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Short communication

Effect of biochar amendment on greenhouse gas emission and bio-availability of heavy metals during sewage sludge co-composting

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ABSTRACT

In the present study, we evaluated the feasibility of biochar amended with lime (B + L) to reduce the loss of ammonia, greenhouse gas (GHG) emissions and the bio-availability of heavy metals (HMs) during composting of dewatered fresh sewage sludge (DFSS) and to improve the end product quality. Biochar mixed with a low dosage of lime was supplemented at a 1:1 ratio into DFSS and wheat straw (dry weight basis), and compared with a lime only amendment and a control without any amendment. The CO_2 emission profile clearly indicated that the B + L addition was effectively buffered a pH ~8.0, and the B + L amendment experienced an enhanced the rate of decomposition compared to control and lime amended treatments. In aerobic co-composting, the B + L amendment effectively reduced the loss of ammonia, CH_4, and N_2O emission. B + L amended DFSS compost also showed significantly higher concentrations of humic-acid (17.23%) and fulvic-acid (3.79%) compounds, effectively reduced the bio-availability of HMs (34.81% Cu, 56.74% Zn, 87.96% Pb and 86.65% Ni) and improved compost maturity compared to control and lime amendments. Furthermore, the B + L amendment increased the adsorption of ammonium ions by reducing the ammonia loss and N_2O emission, resulting in compost with higher nutrient concentrations. These results can be used to formulate the initial feedstock for industrial scale composting processes.

1. Introduction

The amount of sewage sludge (SS) generated in China reached more than 30 million t/y in 2014, which accounted for a quarter of the total organic waste (Cai et al., 2016). Managing such a huge quantity of SS has become a major environmental issue. In the last several decades, a number of methods were applied to overcome this problem and to avoid the deposition of SS in landfills. Composting is one of the more acceptable and economically feasible technologies for recycling SS, especially in developing countries (Villasenor et al., 2011). Composting enables the bio-conversion of organic waste into a well-stabilized, value added product. The major drawbacks associated with SS composting are the nitrogen loss and greenhouse gas (GHG) emissions during the decomposition of organic waste and the high levels of heavy metals (HMs) and salts in the end-product (Wong and Fang, 2000; Malinska et al., 2014; Scoton et al., 2016).

To date, a number of studies have demonstrated that co-composting SS with alkaline minerals, such as coal fly ash, zeolite, bentonite and alkaline bauxite residue, is a feasible technology for reducing the nitrogen loss and the soluble and exchangeable fractions of HMs (Fang and Wong, 1999; Wong and Selvam, 2006; Villasenor et al., 2011). Biochar, generated from biomass waste pyrolyzed under O_2 limited conditions, has recently been suggested to help control GHG emissions and stabilize HMs during composting. Several researchers have demonstrated that biochar amendment is one of the better approaches to reduce the mobility of HMs and to increase the rate of composting (Chen et al., 2010; Sonoki and Bastida, 2012; Zhang et al., 2014). Researchers have also reported the effect of biochar concentrations on ammonia emissions and the reduction of GHG emission during the

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Table 1
Characteristics of the raw materials (dry weight basis) (mean ± standard deviation): Not determined (ND), Dewatered fresh sewage sludge (DFSS); Wheat straw (WS).

Parameters	DFSS	WS	Biochar	Lime
Moisture content (%)[a]	81.53 ± 2.10	14.20 ± 0.32	4.76 ± 0.10	3.23 ± 0.06
pH	8.17 ± 0.14	5.03 ± 0.13	8.86 ± 0.21	9.29 ± 0.14
Electrical conductivity (mS/cm)	3.05 ± 0.03	1.74 ± 0.05	0.62 ± 0.03	0.64 ± 0.03
Total organic matter (%)	76.14 ± 2.01	96.03 ± 3.15	94.21 ± 2.32	1.67 ± 0.02
Total organic carbon (%)	38.25 ± 1.04	56.61 ± 1.43	62.15 ± 2.10	ND
Total Kjeldahl nitrogen (%)	3.12 ± 0.20	0.82 ± 0.04	0.32 ± 0.02	ND
C/N ratio	12.25 ± 0.05	69.03 ± 1.23	194 ± 13.84	ND
Total phosphorus (%)	1.8 ± 0.06	0.36 ± 0.04	2.92 ± 0.08	ND
Total sodium (%)	3.1 ± 0.05	0.17 ± 0.02	1.35 ± 0.06	1.08 ± 0.16
Total potassium (%)	1.8 ± 0.08	0.12 ± 0.04	2.62 ± 0.10	1.02 ± 0.10
Total copper (mg/kg)	266 ± 13.02	2.30 ± 0.12	3.73 ± 0.05	0.85 ± 0.04
Total zinc (mg/kg)	756 ± 28.34	1.26 ± 0.05	2.70 ± 0.08	2.15 ± 0.02
Total lead (mg/kg)	87.12 ± 9.15	0.20 ± 0.001	0.85 ± 0.004	ND
Total nickel (mg/kg)	14.45 ± 2.06	1.75 ± 0.04	2.65 ± 0.02	0.5 ± 0.002

[a] Calculated based on fresh weight.

composting of SS (Steiner et al., 2010; Jindo et al., 2012; Malinska et al., 2014). The production and amendment of biochar can be implemented as an effective waste management strategy when dealing with a high volume of waste biomass, such as crop residues, yard waste, food wastes and industrial organic wastes (Malinska, 2012; Chowdhury et al., 2014). Furthermore, biochar may represent an economically beneficial and environmentally friendly option for the remaining, unutilized fractions of waste biomass and can be used in composting to reduce nitrogen loss, increase the porosity and increase the water holding capacity (Czekala et al., 2016). Dias et al. (2010) and Steiner et al. (2010) determined that biochar amendment can facilitate the biodegradation of organic waste with a 64% reduction in ammonia emissions and odors during the composting of poultry manure. Previous studies have also reported the ability of biochar to reduce emissions of GHGs and NH_4^+-N, as well as the bio-availability of HMs during the composting of SS mixed with agricultural wastes (Sonoki and Bastida, 2012; Zhang et al., 2014; Czekala et al., 2016).

To the best of our knowledge, no studies have reported on co-composting of SS amended with a mixture of additives to further the goals of nitrogen conservation, GHG emission reduction and influencing the bio-availability of HMs.Therefore, the main objectives of this study are a) to investigate the effect of biochar combined with lime (B + L) to reduce the nitrogen losses and GHGs emissions,b) to evaluate whether B + L and only lime amendments can inhibit or enhance the bio-availability of selected HMs during composting of dewatered fresh sewage sludge (DFSS) mixed with wheat straw (WS) and c) to examine the compost maturity at the end of the composting period.

2. Materials and methods

2.1. Collection and preparation of feedstock

DFSS was collected from the Wastewater Treatment Plant at Yangling (Shaanxi Province, China), and WS was obtained from the university experimental farm. Commercially available lime and biochar (produced from WS) were used in this experiment. The procedures used to prepare the raw materials have been well-described in previous papers (Kang et al., 2011; Zhang et al., 2014). Table 1 provides physicochemical properties of the experimental raw materials.

2.2. Experimental design

The DFSS was mixed with WS at a ratio of approximately 1:1 on a dry weight basis to obtain a C/N ratio of ~25, and the mixture was subsequently amended with 1% lime or 12% biochar +1% lime on dry weight basis. A mixture of DFSS and WS without any further amendment used as the control. The addition of 12% biochar and 1% lime were recommended as the optimum dosage for SS composting (Zhang et al., 2014; Fang and Wong, 1999). For each treatment, 50 kg of the mixture was prepared and composted for 56 days in a 130-L bench-scale composter. The systematic layout of the reactors, the optimum conditions and the operational details have been described in our previous study (Li et al., 2012). Sampling and mixing of the composting mass was carried out on days 0, 3, 7, 10, 14, 21, 28, 35, 42, 49 and 56 of the composting period.

2.3. Analysis

A 1:5 ratio of aqueous extract of compost to water (1:5 ratio on dry weight basis) was used to analyzed the pH and electrical conductivity (EC) of the sample using a pH meter (INESAPHSJ-3F, China) and EC meter (INESADDS-307,China), respectively. The temperature was monitored four times a day using a digital thermometer, and the moisture content was determined through oven-drying at a temperature of 1052 ±2 °C. The concentration of total organic matter (TOM), total organic carbon (TOC), extractable ammonia (NH_4^+-N), total Kjeldhal nitrogen (TKN), total phosphorous (TP), total sodium (TNa), and total potassium (TK) were determined using the Test Methods for the Examination of Composts and Composting (TMECC, 2002). Diethylene triamine pentaacetic acid (DTPA)-extractable HMs (Cu, Zn, Ni and Pb) were analyzed using the methods described in Page et al. (1982) using an inductively coupled plasma analyzer (Thermo Solar MKII-6). The pathogen (*Salmonella* sp. and Fecal coliforms) population was analyzed according to Huang et al. (2006). The seed germination index (SGI) was also determined to assess compost maturity as described in Zucconi et al. (1981).