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Research article

N_2O emissions and nitrogen transformation during windrow composting of dairy manure

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ABSTRACT

Windrow composting involves piling and regularly turning organic wastes in long rows, being in the succession of static standing periods between two consecutive pile turnings as well as a period of pile turning. N_2O emissions and N transformation were investigated during the processes of windrow composting. In contrast to the conventional understanding, we observed that N_2O concentrations inside compost materials were significantly higher after pile turning (APT) than before pile turning (BPT). Pile turning triggered a burst of N_2O production rather than simple gaseous N_2O escape from the stirred compost. Denitrification was the dominant pathway in pile turning because the observed NO_2^- and NO_3^- concentrations were significantly lower APT compared to BPT. The sudden exposure of O_2 severely inhibited N_2O reductase, which can block the transformation of N_2O to N_2 and thus caused an increase of N_2O emission. As the NO_2^- and NO_3^- concentrations rose during the following 48 standing hours, nitrification dominated N transformation and did not cause an increase of surface N_2O emissions. Thus, pile turning resulted in a dramatic conversion of N transformation and strongly influenced its flux size. It was also found that high NO_2^- was accumulated in the compost and had a strong correlation with N_2O emissions. Practical methods regulating nitrite and the frequency of pile turning would be useful to mitigate N_2O emissions in manure composting.

1. Introduction

With the ongoing intensification and amplification of livestock breeding (Gerber et al., 2005), GHG emissions caused by animal waste handling has gained increased attention. N_2O is a powerful GHG which has 298 times of the global warming potential of CO_2 based on a 100 year projection (IPCC, 2007). According to the People's Republic of China Second National Communication on Climate change (2013), manure management contributed 28.35% of N_2O emissions from China's agricultural activities, exceeded only by farmland soils.

As a simple process that converts organic wastes into stabilized compost, composting has recently become an alternative option to conventional manure handling (Bernal et al., 2009). Windrow composting, with piles mechanically turned using a special machine on a regular basis, has become the most popular form of industrial manure management, especially in southern China (Chen et al., 2014). Despite the advantages of composting, such as reducing odor and the pollution of soil and water (Larney and Hao, 2007), there are debates regarding the gaseous emissions of NH_3, N_2O and CH_4 (Andersen et al., 2010). For N_2O emissions involved in the processes of slurry treatment and after field application, the overwhelming majority (>80%) of emitted N_2O was caused by manure treatment (Amon et al., 2006). Thus N_2O emissions can be most effectively abated if they are reduced during manure management. Studies of different composting practices have shown a wide range of N_2O emissions, accounting for 0.1–5% of total nitrogen in the initial material (Mulbry and Ahn, 2014, Sommer, 2001; Maeda et al., 2013; Tamura and Osada, 2006). Aeration, usually accomplished by pile turning, is an important factor influencing N_2O emissions in the composting process (Ahn et al., 2011). Decreased N_2O emissions from pile turning/aeration have been reported by Osada et al. (2000) and Szanto et al. (2007). However, other studies found the opposite, showing that pile turning/aeration increased N_2O emissions (Hao et al., 2001; El Kader et al., 2007). Due to the disparity of previous studies, more *in situ* experiments are required to study the influence of pile turning on surface N_2O emissions from composting systems.

As also shown by the above studies, most of them focused on the surface emissions during the compost standing period, and the

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interval between twice sampling ranged from days to months. However, compost is frequently mixed or aerated and interchanged with pile standing periods (Martin and Dewes, 1992), and it is believed that the interchanging of the oxic–anoxic state in the manure from pile turning influences the accumulation of N_2O (Petersen et al., 2013). Up to now, only a few studies investigated the N_2O emissions related to pile turning. Therefore, the quantification of N_2O emissions caused by pile turning appears to be important for the accuracy of emission data across national and international databases.

N_2O is an intermediate product of nitrification and denitrification, which are the main mechanisms for nitrogen removal and generally occur in manure treatment processes; therefore, factors influencing the N cycle could affect N_2O emissions. It has been found that N_2O emissions are a function of the compost age, pile depth, temperature, pH, aeration and water filled pore space (Petersen et al., 2013). Despite numerous studies on N transformation related to the investigation of N_2O emissions in soil, fundamental N transformation processes in to manure management are still poorly understood and relevant studies are extremely limited Further investigations are necessary in the area of N transformations during the windrow composting process, specifically at the moment of pile turning. Less nitrogenous emissions would lead not only to the improvement of N efficiency from composting but also to the mitigation of N_2O emissions that could be a risk of global warming (Fukumoto and Inubushi, 2009). This would bring both environmental and economic profits, with the conservation of valuable N fertilizer maintained in the final compost product.

In the present study, site experiments were conducted in a composting plant involved in N_2O emissions and N transformation during the windrow composting process. As for the whole process, we were concerned not only with the static standing period between two consecutive pile turnings but also at the moment of pile turning. The aims of this study were to (1) investigate N_2O emissions caused by the movement of pile turning, (2) investigate the influence of pile turning on the surface N_2O emissions during the standing period, and (3) gain a deep insight into the N transformation underlying N_2O emissions. The results are helpful for compost emission modeling and mitigation strategies in manure management.

2. Materials and methods

2.1. Experimental design

This study was conducted on a commercial compost plant in Suqian (33°8′N, 117°56′E), eastern China, with a warm temperate monsoon climate. Fresh dairy manure was obtained from a small-scale feedlot until the start of manure management. The raw material was 85% dairy manure and 15% straw based on fresh weight. The windrow was placed in an open-sided and roofed workshop that was 2.0–2.5 m wide, 15–20 m long and 1.0–1.1 m in height.

After the initial construction, the windrow was regularly turned using a straddle compost turner. As shown in Fig. 1a, the windrow compost was interchanged with pile turnings and pile standing, with the period between two consecutive pile turnings considered to be one composting cycle. Three experiments were conducted with three independent windrow composting trials. Each composting process lasted 3–4 weeks from the date of construction.

2.1.1. Experiment I

The pattern of surface N_2O flux during one 48-h cycle between two periods of pile turning was investigated in Experiment I. Gas samples were collected immediately after one pile turning and then collected after 1, 2, 4, 7, 10, 14, 18, 24, 30, 36, 42, 48 h, with the last collection (at 48 h) just before the next pile turning. At the first sampling, PVC chamber bases (Ø = 30 cm), which had a water groove, were inserted 25 cm into the pile. The chamber bases were maintained in the pile to reduce the disturbance caused by moving them. When sampling, the PVC chambers with diameters of 30 cm and heights of 66 cm were first sealed by water. At 0, 5, 10, 20 and 30 min after the chamber sealing on the pile surface, 30 mL of gas samples were extracted with an airtight syringe (volume = 30 mL) and injected into a 20 mL pre-evacuated Exetainer. Then, the gas samples were transported to the laboratory, and the N_2O concentration was analyzed by gas chromatography.

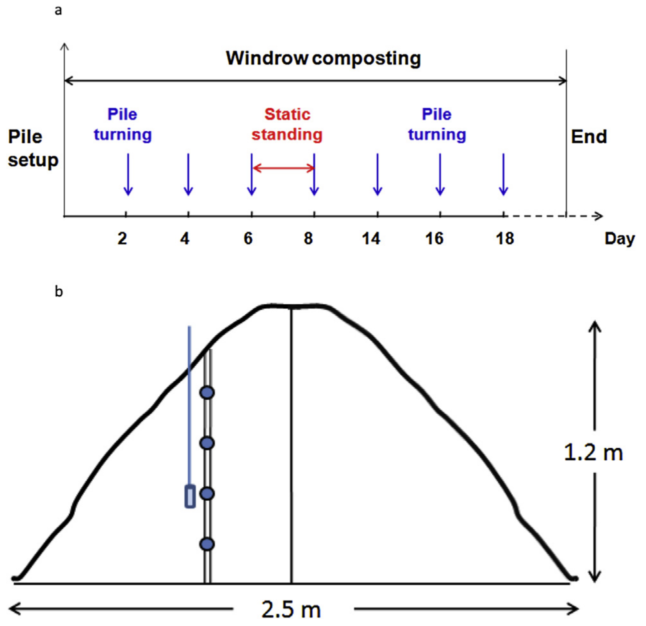

Fig. 1. Schematic diagram of the experimental design: (a) the windrow composting process: after the initial pile setup, the windrow was turned every 2 days (in real cases 2–3 days). (b) The gas probe collection from the compost pore space: probes were placed at 4 monitoring points in the cross-section, which was bilaterally symmetric.

2.1.2. Experiment II

N_2O concentrations were investigated in the compost pore space before pile turning (BPT) and after pile turning (APT) to map the variation of N_2O caused by pile turning. The windrow was turned every 2–3 days during the whole composting period. Gas probes were collected along the cross-section of bilaterally symmetric windrow compost. The N_2O concentration in the compost pore space was the mean of 4 specified points (Fig. 1b), which were considered to be representative of the concentration of the cross-section (data not shown). Four cross-sectional measurements were made, as four replicates for each sampling.

The gas probes were composed of a stainless steel pipe with an inner diameter of 1.5 mm. A cylinder chamber 3 cm long and 1 cm in diameter that was hollow inside with a porous surface was wrapped with wire mesh and welded onto the top of the pipe. An airtight syringe (volume = 30 mL) was connected to the other end of the pipeline. When sampling, the cylinder chamber was inserted into the compost material to a certain depth and the gas sample was collected from the syringe over the windrow surface. To eliminate the dead volume in the probes, each probe sampling system was flushed 3 times by discarding ca. 100 mL of the compost gas, and then, 30 mL of gas was collected and injected into a 20-mL pre-evacuated Exetainer. Then, the gas samples were transported