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Emissions of ammonia and greenhouse gases during combined pre-composting and vermicomposting of duck manure

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ABSTRACT

Combined pre-composting and vermicomposting has shown potential for reclamation of solid wastes, which is a significant source of ammonia (NH_3), and greenhouse gases (GHG), including nitrous oxide (N_2O), methane (CH_4), and carbon dioxide (CO_2). Earthworms and amendments may both affect physico-chemical characteristics that control gas-producing processes, and thus affect NH_3 and GHG emissions. Here, we used two-way ANOVA to test the effects of addition of reed straw and combined addition of reed straw and zeolite on NH_3 and GHG emissions during pre-composting of duck manure, either with or without a follow-up phase of vermicomposting. Results showed that cumulative N_2O, CH_4, and CO_2 emissions during pre-composting and vermicomposting ranged from 92.8, 5.8, and 260.6 mg kg^{-1} DM to 274.2, 30.4, and 314.0 mg kg^{-1} DM, respectively. Earthworms and amendments significantly decreased N_2O and CH_4 emissions. Emission of CO_2 was not affected by earthworms, but increased in responses to addition of reed straw. Cumulative NH_3 emission ranged from 3.0 to 8.1 g kg^{-1} DM, and was significantly decreased by reed straw and zeolite addition. In conclusion, combined pre-composting and vermicomposting with reed straw and zeolite addition would be strongly recommended in mitigating emissions of N_2O, CH_4, and NH_3 from duck manure. Moreover, this method also provides nutrient-rich products that can be used as a fertilizer.

1. Introduction

The reed wetland of Baiyangdian catchment in China is an important duck farm base with about 8 million ducks, which produce more than 213,300 tons manure each year. Most of the duck manure ends up in the water system, causing eutrophication of surface water. Traditional composting of organic wastes comprises a short period of high temperature followed by a period of low temperature, as such facilitating pathogen reduction, waste stabilization, as well as mass reduction (Barrington et al., 2002; Nair et al., 2006). However, the major problems associated with the traditional composting of organic wastes are the long duration of the process, losses of nutrients during the prolonged composting process, frequent aeration required, and a heterogeneous end-product (Nair et al., 2006; Ndegwa and Thompson, 2001).

Recently, interest in the use of vermicomposting, i.e., using earthworms to breakdown organic materials, has increased (Ndegwa and Thompson, 2000; Pramanik et al., 2007). In its basic form, vermicomposting is a low-cost technology which offers a higher quality product (known as "vermicomposts") than traditional composting. Earthworms accelerate composting by bioturbation and aeration, and by that, produce an end-product that is more nutritional (Albanell et al., 1988; Atiyeh et al., 2000), more fragmented, and has higher microbial activity (Héry et al., 2008; Vivas et al., 2009). However, a main disadvantage of vermicomposting is that temperature in the feed substrate must be maintained below 35 °C to avoid the death of earthworms. The temperature during vermicomposting process is therefore not high enough for effective pathogen control (EPA, 2003). A combined system that integrate pertinent attributes from both traditional composting and vermicomposting has shown potential for reclamation of solid wastes, not only shortening the stabilization time (Frederickson et al., 1997), but also improving the quality of end-products as

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fertilizers (Ndegwa and Thompson, 2001). Moreover, vermicomposting also produces earthworms as a fine fodder for poultry with high protein.

The combined composting and vermicomposting process in the treatment of poultry manure inevitably involves emissions of ammonia (NH_3) and greenhouse gases (GHG), including nitrous oxide (N_2O), carbon dioxide (CO_2), and methane (CH_4), which can contribute to global warming and stratospheric ozone depletion (Crutzen, 1970). Deposition of emitted NH_3 in aquatic and terrestrial systems can cause eutrophication and soil acidification, respectively (Metcalfe et al., 1998). Although earthworms hardly produce any NH_3 and GHG themselves, they can significantly influence physico-chemical properties of the feeding substrate (Hobson et al., 2005), as such indirectly affecting gas-producing processes, and thereby affecting NH_3 and GHG emissions. Effects of earthworms on gas emissions are complicated and no consensus has been reached. For example, Lubbers et al. (2013) showed that earthworms increased emissions of N_2O and CO_2 from soils by 42% and 33%, respectively. Hobson et al. (2005) showed a significant effect of earthworms on the efflux of N_2O from household waste, but only a marginal effect on CH_4 emission. Others showed that earthworms significantly increased CO_2 emission, but did not affect N_2O fluxes from soils (Chapuis-Lardy et al., 2010; Speratti and Whalen, 2008). Similarly, Chan et al. (2011) showed that vermicomposting of household waste emitted more CO_2 and CH_4, but less N_2O than traditional composting.

Amendments can be used to change the carbon and nitrogen content, aerobic conditions, pH, and the adsorbent capacity of manure and hence mitigate NH_3 and GHG emissions. Carbon-rich organic materials have been used as amendments to increase aeration and immobilization of nitrogen in manure, thereby reducing gas emissions. For example, Kirchmann and Witter (1989) showed a reduction of NH_3 emission from chicken manure amended with straw, and Yamulki (2006) reported a reduced N_2O and CH_4 emissions from fresh cattle farmyard manure amended with straw. Zeolite, a porous mineral with a high cation exchange capacity and affinity for ammonium (NH_4^+), has used to reduce NH_3 emission from poultry manure (Witter and Kirchmann, 1989). Similarly, Wang et al. (2012) showed that reed straw applied singly or in combination with zeolite reduced NH_3 and GHG emissions for composting duck manure.

Most of previous studies on vermicomposting focus on the feasibility of vermicomposting of different organic wastes (Sangwan et al., 2008), the factors affecting the growth and reproduction rate of earthworms (Ndegwa et al., 2000), as well as the quality of vermicomposts (Pramanik et al., 2007). In addition, several recent studies have focused on the effects of earthworms on GHG emissions from soils (e.g., Bradley et al., 2012; Lubbers et al., 2013). However, little is known about the effects of earthworms on gas emission during vermicomposting of organic wastes, especially for the poultry manure. The objectives of this experiment were therefore to assess the effects of earthworms and amendments on NH_3 and GHG (i.e., N_2O, CH_4, and CO_2) emissions during combined pre-composting and vermicomposting of duck manure and to develop environment friendly and economic method for reasonable duck manure management.

2. Materials and methods

2.1. Experimental design

Our experiment was carried out at the University of Chinese Academy of Sciences, Beijing in autumn 2011. Recently deposited duck manure was collected from a duck farm in Baiyangdian, Hebei province, China. Our experiment consisted of a traditional composting phase (hereafter referred to as 'pre-composting') and a subsequent vermicomposting phase. Reed straw and zeolite were used as amendments. Dried reed straw was provided by a local farmer and shredded (<1 cm pieces), the organic carbon, total nitrogen, total phosphorus of reed straw were 451.6, 5.8, and 0.8 g kg^{-1}, respectively. The zeolite with 8.4 of pH was bought in Hebei province from the Luanping zeolite company, and was ground and sieved (0.178 mm mesh) for use.

During the pre-composting phase, the experiment included three treatments: (i) duck manure without any amendments (C), (ii) duck manure with 40% (w/w) reed straw (S), and (iii) 40% (w/w) reed straw plus 12% (w/w) zeolite (SZ). All amendments were applied on a dry weight basis. The treatments were replicated three times, giving a total of 9 experimental units. Mixtures of 10 kg duck manure (38% moisture content) and corresponding amendments were completely mixed and placed into each of 9 incubation containers (length × width × height, 53 × 38 × 32 cm).

After 45 days of pre-composting, from each container, part of the pre-composting material was transferred to worm-bins (length × width × height, 31 × 24 × 22 cm) for subsequent vermicomposting. This provided 0.07 m^2 of exposed top surface. The vermicomposting stage lasted 32 days. Each worm-bin received 120 g of earthworms (*Eisenia fetida*, provided by a farmer in Beijing, China), corresponding with an optimal stocking density of 1.60 kg worms m^{-2} (Ndegwa et al., 2000). Considering the optimal C/N ratio of 25 for vermicomposting (Ndegwa and Thompson, 2000), more reed straw was added to optimize environmental conditions for the earthworms. Control bins did not receive earthworms, but were amended with the same amount of reed straw. The vermicomposting phase involved the following treatments: pre-composting (C, S, SZ) × earthworms (absent, present) × 3 replicates = 18 experimental units. Over the course of the experiment no additional food was added at any stage. The moisture level of the material was maintained at about 60–65% of wet mass throughout the vermicomposting stage by spraying the surface with water at two-day intervals. The worm-bins were incubated in a humid and dark room at approximately 20 °C.

2.2. Measurements of NH_3 and GHG emissions during pre-composting

Emissions of NH_3, N_2O, CO_2, and CH_4 during pre-composting were measured by a closed chamber technique (Czepiel et al., 1996; Wang et al., 2012). Plastic vessels were transformed into closed chambers by a tight fit lid with two ports for headspace gas sampling and for measurement of air temperature (Fig. 1a). The plastic vessels, which had no bottom, inserted directly into the duck manure mixture about 2 cm below the surface. The average headspace volume of vessels was maintained at 2.6 l.

Gases measurements were done at 1, 3, 6, 8, 11, 15, 19, 23, 29, 36, and 45 days after the start of the experiment. During each measurement, 30-ml gas samples were taken from each experimental container after 0, 10, and 20 min using a 50-ml syringe, and then immediately sent back to the laboratory for analysis of GHG using a gas chromatograph coupled with a flame ionization detector and an electron captor detector (Agilent 7890A, USA). Concentration of NH_3 was measured using M4+ gas monitoring instrument (Changzhou Nuoji Instrument Co., Ltd., China) during the early stage of pre-composting when NH_3 emission was high. Gas fluxes (F, mg kg^{-1} DM d^{-1}, DM = dry matter) were calculated according to Czepiel et al. (1996):

$$F = \rho \frac{V}{M} \times \frac{dC}{dt} \quad (1)$$

where ρ is the density of the gas at sample temperature (°C), V is the air volume of headspace in the container (m^3), M is the initial