Waste Management 36 (2015) 70–76

Contents lists available at ScienceDirect

Waste Management

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

Effects of phosphogypsum and superphosphate on compost maturity and gaseous emissions during kitchen waste composting

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ARTICLE INFO

Article history:
Received 7 April 2014
Accepted 12 November 2014
Available online 4 December 2014

Keywords:
Kitchen waste
Composting
Phosphogypsum
Superphosphate
Gaseous emissions

ABSTRACT

This study investigated the effects of phosphogypsum and superphosphate on the maturity and gaseous emissions of composting kitchen waste. Two amended compost treatments were conducted using phosphogypsum and superphosphate as additives with the addition of 10% of initial raw materials (dry weight). A control treatment was also studied. The treatments were conducted under aerobic conditions in 60-L reactors for 35 days. Maturity indexes were determined, and continuous measurements of CH_4, N_2O, and NH_3 were taken. Phosphogypsum and superphosphate had no negative effects on compost maturity, although superphosphate inhibited the temperature rise in the first few days. The addition of phosphogypsum and superphosphate drastically reduced CH_4 emissions (by 85.8% and 80.5%, respectively) and decreased NH_3 emissions (by 23.5% and 18.9%, respectively). However, a slight increase in N_2O emissions (by 3.2% and 14.8%, respectively) was observed. Composting with phosphogypsum and superphosphate reduced total greenhouse gas emissions by 17.4% and 7.3% respectively.

1. Introduction

Kitchen waste produced from households and restaurants currently accounts for more than 40% of municipal solid waste (MSW) in China, and will continue to increase with increasing human populations and intensive urbanization (Dong and Qu, 2001). The conversion of kitchen waste into beneficial materials is an important aspect of environmental cleaning and resource recycling. Composting is the preferred treatment method of kitchen waste around the world because it can reduce the volume and mass of kitchen waste, as well as produce a safe, stable and nutrient-enriched soil amendment (Mato et al., 1994). However, the by-products of kitchen waste composting, such as greenhouse gas (GHGs; mainly methane (CH_4) and nitrous oxide (N_2O)) and ammonia (NH_3) emissions are detrimental to the environment and can cause secondary environmental pollution. The published literatures have shown that 9.6–46% of initial total nitrogen (N) is lost in the form of NH_3 during the composting period, which leads to serious N losses from compost; 0.2–9.9% of initial total N and 0.08–6% of initial carbon (C) is lost in the form of N_2O and CH_4, respectively (Fukumoto et al., 2003; Morand et al., 2005; Jiang et al., 2013). According to the report of the International Panel on Climate Change, the global warming potentials of CH_4 and N_2O, in a 100-year time frame, are 25 and 298 times higher than that of CO_2 (IPCC, 2007). Kitchen waste was reported to emit CH_4 in the amount of about 43 kg CO_2-eq t^{-1} dry matter (DM) and N_2O in the amount of 118 kg CO_2-eq t^{-1} DM when composted without any chemical additives (Yang et al., 2013).

Several studies have concluded that adding a certain amount of mineral additives in agricultural waste composting could decrease gaseous emissions (Wu et al., 2001; Hao et al., 2005; Predotova et al., 2010; Luo et al., 2013). It was reported by Hao et al. (2005) that phosphogypsum, the main by-product of phosphoric acid production, might be effective in reducing CH_4 emissions during cattle manure composting by increasing SO_4^{2-} content of the compost, and Luo et al. (2013) indicated that the addition of phosphogypsum at a rate of 10% of total compost mixture (dry weight) decreased NH_3 and CH_4 emissions significantly during pig manure composting. On the other hand, superphosphate, a commonly used fertilizer, was shown to be effective in reducing NH_3 emissions and nitrogen loss from animal manure composting systems, and did not have any negative effects on compost maturity (Wu et al., 2001; Predotova et al., 2010).

The physical and chemical properties of kitchen waste, however, vary widely from those of animal manure, and for kitchen waste composting systems, limited research has focused on the effect of mineral additives on maturity and gaseous emissions. The objective of this study was to investigate the influence of phosphogypsum and superphosphate as amendments on

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http://dx.doi.org/10.1016/j.wasman.2014.11.012
0956-053X/

compost maturity and gaseous emissions (CH_4, N_2O and NH_3) during kitchen waste composting.

2. Methods

2.1. Composting materials

The kitchen waste was manually sorted from MSW provided by the Majialou MSW transfer station (Beijing, China). The proportions (wet weight) of kitchen waste components were as follows (in%): vegetables, 45.3; fruits, 24.5; staple food, 17.6; bones and shells, 6.1; meat, 3.3; others, 3.2. Withered cornstalks were collected from farmland in Beijing, and cut to lengths of 1–5 cm. The phosphogypsum was obtained from a phosphate fertilizer plant in Shandong Province, China, and the superphosphate was purchased from a market in Hebei Province, China. The physical and chemical properties of the raw materials are presented in Table 1.

2.2. Experimental design

In this study, we investigated three treatments and each treatment was duplicated. 15% cornstalks (proportions of total materials, wet weight) were used as bulking agent and mixed with kitchen waste, because 15% was verified to be the optimal additive amount for adjusting moisture content (~60%) and C/N ratio (~20) of composting materials, and also for the best effect on reducing leachate (Zhang et al., 2011). Besides a control treatment (CK) without any additives, two treatments were amended with phosphogypsum and superphosphate (marked as PPG and SPP treatments), with the addition of 10% (dry weight) of initial raw materials (Luo et al., 2013). A series of laboratory-scale composting reactors (60-L in volume, 0.6 m in height, and 0.36 m inner diameter) were used to simulate the forced aeration system. These cylindrical vessels had removable lids and were insulated with two layers of stainless steel for heat preservation. To create aerobic conditions, the air pump installed with the reactor was operated by an automatic controller with an air flow rate of 0.2 L kg^{-1} dry matter (DM) min^{-1}. The control parameter of automatic controller was set as started every 60 min, that means the air pump operated "30 min on and 30 min off". This ventilation pattern was verified to be sufficient for oxygen supply of composting reactions, and more effective on energy conservation and emission reduction (Leton and Stentiford, 1990; Shen et al., 2010; Shen et al., 2011; Jiang et al., 2013). The trial was operated for 35 days from 1st August to 4th September, 2013. The composting materials were turned and mixed weekly in case of stratification, which would bring about poor ventilation (Jiang et al., 2013; Luo et al., 2014).

2.3. Compost sampling and analysis

The temperature was monitored by a sensor inserted into the middle of the composting materials, and continuously recorded by a computer connected to the reactor. After totally mixing the materials during starting, turning, and ending on the 0th, 4th, 7th, 14th, 21st, 28th, and 35th days, homogeneous samples of compost were collected using the multipoint sampling method, and were mixed thoroughly before analysis. The solid samples were then divided into two parts, and one was stored at 4 °C for the measurement of pH and germination index (GI). The other part was air dried, then ground and sieved to 0.5 mm, for the determination of total nitrogen (TN), total organic carbon (TOC) and total sulfur (TS) content.

The fresh compost samples ($n = 3$) were mixed with distilled water (1:10 w/w ratio) and shaken for 0.5 h. The pH and EC values of the compost were determined by a pH and electric conductivity meter (MP-521) from the mixture. The SO_4^{2-} concentration was determined by the extract using an ion chromatography (ICS-2000). The extract was centrifuged and the supernatant was removed and filtered through a 0.45 μm filter membrane to determine the GI. The seed GI was used to assess the phytotoxicity of the compost. Twenty *pakchoi* seeds were distributed on filter paper in petri dishes (10 cm in diameter) and moistened with 10 mL of the compost water extract. Three replicate dishes for each sample were incubated at 20 °C for 3 days. The number of germinating seeds and root length was measured, with distilled water used as a control. The GI was calculated by the following formula:

$$\mathrm{GI}\,(\%) = \frac{[\text{Seed germination of treatment }(\%)][\text{Root length of treatment}]}{[\text{Seed germination of control }(\%)][\text{Root length of control}]}\,(\%)$$

The concentrations of NO_x^- and NH_4^+ were measured by extracting the fresh solid samples with 2 M KCl (1:10, weight/volume), and analyzed in triplicate using a segmented flow analyzer (Technicon Autoanalyser system, Germany).

The TN and TOC content were analyzed in accordance with the methods of the Chinese national standard (NY 525-2012) using the air-dried samples, and the TS content was determined by the barium sulfate turbidimetry method after heating-digestion (HCl + HClO). The elemental analysis of raw materials and final compost was completed by ICP-OES (Optima 3000DV, Perkin Elmer, USA).

The O_2 content in compost and CO_2 concentration at the outlet of composting reactor were measured daily by an O_2 and CO_2 detector (BIOGAS-5000, Geotech). The NH_3, CH_4 and N_2O samples were collected daily from the gas outlet of the reactor using syringe sampling method. The NH_3 was trapped in boric acid (2%) and titrated against H_2SO_4 (0.01 M). The CH_4 and N_2O concentrations were analyzed by gas chromatograph (3420A, Beifen, China) equipped with both electron capture and flame ionization detectors. The CH_4 and N_2O emissions rates were calculated in accordance with the following formulas:

$$C_{sample}(ppm) = \frac{A_{sample} \times C_{standard}}{A_{standard}} \tag{1}$$

C – gas concentration, ppm and *A* – peak area.

$$N_{sample}(\mathrm{g}\cdot\mathrm{t}^{-1}DM\cdot d^{-1}) = \frac{C_{sample} \times AR \times M}{m \times 22.4 \times 10^6} \tag{2}$$

N – gas emissions rate, g t^{-1} DM d^{-1}, *AR* – air flow rate, L d^{-1}, M – the molar mass of gas, g mol^{-1}, *m* – dry weight of compost materials, *t*, 22.4 – the molar volume of gas (STP), L mol^{-1}.

Table 1
Physical and chemical properties of raw composting materials.

Materials	pH	TN[a] (g kg^{-1})	TOC[a] (%)	NH_4^+ (g kg^{-1})	Germination index (%)	Moisture content (%)	Bulk density (kg m^{-3})
Kitchen waste	4.2	13.6	37.3	0.58	20	66.9	505
Cornstalks	5.4	10.1	40.1	0.38	42	4.8	162

TN: total nitrogen; TOC: total organic carbon.
[a] Dry weight basis.