Chemosphere 169 (2017) 23–31

Contents lists available at ScienceDirect

Chemosphere

journal homepage: www.elsevier.com/locate/chemosphere

Nutrient conservation during spent mushroom compost application using spent mushroom substrate derived biochar

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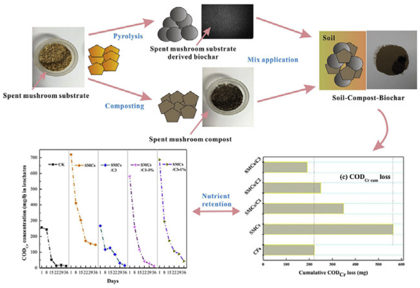
HIGHLIGHTS

- Pyrolytic temperature influenced spent mushroom substrate based biochar properties.
- Biochars could reduce leaching of nitrogen and COD_{Cr} from spent mushroom compost.
- COD_{Cr} retention increased with increasing pyrolytic temperature.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 26 May 2016
Received in revised form
29 October 2016
Accepted 9 November 2016
Available online 14 November 2016

Handling Editor: Hyunook Kim

Keywords:
Biochar
Nutrient retention
Spent mushroom compost
Soil fertility
Contamination

ABSTRACT

Spent mushroom compost (SMC), a spent mushroom substrate (SMS) derived compost, is always applied to agriculture land to enhance soil organic matter and nutrient contents. However, nitrogen, phosphate and organic matter contained in SMC can leach out and contaminate ground water during its application. In this study, biochars prepared under different pyrolytic temperatures (550 °C, 650 °C or 750 °C) from SMS were applied to soil as a nutrient conservation strategy. The resultant biochars were characterized for physical and mineralogical properties. Surface area and pore volume of biochars increased as temperature increased, while pore size decreased with increasing temperature. Calcite and quartz were evidenced by X-ray diffraction analysis in all biochars produced. Results of column leaching test suggested that mixed treatment of SMC and SMS-750-800 (prepared with the temperature for pyrolysis and activation was chosen as 750 °C and 800 °C, respectively) could reduce 43% of TN and 66% of COD_{Cr} in leachate as compared to chemical fertilizers and SMC, respectively. Furthermore, increasing dosage of SMS-750-800 from 1% to 5% would lead to 54% COD_{Cr} reduction in leachate, which confirmed its nutrient retention capability. Findings from this study suggested that combined application of SMC and SMS-based biochar was an applicable strategy for reducing TN and COD_{Cr} leaching.

1. Introduction

Spent mushroom compost (SMC) is a by-product of the mushroom industry and generally composed of straw, gypsum and some nutrient constituents, such as ammonium nitrate, superphosphate, potassium salts, etc (Stewart et al., 1997; Guo et al.,

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http://dx.doi.org/10.1016/j.chemosphere.2016.11.044
0045-6535/

2001a). China has a large mushroom industry that accounts for about 75% of annual global mushroom production. About 5 kg of waste is produced for each kilogram of mushroom (Paredes et al., 2009). As a result, substantial amounts of SMC generated from mushroom production have caused a significant waste disposal challenge. The traditional disposal of SMC includes incineration or deposit in landfills, which would lead to negative environmental consequences. Thus, findings for good end use of SMC have attracted researchers' interests in recent years (Curtis and Suess, 2006).

Soil application is a promising strategy for the sustainable recycling of SMC (Medina et al., 2012). After several mushroom cultivation cycles, the productivity decreases and SMC can not be used as cultivating medium any more. However, it is still rich in nutrients and organic matters. As shown in other studies, SMC application gave similar or higher grain yield and N uptake when compared to fertilizer only treatments at corresponding fertilizer N rates (Hackett, 2015). The advantages of using SMC as a soil fertilizer over a chemical fertilizer is that it provides slow-release nutrients that will not burn crops upon application. SMC has a low bulk density which indicates its relatively porous medium that can enhance the structure of the soils it is amended to (Curtis and Suess, 2006). It possesses comparatively high macronutrient concentrations as compared to urban wastes and animal manure (Medina et al., 2012). Moreover, the soil microorganisms in SMC accelerate the regular soil processes such as nutrient immobilization and aggregate formation (Curtis and Suess, 2006). However, application of excessive amount of SMC to soil leads to nutrient losing, which may cause water or soil pollution. Field studies have shown that SMC leachate contains elevated levels of inorganic salts and dissolved organic carbon (Guo and Chorover, 2006). Additionally, SMC leachate migrates through the organic-rich surface soil mainly by preferential flow, which limits the retention of dissolved organic matter (Guo et al., 2001b). In our previous study (Lou et al., 2015), we also found that the excessive organic matter (represented as COD_{Cr}) in leachate could cause serious environmental problems during application.

Biochar is carbon-rich pyrolyzed biomass, which is recognized as a multifunctional material (Iqbal et al., 2015). The application of biochar to agricultural contributes to soil aggregation. Furthermore, addition of biochar would increase water holding capacity and organic content of soil (Cao et al., 2009). Several studies have claimed that biochar could prevent leaching of nitrogen, phosphate and organics from compost (Zheng et al., 2013; Iqbal et al., 2015). Laird and co-workers (Laird et al., 2010) found that the amendment of hardwood biochars to soil with swine manure applied would decrease nitrogen and phosphate leaching. Angst et al. (2013) reported of a great leaching reduction of cumulative N and P in sandy soil due to biochar application. In addition, Bradley et al. (2015) reported that increasing levels of biochar amendment decreased BOD_5 of leachate from manure amended sand soil. Based on the aforementioned facts, we assumed that the application of biochar could prevent the loss of nutrients from SMC.

The aim of this study is to develop the nutrient retention strategy during SMC application using spent mushroom substrate-based biochars. For this purpose, both SMC and biochars were prepared from spent mushroom substrates. In this study, biochars pyrolyzed under different temperatures (550–750 °C) were analyzed for their elemental composition and surface morphology. In addition, column leaching experiments were performed in simulated mixtures with SMCs, biochars and soils.

2. Materials and methods

2.1. Spent mushroom substrate, compost and soil

Spent mushroom substrates (SMSs) were collected from a local mushroom industry. SMSs mainly consist of bagasse, corncob and sawdust. Afterwards, approximately 2% of gypsums and 10% of wood dusts were added to SMSs and kept for 3 months to compost as mature materials, which is known as SMCs. Approximately, samples of 5 kg each was randomly taken from sample material. Fresh samples were air-dried for one week to reduce the volume to quarter. The representative samples were then crushed into 1 mm particles for chemical analysis, while the rests were well-kept before application. All the loam soil used in this study were collected from a rice cropland located in Hangzhou city (30°18'20″N, 120°4'21″E) of Zhejiang Province (Lou et al., 2015). The sampling site is in a subtropical monsoon climate. Table 1 presents the properties of soil.

2.2. Biochar preparation

Pretreated SMSs were used as the precursor materials for biochars. Approximately 20 g of the dried materials (less than 2 mm) were loaded into a cylinder of a vacuum tube furnace as described earlier (Zhang et al., 2011). The slow-pyrolysis process was conducted under nitrogen atmosphere with 2.5 $m^3\ h^{-1}$ flow rate at a heating rate of 5 °C per min for 30 min. The activation temperature was usually 50 °C higher than the pyrolysis temperature, and an activation gas containing 4% of steam with nitrogen as carrier gas was ventilated for 60 min. An absorption flask filled with water was set as collector for tail gas. After cooling down to room temperature, the residues remaining in the cylinder was regarded as biochars. In this study, there were three types of biochars prepared with the pyrolysis temperature of 550 °C, 650 °C, 750 °C and the activation temperature of 600 °C, 700 °C, 800 °C, respectively, which were labeled as "SMS-550-600", "SMS-650-700" and "SMS-750-800".

2.3. Treatments and column setup

A set of plexiglass columns (height of 20 cm and diameter of 10 cm) fixed with porous baffles in the bottom were selected as leaching units. To prevent the soil leakage, quartz sands of 2 cm size were loaded on the baffle. The quartz sands were pretreated as reported in the previous study (Xu et al., 2012).

Soils, chemical fertilizers (CFs), SMCs and biochars were mixed and packed into columns for comparison. Urea (U) and calcium superphosphate (CS) were applied as typical chemical fertilizers. Table 2 presents the dosage of materials in each column with details. For control, all the columns were packed with 600 g of 2 mm-soil samples. The application rates of chemical fertilizers and SMCs were equivalent to 300 mg N kg^{-1}, as reported in the previous study (Ju et al., 2009), while each column had an equal amount of 5% biochar (w w^{-1}) (Zhao et al., 2014). All the well-packed columns were covered with a bed of quartz stones to make a uniform

Table 1
Physiochemical characteristics of selected soil.

Location	pH	SOM[a](%)	CEC[b](cmol kg^{-1})	Particle size distribution (V V^{-1}, %)		
				Sand	Silt	Clay
Hangzhou	6.8	3.5	12.8	26.6	59.9	13.5

[a] SOM refers to soil organic matter.
[b] CEC refers to cation exchangeable capacity.