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Comparison of biochar, zeolite and their mixture amendment for aiding organic matter transformation and nitrogen conservation during pig manure composting

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ABSTRACT

The aim of this work was to compare the impact of biochar, zeolite and their mixture on nitrogen conservation and organic matter transformation during pig manure (PM) composting. Four treatments were set-up from PM mixed with wheat straw and then applied 10% biochar (B), 10% zeolite (Z) and 10% biochar + 10% zeolite (B + Z) into composting mixtures (dry weight basis), while treatment without additives applied used as control. Results indicated that adding B, Z and B + Z could obviously ($p < 0.05$) improve the organic matter degradation and decrease the nitrogen loss. And combined addition of B and Z further promoted the organic matter humification and reduced the heavy metals mobility. Meanwhile the highest mitigation of ammonia (63.40%) and nitrogen dioxide (78.13%) emissions was observed in B + Z added treatment. Comparison of organic matter transformation, nitrogen conservation and compost quality indicated that the combined use of biochar and zeolite could be more useful for PM composting.

1. Introduction

In China, the fast development of intensive pig production has generated large quantities of pig manure (PM) with relatively insufficient land for application (Li et al., 2012; Jiang et al., 2016b). Unsuitable management of PM would result in a series of environmental issues such as water and soil pollutions by excessive input of nutrients, immature organic materials and heavy metals (HMs) (Huang et al., 2006; Chen et al., 2010). Composting of PM has been widely accepted and one of the most eco-friendly approaches, which could transform the complex organic substrate into sanitary and stabilized end product, thus serving as organic fertilizer (Bernal et al., 2009; Li et al., 2012). However, adverse manifestation during the traditional composting process is the excessive ammonia (NH_3) emission and the low degree of organic matter transformation, which not only reduced the agronomic value of compost as a soil fertilizer or amendment, but also decreased the environmental benefits of composting (Huang et al., 2006; Yang et al., 2015; Awasthi et al., 2017a,b).

Recently, many practical approaches such as adjusting the physicochemical parameters (Huang et al., 2004; Dias et al., 2010), changing the aeration rate (Chowdhury et al., 2014; Yuan et al., 2016) and adding the different kinds (chemical, microbial and mineral, etc.) of additives (Gabhane et al., 2012; Jiang et al., 2015; Chan et al., 2016; Awasthi et al., 2017a,b) have been carried out to promote the composting process and reduce the adverse effect as mentioned above for composting. To date, the addition of the mineral additives to improve the composting efficiency, organic matter transformation, nitrogen conservation and greenhouse gases (GHGs) mitigation are increasingly attracted the interest of researchers (Chen et al., 2010; Li et al., 2012; Wang et al., 2016b; Zhang and Sun, 2017b). Among the all additives, biochar and zeolite were the most common amendments and have been widely used to improve the organic matter transformation and nitrogen conservation (Li et al., 2015; Chan et al., 2016; Awasthi et al., 2017a,b). For example, Chen et al. (2010) and Awasthi et al. (2016a) investigated that the amendment of biochar could improve nitrogen conservation and facilitate the organic matter degradation during the PM and sewage sludge (SS) composting. Dias et al. (2010) and Jindo et al. (2016) demonstrated that co-composting animal manure with biochar could promote the organic matter humification and promote the final compost quality. On the other hand, Zhang and Sun (2015) stated that adding the zeolite could obviously improve lignocellulose decomposition and increase the humic acid content during the green waste

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composting. Chan et al. (2016) indicated that zeolite could mitigate 25.02% NH_3 emission and accelerate the organic matter decomposition during food waste composting. Moreover, our early research also found that combined addition of biochar and zeolite could prominently lower the GHGs emission and improve the nitrogen conservation during SS composting (Awasthi et al., 2016c).

Consequently, the literatures above-cited indicated that adding the biochar, zeolite and their mixture could be an effective method to improve the composting process and reduce the secondary pollution. However, comparison of biochar, zeolite and their mixture amendments for improving the organic matter transformation and nitrogen conservation during the PM composting has not been well reported. Therefore, the purpose of this study was to compare the effect of biochar, zeolite and their mixture on organic matter transformation and nitrogen conservation as well as the quality of end product during PM composting.

2. Materials and methods

2.1. Composting material collection and processing

Fresh PM and wheat straw (WS) were collected from a local hoggery and farmland in Yangling town, Shaanxi, China. Biochar and zeolite were purchased from Yangling Yixing Biotechnology Co. Ltd., China and Zhejiang Shenshi Mining Industry Group Co., Ltd., China, respectively. Biochar were crushed into fine particles (2–5 mm), and mixed with zeolite and then added into composting mass as additives. WS was chopped to 1 cm and used to adjust the moisture content (~55–60%), C/N ratio (~25) and bulk density (~0.5 kg/L) of the initial compost mixtures (Bernal et al., 2009; Li et al., 2012). The selected physicochemical characteristics of raw materials were presented in Table 1, and the Brunauer-Emmett-Teller (BET) surface area (5.99 $m^2 g^{-1}$), C (43.85 ± 2.42%), O (10.02 ± 0.08%) and H (2.16 ± 0.05%).

2.2. Composting system and experimental design

The composting experiment was done in 130-L polyvinyl chloride (PVC) reactors (100-L work volume) for 50 days, and the operational composting process and reactor dimension were already define in Wang et al. (2016a). Fresh PM and WS were mixed at 2:1 ratio (dry weight basis) and then combined with 10% biochar (B), 10% zeolite (Z) and 10% biochar + 10% zeolite (B + Z) on initial feed stock dry weight basis, respectively. Whereas, the treatment without additives was regarded as control for comparison purpose. The temperature of composts and ambient was monitored three times per day and then recorded the average value. After composting materials were mixed thoroughly, homogeneous samples of compost were taken on days 1, 8, 22, 36 and 50 during composting. The collected samples was divided into two parts; one part was stored at 4 °C till analysis, while the another part was air dried, grounded to pass through a 0.1 mm sieve and thoroughly mixed for further analysis.

Table 1
The physicochemical properties of raw materials used in this research.

Parameter	Pig manure	Wheat straw	Biochar	Zeolite
Moisture (%)	63.12 ± 1.10	6.45 ± 0.20	7.31 ± 0.21	0.60 ± 0.06
pH	8.00 ± 0.06	6.57 ± 0.14	10.80 ± 0.02	9.39 ± 0.03
EC (mS/cm)	5.41 ± 0.11	2.72 ± 0.26	12.09 ± 0.40	0.06 ± 0.00
OM (%)	73.04 ± 0.20	90.91 ± 0.88	65.12 ± 1.00	ND
TP (g/kg)	29.38 ± 1.70	4.18 ± 0.37	5.47 ± 0.45	0.52 ± 0.06
TKN (g/kg)	26.11 ± 0.09	1.03 ± 0.07	6.26 ± 1.24	0.93 ± 0.06
TK (g/kg)	12.54 ± 0.39	0.80 ± 0.00	74.79 ± 4.74	0.69 ± 0.03

ND (Not detected), EC (Electrical conductivity), OM (Organic matter), TP (Total phosphorus), TKN (Total Kjeldahl nitrogen) and TK (Total potassium). Results are the mean of three replicates and error bars indicate standard deviation.

2.3. Analytical methods and analysis

The collected fresh samples mentioned above were used to detect the pH, electrical conductivity (EC), dissolve organic carbon (DOC) and seed germination index (GI) as per the laboratory procedures (Li et al., 2012; Wang et al., 2016b). An MP521 pH/EC meter (Shanghai, China) was used to measure the pH and EC according to Li et al. (2015). To determine the DOC, the extraction procedure was depended on our previous method (Wang et al., 2016a), and then detected by using the automated TOC analyzer (Shimadzu TOC-V). The humic acid (HA), fulvic acid (FA), HA-complexed Cu, HA-complexed Zn, FA-complexed Cu, FA-complexed Zn and water soluble HMs (Cu and Zn) were extracted and determined according to Kang et al. (2011). The organic matter (OM), total organic carbon, total Kjeldahl nitrogen (TKN), total phosphorus, total potassium, available phosphorus and potassium were analyzed according to test methods for the composts examination (TMECC, 2002). Ammonia gas was trapped in boric acid solution and then measured by titrated with 1 mol/L hydrochloric acid (Yang et al., 2015). The N_2O samples were collected daily in the first two weeks and two or three times weekly thereafter, while the gases concentrations was determined using gas chromatography (Agilent Technologies 6890N Network GC system, China) as reported by Awasthi et al. (2016c). The biochar C, H and O properties were analyzed using Vario EL cube CHNOS element analyzer (Elementar, Germany), while BET surface area was determined according to Mc-Naughton (1976).

2.4. Statistical analysis

All of the physic-chemical analyses were repeated three times. The data were superintend to the one-way analysis of variance (ANOVA) and multiple comparison test to compare the least significance difference at $p = 0.05$ using SPSS v.18.0 software for windows. The redundancy analyses (RDA) was performed to find out the correlation of physiochemical properties, N_2O and NH_3 emission during the composting using Canoco 5 software.

3. Results and discussions

3.1. Effect of additives on cumulative NH_3 and N_2O emissions

NH_3 emission is an inevitable problem during the composting process which would not only cause the environmental pollution, but also decrease the final quality of compost (Chan et al., 2016; Wang et al., 2016b). The evolutions of cumulative NH_3 emission in all treatments are presented in Fig. 1a. At the beginning of composting, the rapid NH_3 emission in all treatments was likely due to the fast organic matter degradation and high temperature (Yang et al., 2015; Jiang et al., 2016a). The cumulative NH_3 emission from all treatments quickly increased to 8.09, 6.76, 7.21 and 3.58 g in control, B, Z and B + Z applied treatments, respectively, on day 8. The similar observation was also reported by Chowdhury et al. (2014) who adding biochar and adjusting the aeration flow rate to reduce the GHGs and ammonia emissions during cattle manure composting. After eight days, the cumulative NH_3 emission in B, Z and B + Z applied treatments tended to be stable or slightly increased, while the cumulative NH_3 emission in control treatment continuously rose and then leveled off until the end of composting. The longer duration of high temperature (> 50 °C) in control (data not show) might explained this phenomena. At the end of the experiment, the cumulative NH_3 emission was in the order of control (10.93 g) > Z (7.53 g) > B (7.01 g) > B + Z (4.00 g). And compared to the control, the cumulative NH_3 emission in B, Z and B + Z applied was reduced by 35.88%, 31.13% and 63.40%, respectively. Similar reduction was also observed by Fukumoto et al. (2011) and Awasthi et al. (2016a) for swine manure and SS composting. Biochar and zeolite have the high porosity and large specific surface which could effectively adsorb the NH_3 and NH_4^+-N and consequently