



Contents lists available at ScienceDirect

Waste Management

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

Effects of woody peat and superphosphate on compost maturity and gaseous emissions during pig manure composting

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ARTICLE INFO

Article history:

Received 17 November 2016

Revised 19 May 2017

Accepted 26 May 2017

Available online xxxxx

Keywords:

Composting

Pig manure

Woody peat

Superphosphate

Maturity

Greenhouse gases

ABSTRACT

This study investigated the effect of calcium superphosphate on compost maturity and gaseous emissions during pig manure composting with woody peat as the bulking agent. Two treatments were conducted with or without the addition of calcium superphosphate (10% dry weight of the composting mass), which were denoted as the control and superphosphate-amended treatment, respectively. Results show that the composting temperature of both treatments was higher than 50 °C for more than 5 days, which is typically required for pathogen destruction during manure composting. Compared to the control treatment, the superphosphate-amended treatment increased the emission of nitrogen oxide, but reduced the emission of methane, ammonia and hydrogen sulfide by approximately 35.5%, 37.9% and 65.5%, respectively. As a result, the total greenhouse gas (GHG) emission during manure composting was reduced by nearly 34.7% with the addition of calcium superphosphate. The addition of calcium superphosphate increased the content of humic acid (indicated by E_4/E_6 ratio). Nevertheless, the superphosphate-amended treatment postponed the biological degradation of organic matter and produced the mature compost with a higher electrical conductivity in comparison with the control treatment.

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1. Introduction

Animal dung is a vexing issue to the environment. This is further aggravated by the development of the large-scale livestock breeding industry at an alarming rate (Sun et al., 2014). Therefore, great efforts have been dedicated to develop the effective and cost-efficient technologies, such as composting, for the disposal of these solid wastes. Composting is a biological stabilization process that transforms organic matter into a potentially stable and sanitized final product (Bernal et al., 2009).

Composting does not come without any drawbacks. A major challenge of manure composting is gaseous emission, which not only reduces the compost nutrient, but also results in severe atmospheric pollution (Tiquia and Tam, 2000; Bernal et al., 2009; Chowdhury et al., 2014; Sánchez et al., 2015; Zang et al., 2017). Previous studies have demonstrated that a large amount (9.6–50%) of nitrogen in the raw material was released in the form of gases, mainly as ammonia (NH₃) during composting (Fukumoto et al., 2003; Luo et al., 2013a, b; Pardo et al., 2015). In addition, methane (CH₄) and nitrous oxide (N₂O) emissions during composting is of significant concern due to their high global warming

potential. It has been estimated that the global warming potential of CH₄ and N₂O is 25 and 298 times higher than that of carbon dioxide (CO₂) based on a 100 year projection, respectively (IPCC, 2007). Moreover, N₂O contributes significantly to ozone depletion (Kebreab et al., 2006). Thus, it is necessary to control gaseous emissions during composting to offer an effective, economic, and environmentally-friendly process for manure disposal.

Several strategies have been developed to mitigate gaseous emissions during composting. These include aeration control (Chowdhury et al., 2014; Yuan et al., 2016), addition of bulking agents (Doublet et al., 2011; Maeda et al., 2013) and amendments (Luo et al., 2013a, b; Wang et al., 2013; Zang et al., 2017), as well as microbial inoculation (Wakase et al., 2008). Of these mitigation methods, adding bulking agents is a simple and viable option to reduce gaseous emissions during manure composting by improving the raw material properties, such as carbon/nitrogen (C/N) ratio and moisture, and the ventilate structure of composting matrix (Maeda et al., 2013; Santos et al., 2016). Barrington et al. (2002) reported that the addition of bulking agents significantly reduced carbon and nitrogen losses during composting. It is noteworthy that different bulking agents exert various effects on gaseous emission and even maturity of composting (Bernal et al., 2009). Sun et al. (2014) demonstrated that corn stalk was better than sawdust to be a bulking agent to reduce CH₄ emission during

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pig manure composting. Given its wide C/N ratio, high surface area, and large capacities, peat, such as sphagnum peat, has been widely used as the bulking agent for composting fish offal (Mathur et al., 1986; Liao et al., 1997), chicken manure (Martin et al., 1993) and solid organic waste (Eklind and Kirchmann, 2000; Koivula et al., 2004; Himanen and Hänninen, 2009; Kurola et al., 2010). Compared to sphagnum peat, woody peat would be a better bulking agent for composting owing to its higher pH range (5–7.5) and more humic acid (Fuchsman, 1980). Nevertheless, little is known about the effects of woody peat on the performance of manure composting, particularly in terms of gaseous emission and maturity. Mineral additives, such as superphosphate and phosphogypsum can also effectively reduce gaseous emissions during manure composting (Liu et al., 2010; Luo et al., 2013b; Jiang et al., 2014). Mineral additives can react with ammonium to form beneficial substances, such as struvite, a slow-release fertilizer, and thus significantly alleviate ammonia emission. Indeed, several recent studies reported that mineral additives can improve the compost quality when the raw composting materials were green waste (Zhang et al., 2013) and kitchen waste (Himanen and Hänninen, 2009). Nevertheless, there remains a diverse view regarding the effects of mineral additives on composting performance. For example, Yang et al. (2015) reported that the addition of phosphogypsum or calcium superphosphate postponed organic biodegradation in kitchen waste composting; while no remarkable effect on the composting process was observed by Luo et al. (2013a) who added phosphogypsum with pig manure and cornstalks. Thus, more studies are necessary to validate the impacts of mineral additives, especially superphosphate and phosphogypsum, on composting performance.

This study aimed to investigate the effects of calcium superphosphate on the performance of pig manure composting with woody peat serving as the bulk agent. The composting performance was evaluated in terms of gaseous emissions and maturity. In addition, contributions of gaseous emission toward the carbon and nitrogen loss of the composting matrix were also quantified.

2. Materials and methods

2.1. Composting materials

Pig manure was collected from a local pig farm (Beijing, China) using the “Gan Qin Fen” system in which feces were collected manually before flushing urine with water. Woody peat (WP) was produced in Indonesia and provided by a Chinese company (Sino-View International, China). Calcium superphosphate (SSP) ($P_2O_5 \geq 12\%$, dry weight basis) was obtained from a Chinese chemical company (Zhongxiang, China). Both woody peat and calcium superphosphate were ground to powder before adding to pig manure for composting. Key physicochemical properties of these raw composting materials are shown in Table 1.

2.2. Composting system and protocol

A series of 60L heat insulated composting vessels were used in this study (Fig. 1). Each composting vessel had a height of 0.6 m and inner diameter of 0.36 m, with a forced aeration input at the bottom. A temperature sensor connected to a data logger was inserted into the composting vessel from the lid to automatically record the composting temperature. A perforation plate was embedded inside the vessel, which was approximately 5 cm higher from the bottom, to support the composting materials, diffuse aeration, and drain leachate. Detailed description of the composting system can also be found elsewhere (Guo et al., 2012; Yuan et al., 2016).

Table 1

Key physicochemical properties of raw materials used in this study (Average values \pm standard deviations from three samples).

Parameters	Pig manure	Woody peat	Calcium superphosphate
Moisture content (%)	69.74 \pm 1.92	21.52 \pm 1.40	8.21 \pm 0.08
pH	8.24 \pm 0.21	5.13 \pm 0.55	6.01 \pm 0.03
EC (mS cm ⁻¹)	2.31 \pm 0.380	0.13 \pm 0.131	1.56 \pm 0.564
TOC (% dw)	30.99 \pm 1.03	52.14 \pm 2.11	2.93 \pm 1.54
TN (% dw)	2.68 \pm 0.14	0.65 \pm 0.30	0.02 \pm 0.02
TS (% dw)	0.55 \pm 0.04	0.38 \pm 0.02	7.04 \pm 0.20
C:N ratio (dw)	11.56 \pm 1.02	80.34 \pm 1.31	133.18 \pm 0.98
NH ₄ ⁺ -N (g/kg)	5.347 \pm 0.003	0.083 \pm 0.002	0.042 \pm 0.003
NO ₃ ⁻ -N (mg/kg)	5.601 \pm 0.004	0.002 \pm 0.003	0.003 \pm 0.003

Note: EC – electrical conductivity; TOC – total organic carbon; TN – total nitrogen; TS – total sulfur; dw – dry weigh basis.

Two treatments were conducted in this study using pig manure mixed completely with woody peat at a wet mass ratio of 9:1 as the raw composting materials. This mass ratio of pig manure and woody peat was determined based on our batch tests with smaller composting vessels, which showed the optimal composting performance in terms of gaseous emissions and final maturity (data were not shown). In addition to the control treatment, calcium superphosphate was mixed with the composting raw materials with a weight of 10% of the dry mass of the raw composting materials. This treatment was denoted as the “superphosphate amended treatment”. The addition amount was determined based on that reported previously by Luo et al. (2013b). Two treatments were performed in duplicate. In other words, four composting vessels were operated in parallel. Each vessel was continuously aerated with an air flowrate of 0.36 L min⁻¹ kg⁻¹ DM (Dry Mass) to allow for sufficient aerobic composting conditions (Beck-Friis et al., 2001). Exhaust gas was released from the lid of the vessel and was collected for gaseous analysis. Both treatments were continuously operated for 28 days with turning over the composting materials manually on day 3, 7, 14 and 21.

2.3. Sample analysis

A portable biogas analyzer (BIOGAS-5000, Geotech) was used to measure O₂, CO₂ and H₂S content during composting. NH₃ was determined by absorbing it in a 2% boric acid solution and then titrating with 0.01 M H₂SO₄. Syringe sampling method was used to collect gases for CH₄ and N₂O quantification using the gas chromatograph (3420A, Beifen, China) equipped with flame ionization detector and electron capture detector.

Solid samples (approximately 300 g) were collected at the beginning, composting turn-over, and conclusion of the experiment. Moisture content was measured by drying 5 g fresh sample at 105 °C for over 24 h. Water extract of fresh samples was performed to analyze the composting pH, electrical conductivity (EC), E₄/E₆ and germination index (GI). The pH/EC meter was used to measure the water extract pH and EC. E₄/E₆ was the absorbance ratio of the water extract at the wavelength of 465 and 665 nm using an infrared spectrophotometer. GI was measured and calculated according to Guo et al. (2012). KCl (2 mol/L) extract of fresh samples was also performed for analyzing ammonium nitrogen (NH₄⁺-N) and nitrate nitrogen (NO₃⁻-N) using the Segmented Flow Analyzer (Auto Analyzer 3, Seal, Germany). Some fresh samples were also air-dried for TOC and TN analysis based on the Kjeldahl method and potassium dichromate titrimetric method of the Chinese national standard (NY 525-2002).

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