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Evaluation of medical stone amendment for the reduction of nitrogen loss and bioavailability of heavy metals during pig manure composting

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HIGHLIGHTS

- Medical stone was used as amendment for pig manure composting.
- Medical stone could promote pig manure degradation and reduce nitrogen loss.
- 10% medical stone reduced the 48.76% NH_3 loss and 85.26% N_2O emission.
- Medical stone decreased the bioavailability of Cu and Zn in compost.

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ABSTRACT

The purpose of this research was to evaluate the effect of medical stone (MS) on nitrogen conservation and improving the compost quality during the pig manure (PM) composting. Five treatments were designed with different concentrations of MS0%, 2.5%, 5%, 7.5% and 10% (on dry weight of pig manure basis) mixed with initial feed stock and then composted for 60 days. The results showed that MS amendment obviously ($p < 0.05$) promoted the organic waste degradation and prolonged the thermophilic phase as well as enhanced the immobilization of heavy metals Cu and Zn. With increasing the amount of MS, the NH_3 loss and N_2O emission were significantly reduced by 27.9–48.8% and by 46.6–85.3%, respectively. Meanwhile, the MS amendment could reduce the NO_2^--N formation and increase the NO_3^--N content. Finally our results suggested that 10%MS addition could significantly reduce the nitrogen conservation as well as improve the quality of compost.

1. Introduction

With the increasing pork demand in China, more than 10,000 pigs have been bred in many large livestock farms in the past 15 years, which leading to175 million tons of pig manure (PM) production in 2013 (NBSC, 2014). PM is a kind of organic nutrients sources, and which has been used as an organic fertilizer in China for thousands of years, but it's over production, un-appropriate management and direct application to farmland have caused numerous environmental and health hazard problems such as foul odor, greenhouse gas emission, soil and water pollution by excessive input of heavy metals (HMs), inorganic salts, pathogens and eutrophication of waterways (Li et al., 2012; Lu et al., 2014; Wang et al., 2016). Hence, it is in urgent need of environmental friendly and economically feasible technologies for management of PM before direct land application. In this behalf, composting provides an alternative way to recycle the PM by breaking down complex organic materials into relatively stable organic matter (OM), which is a well-developed technology for treating PM and converting it into a soil amendment or an organic fertilizer (Bernal et al., 2009; Chen et al., 2010; Jiang et al., 2014). Meanwhile, composting also implies the volume reduction of the wastes, destruction of weed seeds and pathogenic microorganisms (Bernal et al., 2009; Awasthi et al., 2016d). However, the nitrogen loss through volatilization of ammonia during composting process and the high bioavailability of HMs of the final product, which are the major disadvantages of traditional composting (Li et al., 2012; Jiang et al., 2014; Yang et al., 2015; Awasthi et al., 2016b). And as a consequence, insufficient decomposition of organic matter leads to produce the low quality of immature compost

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(Chen et al., 2010; Chan et al., 2016). In addition, the greenhouse gas or odor emission during the composting process has aroused wide attention (El Kader et al., 2007; Wang et al., 2013; Awasthi et al., 2016b; Jang et al., 2016). As the International Panel on Climate Change (IPCC) reported that nitrous oxide (N_2O) is one of the major greenhouse gas emissions, which has 210 times higher global warming impact than carbon dioxide (IPCC, 2007). Hence, these aspects as mentioned above would restrict the organic waste management by composting and its end product application for organic farming (Li et al., 2012; Awasthi et al., 2016b).

Among the all practical methods for decreasing nitrogen loss, inhabiting the N_2O emission and reducing the availability of HMs during the composting process, the amendment of various mineral additives is the most effective way which has been received more attention in recent years. The widely studied additives such as zeolite, bentonite, phosphogypsum and biochar (Wong et al., 2009; Chen et al., 2010; Wang et al., 2013; Yang et al., 2015; Awasthi et al., 2016c,d) are proven effectively to control NH_3 and N_2O emission as well as decrease the bioavailability of HMs. For example, Chen et al. (2010) reported that co-composting of PM with 9% bamboo charcoal could significantly improve the decomposition efficiency, reduce 65% nitrogen loss and the mobility of Cu (by 35%) and Zn (by 39%). Yang et al. (2015) pointed out that co-amendment with 10% phosphogypsum could reduce the nitrogen loss up to 23.5% while slightly increase the N_2O emission during the kitchen waste composting. In addition, Chan et al. (2016) reported that 10% zeolite and struvite salt addition could decrease the NH_3 emission (18–26%) and EC value (2.82 $mS \cdot cm^{-1}$) during the food waste composting through adsorption of ammonium/ammonia ions and other cations. Meanwhile, our previous studies also indicated that bentonite and biochar could accelerate the organic matter decomposition, reduce the nitrogen loss and decrease the bioavailability of Cu and Zn during PM composting (Li et al., 2012, 2015; Wang et al., 2016).

Many previous studies have demonstrated the advantage of various additives on composting process. But considering the economic benefits and practical applications, searching more feasible and effective additives to enhance the composting process and reduce the nitrogen loss as well as improve the compost quality is still one of the research areas. In this sequence, medical stone (MS) is a new kind of economically feasible and harmless mineral which has been widely used in medical care, food, decontamination and dealing with polluted water because of its sponge structure, cation-exchange, special porous properties and large specific surface areas (Li et al., 2011; Yan et al., 2015). However, there has been no information available in past few years on the potential effects of MS mixed with PM for the reduction of nitrogen loss and bio-availability of HMs during PM composting. Therefore, the aim of the present study was to evaluate the potential effect of MS addition on nitrogen conservation, HMs immobilization and the end product quality improvement during PM composting.

2. Materials and methods

2.1. Composting materials

The PM and sawdust (SD) were collected from a local pig farm and a wood-processing factory in Yangling town, Shaanxi, China. The medical stone (MS) was purchased from Shijiazhuang Jiacheng Building Materials Co. Ltd., China. The purpose of SD addition was to adjust the C/N ratio ~35, moisture content 55–60% and bulk density 0.5 $kg \cdot L^{-1}$of the composting mass (Bernal et al., 2009). Selected physicochemical properties of each raw material are presented in Table 1.

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

Parameter	Pig manure	Sawdust	Medical stone
Moisture (%)	74.63 ± 0.13	14.01 ± 0.05	0.05 ± 0.00
pH	8.27 ± 0.01	6.75 ± 0.01	9.76 ± 0.07
EC ($mS \cdot cm^{-1}$)	2.95 ± 0.03	0.35 ± 0.00	0.53 ± 0.02
OM (%)	72.27 ± 0.11	96.12 ± 0.20	ND
TP ($g \cdot kg^{-1}$)	21.53 ± 0.47	0.16 ± 0.04	0.30 ± 0.04
TKN ($g \cdot kg^{-1}$)	20.71 ± 0.32	1.72 ± 0.11	ND
TK ($g \cdot kg^{-1}$)	11.80 ± 0.11	2.09 ± 0.07	0.84 ± 0.15
C/N	20.22 ± 0.02	324.2 ± 0.2	ND
Cu ($mg \cdot kg^{-1}$)	523.7 ± 2.5	7.99 ± 0.35	9.66 ± 0.89
Zn ($mg \cdot kg^{-1}$)	593.7 ± 5.4	43.19 ± 0.85	52.98 ± 3.20

ND (not detected). Values indicate mean ± standard deviation based on one samples with three times replication.

2.2. Composting experiments and sampling

The composting experiment was performed in 130-L PVC reactors with 100-L effective volume for 60 days, while schematic diagram and operation of the composting process was already reported in our previous study (Li et al., 2012; Wang et al., 2016). The PM and SD were mixed in 2:1 ratio (on dry weight basis) and then five different ratios of MS (0%, 2.5%, 5%, 7.5% and 10% on dry weight of pig manure basis) were added into the initial feed stock, respectively, while the treatment without MS was denoted as control. The compost and ambient temperatures were monitored daily three times (9:00AM, 3:00PM and 9:00PM), and the average temperatures were reported. Samples were collected on schedule (Wang et al., 2016), meanwhile composting mass was mixed properly in a large vessel with the addition of deionized water to restore the moisture content ~55–60% through the composting. The collected sample was divided into two parts; one part was stored at 4 °C till analysis, while the other part was air-dried, grinded to pass through a 0.15 mm sieve and stored in desiccator for further analysis.

2.3. Analytical methods

As mentioned above the collected fresh samples were used to analyze the pH, electrical conductivity (EC), NH_4^+-N, NO_2^--N, NO_3^--N, dissolved organic carbon (DOC) and germination index (GI) as per the standard laboratory procedures (Li et al., 2012; Chen et al., 2015; Wang et al., 2016). EC and pH were measured using an MP521 pH/EC meter (Shanghai, China) according to Li et al. (2012). Organic matter (OM) content was determined with dried samples cremated at 550 °C for 24 h in a muffle furnace. To determine the DOC, fresh samples were extracted at 25 °C with ultrapure water at ratio of 1:5 (w/w) using a shaker at 200 rpm for 24 h, following by centrifugation at 8000 rpm for 5 min and filtration with 0.45 μm nylon syringe filter and then detected by using the automated TOC analyzer (Shimadzu TOC-V). Total Kjeldahl nitrogen (TKN) was determined by Kjeldahl methods, while NH_4^+-N, NO_2^--N and NO_3^--N were extracted with 50 ml 2 $mol \cdot L^{-1}$ KCl extracts (solid:extractant, 1:10 (w/v) and analyzed using a segmented flow analyzer (Technicon Auto-analyzer II System, Germany) (Chen et al., 2015). Exhausted ammonia gas was trapped in boric acid and detected by titrated with 1 $mol \cdot L^{-1}$ hydrochloric acid (Komilis and Ham, 2006), and for the N_2O, gas samples were collected daily in the first 3 week and three times weekly thereafter, while the N_2O concentration was determined using gas chromatography (Agilent Technologies 6890 N Network GC system, China) as described by Jiang et al. (2016). Total and DTPA-extractable of Cu and Zn were monitored according to the methods described by Chen et al. (2010). Cu and Zn contents in the resulting