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Combining biochar, zeolite and wood vinegar for composting of pig manure: The effect on greenhouse gas emission and nitrogen conservation

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ABSTRACT

The effect of enhancing wood vinegar (WV) with a mixture of biochar (B) and zeolite (Z) to compost pig manure (PM) in a 130 L reactor was evaluated to determine the levels of greenhouse gas (GHG) and ammonia emissions. Six treatments were prepared in a 2:1 ratio of PM mixed with wheat straw (WS; dry weight basis): PM + WS (control), PM + WS + 10%B, PM + WS + 10%B + 10%Z, and PM + WS with 0.5%, 1.0% and 2.0%WV combined with 10%B + 10%Z. These were composted for 50 days, and the results indicated that the combined use of B, Z, and WV could shorten the thermophilic phase and improve the maturity of compost compared to the control treatment. In addition, WV mixed with B and Z could reduce ammonia loss by 64.45–74.32% and decrease CO_2, CH_4, and N_2O emissions by 33.90–46.98%, 50.39–61.15%, and 79.51–81.10%, respectively. Furthermore, compared to treatments in which B and B + Z were added, adding WV was more efficient to reduce the nitrogen and carbon loss, and the 10%B + 10%Z + 2%WV treatment presented the lowest loss of carbon (9.16%) and nitrogen (0.75%). Based on the maturity indexes used, nitrogen conservation, and efficiency of GHG emissions reduction, the treatment 10%B + 10%Z + 2%WV is suggested for efficient PM composting.

1. Introduction

With the rapid development of intensive pig farming, a large quantity of pig manure (PM) is generated each year in China. In 2015, the production of PM had arrived approximately 490 million tons (NBSC, 2016). The effective management of the PM has become a significant issue for the Chinese government and livestock industry (Wang et al., 2016a). In the last decade, methods such as landfill, anaerobic digestion, and composting were tried as ways of disposing PM. Of these, composting has been widely accepted as one of the preferred cost-effective methods for recycling organic waste. It not only reduces the volume of PM and destroys the weed seeds and pathogens, but also converts the organic waste into a humus-like, nutrient-enriched stable organic product (compost) that could improve soil fertility (Bernal et al., 2009; Li et al., 2012). However, the greenhouse gas (GHG; CO_2, CH_4, and N_2O) and excessive ammonia (NH_3) emissions associated with the composting process reduce the agronomic value of compost and cause secondary environmental pollution (Yang et al., 2015; Awasthi et al., 2016d).

Many practical approaches have been applied in order to promote progress in composting and reduce its adverse effect, including using different kinds of bulking agents (Chowdhury et al., 2014a), increasing the aeration rate (Tsutsui et al., 2013; Chowdhury et al., 2014b), and adding chemical agents and mineral additives (Li et al., 2012; Jiang et al., 2015; Awasthi et al., 2016c). To date, using mineral additives to improve the composting efficiency and quality of the end product, as well as reduce GHG emissions, are attracting increased interest from researchers. For example, Chowdhury et al. (2014b) reported that the addition of

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Abbreviations: PM, pig manure; B, Biochar; Z, Zeolite; WV, wood vinegar; GHG, greenhouse gas; WS, wheat straw; GI, germination index; SS, sewage sludge; B+Z, 10%biochar + 10%zeolite; B + Z + 0.5%WV, 10%biochar + 10%zeolite + 0.5%wood vinegar; B + Z + 1.0%WV, 10%biochar + 10%zeolite + 1.0%wood vinegar; B + Z82.0% WV, 10%biochar + 10% zeolite + 2.0% wood vinegar.

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biochar could reduce 27–32% GHG emissions during the chicken manure composting. Yang et al. (2015) discovered that adding the phosphogypsum could decrease 85.8% CH_4 emission during the kitchen waste composting. Chan et al. (2016) demonstrated that co-compost 10% zeolite with food waste could reduce NH_3 emissions by 7.06% and improve the compost maturity compare to a struvite treatment. Meanwhile, our previous study indicated that composting PM with the addition of 10% medical stone could significantly reduce the nitrogen loss and N_2O emissions (Wang et al., 2016b). Moreover, other researchers have revealed that a mixture of additives could reduce GHG emissions and improve the organic matter humification better than a single additive could (Chen et al., 2010; Awasthi et al., 2016b). However, adding a mixture of additives presents some drawbacks. For example, although adding 5% phosphogypsum and 0.2% dicyandiamide decreased N_2O emissions, it lead to higher nitrogen losses and increase in salinity as compared to a treatment using phosphogypsum alone (Luo et al., 2013). Similarly, different amounts of dicyandiamide mixed with struvite reduced N_2O emissions by 76–78%, but had an eligible effect on ammonia emissions from PM composting (Jiang et al., 2016a). In addition, our early researches showed that combinations of zeolite and biochar or lime could inhibit the GHG emissions and improve compost quality, but there is a potential for nitrogen loss when it is compared to the control treatment (Awasthi et al., 2016c, 2016d). Thus, the results of these findings indicate that adding a mixture of mineral additives or other chemical agents could effectively reduce GHG emissions and promote the composting process, but nitrogen conservation still needed to be improved.

Zeolite, as a natural porous mineral, has been widely used to reduce the various gas emissions, nutrients loss and the salinity during the composting process (Zorpas and Loizidou, 2008; Zhang and Sun, 2015; Chan et al., 2016). However, some previous researches indicated that the zeolite alone is not good enough to buffer against the low during the organic waste composting (Villaseñor et al., 2011; Singh et al., 2013). In recent years, Zhang and Sun (2015) and Awasthi et al. (2016c, 2016d) found that zeolite combined with other additives could further promote the composting process and reduce the GHG emissions. Wood vinegar (WV), a byproduct of the carbonization of wood or wood residues, contains large quantities of organic acids or components and has been widely used as an insect repellent, odor remover, and soil fertilizer (Chen et al., 2010; Wu et al., 2015). Recently, WV was used in composting to reduce NH_3 emissions (Chen et al., 2010; Zhang and Sun, 2015). However, to the best of our knowledge, the combination of biochar, zeolite, and different concentrations of wood vinegar as amendments to reduce GHG and ammonia emissions during PM composting has not been reported thus far. Therefore, this study investigated the effect, on GHG (CO_2, CH_4 and N_2O) emissions, nitrogen loss, and compost maturity, of combining different amounts of WV with biochar and zeolite during PM composting.

2. Materials and methods

2.1. Preparation of compost

Fresh PM and wheat straw (WS) were collected from a hoggery and a farm in Yangling town, Shaanxi, China. Biochar (B) and WV were purchased from Yangling Yixing Energy Pvt. Ltd., China, while zeolite (Z) was obtained from the Zhejiang Shenshi Mining Industry Co., Ltd, China. The biochar was prepared from tobacco stalk via slow and dry pyrolysis at temperatures of 500–600 °C at atmospheric pressure for 24 h, initiated by the pyrolysis of feedstock from the bottom of a 5 m^3 kiln. The WS was chopped into 1 cm lengths and used as a bulking agent to adjust the moisture content ($\sim$55%), bulk density ($\sim$0.5 kg/L) and carbon/nitrogen ratio ($\sim$25) of the initial compost substrate (Bernal et al., 2009; Awasthi et al., 2016d). B and Z were crushed into fine particles (2–5 mm) (Awasthi et al., 2016a) and applied to the composting mass as amendments. Selected physicochemical characteristics of the raw materials are presented in Table 1.

The compost was prepared in 130L PVC reactors, according to the reactor layout and composting process described in our previous researches (Li et al., 2012; Awasthi et al., 2017). A total of six treatments were designed, with fresh PM and WS mixed at a 2:1 ratio (dry weight), after which the other additives were added, as presented in Table 2. The temperature of the compost and the ambient were monitored thrice daily and the mean recorded. After the composting materials were mixed thoroughly, about 100L of each mixture was put into the reactors. The dosages of B, Z, and WV were based on the previous studies (Chen et al., 2010; Sonoki et al., 2013; Chan et al., 2016). Air was pumped into the reactor from the bottom of each vessel and an automatic device maintained a constant air flow rate of 0.3 L/kg (dry matter)/min (Li et al., 2012).

2.2. Sampling and analysis of compost

During the composting process, 500 g homogeneous compost samples were taken after 0, 4, 8, 15, 22, 29, 36, 43 and 50d. The samples were divided into two; one part was stored at 4 °C till analysis, while the other was air dried, powdered in an agate mortar, passed through a 0.1 mm sieve, and thoroughly mixed for further analysis. The fresh samples were used to detect pH, electrical conductivity (EC) at 25 °C, NH_4^+-N, and NO_3^--N levels, and the seed germination index (GI), as per laboratory procedures (Zucconi et al., 1981; Lu et al., 2009; Li et al., 2012). An MP521 pH/EC meter (Shanghai, China) was used to measure the pH and EC according to methods in Li et al. (2015). To determine the levels of NH_4^+-N and NO_3^--N, fresh samples were extracted with 50 mL 2 mol/L KCl solution (1:10 (w/v)) and analyzed using a segmented flow analyzer (Technicon Auto-analyzer II System, Germany). Ammonia gas was trapped in a boric acid solution and measured via titration with 1 mol/L hydrochloric acid (Komilis and Ham, 2006). The CO_2, CH_4, and N_2O samples were collected daily in the first two weeks and two or three times weekly thereafter, while gas concentrations were determined using gas chromatography as described by Awasthi et al. (2016b), using an 6890N Network GC system (Agilent Technologies, United States of America) equipped with electron capture and flame ionization detectors. The temperature, pH, and GI were regarded as the maturity indexes in this research.

2.3. Statistical analysis

All physicochemical analyses were performed in triplicate. The data were subject to the one-way analysis of variance (ANOVA) and multiple other tests to compare the least significance difference (LSD) at $p = .05$ using SPSS v.18.0 for Windows. Redundancy analyses (RDA) were performed using Canoco 5 to determine correlations between physiochemical properties and GHG and ammonia emissions during the composting.

3. Results and discussion

3.1. Effect of amendments on maturity indexes

The variations of temperature in all the treatments are presented in Fig. 1a. During the experiment, our mixtures followed the three typical phases of composting: mesophilic, thermophilic,

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