be noted that this study was confined to the chemical and biochemical characteristics of the final composting product.

The objective of the present study was to develop an efficient humification process with the assistance of wood biochar. For this purpose two specific aspects were focused: investigating the temporal humification profile of sewage sludge composting amended with wood biochar; and the effect of supplying different levels of biochar to the system. During the composting process, the following parameters: pH, electrical conductivity (EC), dissolved organic carbon (DOC), the C/N ratio, specific ultraviolet absorbance (SUV_{254}/DOC), and three-dimensional fluorescence excitation–emission matrix spectroscopy (EEM) were determined in the water extracted fraction during the aqueous phase. Elementary analysis involving Fourier transform infrared spectroscopy (FT-IR) and scanning electron microscope (SEM) morphology was also undertaken, to investigate the development of structural changes to organic matter during the composting process.

2. Methods

2.1. Properties of sewage sludge, wood biochar and rice straw

Dewatered sewage sludge was obtained from a local municipal wastewater treatment plant in Shanghai, China where 75,000 m^3 of wastewater (93% domestic and 7% industrial sewage) was treated per day, using an anaerobic–anoxic–oxic (A^2O) process. Water was removed from the sludge by centrifugation, with the addition of organic flocculating agents. Chopped paddy straw (2–5 cm) was used as a bulking agent. Commercial wood biochar (Qunfang Gardening Co., China) was pyrolyzed at 500–600 °C in kilns. Dried wood biochar was crushed and sieved to 2–5 mm and then used as an amendment during composting. The characteristics of the raw materials are listed in Table 1. The wood biochar used was basic, and had advantageous hydrophobic, sorptive, aromatic, as well as it contained more water extractable fulvic-acid-like compounds (Enders et al., 2012; Zhang et al., 2014).

2.2. Composting system

The composting process was performed in foam rectangle reactors, each with a working volume of 12.5 L. The outer wall of each reactor was 4 cm thick. A whirlpool pump and a gas-flow meter were used for aeration in each reactor. A time-based aeration control system was adopted for intermittent O_2 supply, with an air flow rate of 0.03 $m^3\ h^{-1}\ kg^{-1}$ (wet basis). The layout of the reactor used for the experiment is presented schematically in Fig. S1 (Supplemental information: Fig. S1). The initial amount of sludge was 1.5 kg. Wood biochar and paddy straw were amended with sludge. First, the paddy straw at 20% of sludge wet weight as recommended by Zhao et al. (2011), and then the wood biochar at 0%, 6%, 12% and 18% of sludge wet weight were homogeneous added to the sludge-and-straw composting system. These tests are hereinafter referred to as Trial WB0, Trial WB06, Trial WB12 and Trial WB18, respectively. The mixing ratio (%) on a dry weight basis to each treatment was sludge: straw: biochar = 9:1:0, 9:1:3, 9:1:6 and 9:1:9, respectively. Each trial was conducted in duplicate. The water content of the sludge, wood biochar and straw were listed in Table 1, and the blended water content was adjusted to 70–75% and kept constant throughout all trials. The composting materials were turned every seventh day, to homogenize the materials. At the same time, fresh samples were collected for chemical analysis. The aeration process was terminated on the 21st day and the active composting trials terminated on the 42nd day.

Table 1
The characteristics of the raw materials.

	Sludge	Wood biochar	Straw
Moisture content (%)	81.6 ± 0.5	0	10.0 ± 0.3
VS (%, dry basis)	62.2 ± 3.2	40.0 ± 2.4	95.2 ± 1.2
pH value	6.8 ± 0.2	8.4 ± 0.2	7.2 ± 0.1
EC value (ms cm^{-1})	1.9 ± 0.0	0.6 ± 0.0	5.7 ± 0.3
DOC (mg L^{-1})	6680.0 ± 335	662.8 ± 55	23320.5 ± 64
DN (mg L^{-1})	3076.4 ± 16	134.1 ± 26	3148.4 ± 24
NH_4^+—N (mg L^{-1})	2329.5 ± 275	0	444.0 ± 20
C (%, dry basis)	33.1 ± 0.1	49.7 ± 1. 7	42.2 ± 0.3
N (%, dry basis)	5.3 ± 0.3	0.8 ± 0.0	1.1 ± 0.1
H (%, dry basis)	4.8 ± 0.1	2.4 ± 0.1	5.8 ± 0.0
C/N (w/w)	6.2 ± 0.8	62.2 ± 7.3	39.4 ± 4.9

2.3. Analytical methods

The aerobic degradability for sludge, the sludge–straw complex, and the sludge–straw-biochar complex was indicated by the oxygen uptake rate and investigated separately, by means of incubation at constant temperature. Erlenmeyer flasks with 1.5 L volume were used, and the proportion of raw materials was maintained at the same level during this test and during subsequent composting trials. About 10.0 g sludge (fresh wet weight) was spread over the bottom of the first Erlenmeyer flask, to ensure enough space for aerobic respiration of the materials and for the generation of gases. In addition, 10.0 g sludge and 2.0 g straw were placed into the second Erlenmeyer flask. To represent the composition of the initial material in WB06, WB12 and WB18, the 0.6, 1.2 and 1.8 g wood biochar were separately placed into three additional Erlenmeyer flasks filled with a complex of 10.0 g sludge with 2.0 g straw. The mixtures in the flasks were uniformly mixed and maintained the same water-content conditions as the first Erlenmeyer flask. All flasks were placed in hermetically-sealed incubators, maintained at a constant temperature of 35 °C. Prior to sealing, the flasks were aerated with fresh air. During the incubation, about 50 ml of gas was extracted from the flasks on a daily (24 h) basis and the O_2 content was measured using a detector (CYS-1, Xuelian Co., China). After sampling, the flasks were aerated prior to sealing. The total incubation time was 10 days and all tests were duplicated. Oxygen uptake rate was determined by measuring the oxygen concentration in the outlet air flow, which had passed through the raw material of the flask. The oxygen uptake rate (mg $O_2\ g^{-1}$ DM h^{-1}) was then calculated (Supplemental information: Equation).

Fresh composting samples were collected on the start of the experiment (Day 0) and thereafter on the following days: 7th, 14th, 21st, 28th, 35th and 42nd days, based on quartering. Samples were collected after the compost materials had been turned and uniformly mixed. Aqueous extracts were obtained by shaking the samples with deionized water (1:10, w/v) at 200 r min^{-1} for 4 h in a horizontal shaker kept at room temperature. Thereafter, measurements were taken of the pH (AWWA-4500, Clesceri et al., 1998) of the supernatant, using a pH electrode (pHS-2F, Jingke Co., China), and the electrical conductivity (EC, AWWA-2520, Clesceri et al., 1998) (EC meter; DDS-307A, Jingke Co., China). The filtrate of each sample was passed through a 0.45-μm polytetrafluoroethylene filter, after which the dissolved organic matter (DOM) was determined. A total organic carbon analyzer (TOC-V_{CPH}, Shimadzu, Japan) was used to measure dissolved organic carbon (DOC) and total soluble nitrogen (DN); NH_4^+—N concentration