



# Potential of aeration flow rate and bio-char addition to reduce greenhouse gas and ammonia emissions during manure composting



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## HIGHLIGHTS

- Low flow rate reduces NH<sub>3</sub> loss from composting cattle slurry and straw.
- Low flow rate increases CH<sub>4</sub> loss from composting cattle slurry and straw.
- Bio-char addition reduces NH<sub>3</sub> and CH<sub>4</sub> losses from composting hen manure.
- Flow rate appears to have no significant effect on N<sub>2</sub>O emissions from composting.
- Adding bio-char to composting hen manure reduces total GHG expressed in CO<sub>2</sub>-eq.

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## ABSTRACT

Aeration is an important factor influencing CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O and NH<sub>3</sub> emissions from the composting process. Both CH<sub>4</sub> and N<sub>2</sub>O are potent greenhouse gases (GHG) of high importance. Here, we examined the effects of high and low aeration rates together with addition of barley straw with and without bio-char on GHG and NH<sub>3</sub> emissions from composting cattle slurry and hen manure in small-scale laboratory composters. Depending on treatment, cumulative C losses via CO<sub>2</sub> and CH<sub>4</sub> emissions accounted for 11.4–22.5% and 0.004–0.2% of initial total carbon, while N losses as N<sub>2</sub>O and NH<sub>3</sub> emissions comprised 0.05–0.1% and 0.8–26.5% of initial total nitrogen, respectively. Decreasing the flow rate reduced cumulative NH<sub>3</sub> losses non-significantly (by 88%) but significantly increased CH<sub>4</sub> losses (by 51%) from composting of cattle slurry with barley straw. Among the hen manure treatments evaluated, bio-char addition to composting hen manure and barley straw at low flow rates proved most effective in reducing cumulative NH<sub>3</sub> and CH<sub>4</sub> losses. Addition of bio-char in combination with barley straw to hen manure at both high and low flow rates reduced total GHG emissions (as CO<sub>2</sub>-equivalents) by 27–32% compared with barley straw addition alone. Comparisons of flow rates showed that low flow could be an alternative strategy for reducing NH<sub>3</sub> losses without any significant change in N<sub>2</sub>O emissions, pointing to the need for well-controlled composting conditions if gaseous emissions are to be minimised.

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## 1. Introduction

Modern intensive confinement systems of livestock and poultry production in many regions have resulted in significant environmental challenges, with generation of large volumes of manure and slurry in relatively small areas with insufficient surrounding farmland for application. As an alternative environmental technology, composting is being increasingly used to handle large volumes of surplus manure in areas of intensive livestock production. It also minimises unwanted gaseous emissions if proper composting conditions are maintained (Amon et al., 2001; USCC, 2008; Park

et al., 2011). However, composting manure, either solid or liquid, may result in emissions of potent greenhouse gases (GHG) such as CH<sub>4</sub> and N<sub>2</sub>O if aerobic conditions are not maintained. Furthermore, N losses via NH<sub>3</sub> volatilisation during composting may reduce the agronomic value of compost as a soil amendment and contribute to eutrophication and acidification of ecosystems. Therefore, it is important to maintain proper aerobic conditions in order to reduce gaseous emissions during composting.

Aerobic composting requires sufficient O<sub>2</sub> for microbial activity and is usually provided by one of three different aeration systems: physical turning of the material, passive aeration or forced aeration. Insufficient aeration flow rates may result in anaerobic microsites within the composting matrix, whereas excessive flow rates limit microbial activity as a result of excess evaporation, heat loss

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and associated cooling. Thus aeration has a significant influence on the production and emissions of GHG and  $\text{NH}_3$  (Ahn et al., 2011; Li et al., 2013). Compared with physical turning and passive aeration systems, forced aeration composting is generally found to result in lower GHG emissions due to adequate  $\text{O}_2$  supply (Hao et al., 2001; Park et al., 2011). A literature review by Ahn et al. (2007) suggested testing a wide range of aeration flow rates, with values from 0.04 (minimum) up to 3.0 (peak)  $\text{L min}^{-1} \text{kg}^{-1} \text{VS}$  (VS: volatile solids), to optimise composting for a wide variety of organic wastes. However, the effects of aeration flow rates on the trade-off between  $\text{NH}_3$  versus  $\text{CH}_4$  and  $\text{N}_2\text{O}$  emissions during composting are not well understood. Most previous studies have reported that losses of  $\text{NH}_3$  increase and  $\text{CH}_4$  emissions decrease with increasing aeration rate (Osada et al., 2000; Jiang et al., 2011; Shen et al., 2011). However, Paul et al. (2001) observed an increase in  $\text{CH}_4$  emissions with increasing aeration rate. Reported values of  $\text{N}_2\text{O}$  emissions from active aeration composting systems vary. Some studies have reported a decrease in  $\text{N}_2\text{O}$  emissions with increasing aeration rate (Osada et al., 2000; Shen et al., 2011). However, in other studies increased aeration rate is reported to increase  $\text{N}_2\text{O}$  emissions (He et al., 2001; Jiang et al., 2011). Furthermore, some studies report that significant  $\text{N}_2\text{O}$  emissions occur during the thermophilic phase (Jarvis et al., 2009; Jiang et al., 2011), while others have found significant  $\text{N}_2\text{O}$  emissions only during the low temperature, mesophilic (at the beginning) and late composting (maturation) phases (Hellmann et al., 1997; Sommer and Møller, 2000). These varying results are probably attributable to varying physicochemical composition of organic wastes, C and N dynamics during composting,  $\text{O}_2$  availability, and differences in composting system, experimental design and scale.

Manures are typically high in moisture and have a low C/N ratio. High moisture can greatly restrict  $\text{O}_2$  transfer within the composting matrix even if high aeration rates are maintained, prohibiting optimum composting. To overcome this problem, C-rich bulking agents such as woodchips, sawdust or crop residues are commonly mixed with wet manure to adjust the moisture and increase the porosity and thereby improve the aeration conditions and increase the C/N ratio of the compost mixture. This can potentially reduce emissions of  $\text{NH}_3$  and GHG. Over recent decades, there has been increased interest in C sequestration and reduction of GHG emissions through addition of C-rich bio-char to soil. However, there has been little research to date on the potential use of bio-char as a bulking agent in conserving N and reducing GHG emissions during manure composting. The combined effects of aeration flow rate and bulking agent on the trade-off between  $\text{NH}_3$  and  $\text{N}_2\text{O}$  production and emissions during composting are largely unknown. In order to understand the underlying processes that lead to production and emissions of GHG and  $\text{NH}_3$  from a forced-aeration composting system, controlled laboratory studies with simultaneous, continuous measurement of these gases are required.

In the present study, we tested the effects of high and low aeration flow together with addition of barley straw with and without bio-char on  $\text{CO}_2$ ,  $\text{CH}_4$ ,  $\text{N}_2\text{O}$  and  $\text{NH}_3$  emissions from composting cattle slurry and hen manure in small-scale laboratory composters over a 31-d period. Air-filled porosity of all three compost mixtures was set at the same initial level to compare the effect of different air flow rates on gaseous emissions under the same initial physical conditions.

## 2. Materials and methods

### 2.1. Raw manure and bulking agents

Bedding-free dairy (red Danish dairy breed) cattle slurry (CS) and laying hen manure (HM) were collected from commercial

farms in Denmark. The fresh CS was collected directly from the slurry outlet pipe while slurry was being pumped from the animal building to a secondary slurry storage tank. All cattle feed consisted of roughage and concentrates. The fresh HM was directly collected from the conveyor belts located under the cages to collect droppings. Barley straw (BS) was collected from a conventional barley crop at the experimental farm of the University of Copenhagen in Taastrup. Prior to use, the straw was cut to a length of about 25 mm. The bio-char (BC) used was a commercial charcoal product purchased by Skogens Kol AB, Sweden. It was produced by heating biomass, a mixture of hardwood (80%) and softwood (20%), at 500–700 °C. The coarse BC solids used for the composting experiments were separated from the finer materials by sieving through a 16-mm screen and approximately 75% of the material retained was in the particle size range 25–30 mm. Selected initial properties of the CS, HM, BS and BC are presented in Table 1.

Different mixing ratios of manure to bulking agent were selected to give an initial target air-filled porosity (AFP) of about 56% in all compost mixtures (Table 2). In order to achieve this, the compost mixture in each reactor was compacted (as described by Chowdhury et al., 2013) to a constant wet bulk density ( $\text{BD}_{\text{wb}}$ ) of about  $492 \text{ kg m}^{-3}$ . The AFP of the mixture was then calculated using the Agnew et al. (2003) equation as:  $\text{AFP} (\%) = 100 - 0.09 \times \text{BD}_{\text{wb}}$ .

### 2.2. Composting set-up and design

The composting system consisted of six 10-L cylindrical stainless steel reactors. A diagram of a reactor and its associated instrumentation is shown in Fig. 1. A perforated steel plate was placed 20 mm from the bottom of the reactor to support the compost mixture and compressed air was applied beneath the perforated plate. Each reactor was fitted with an airtight lid and was insulated with on average 170 mm polyurethane foam on all sides. The system had a separate flow rate control for each reactor comprising a needle valve (manual) and an electronic mass flow meter (AWM5101VN, Honeywell, USA). The flow rate was measured in the inlet tube only.

Three independent composting experiments were conducted. For each experiment, triplicate reactors were used for the high flow (HF) and low flow (LF) rates, respectively, and each experiment used a similar compost mixture (Table 2). Each experiment was run for 31 d between March and July 2012, at an average ambient room temperature ranging between 22.6 and 24.7 °C. For all three experiments, the HF rate was set to 0.44 and the LF rate to  $0.22 \text{ L min}^{-1} \text{kg}^{-1} \text{TS}$  (TS: total solids) to continuously aerate the composting mass in each reactor throughout the 31 d of composting. However, due to differences in compost resistance, measured flow rate (as  $\text{L min}^{-1} \text{kg}^{-1} \text{TS}$ ) during the composting process varied in the range 0.33–0.48 and 0.17–0.23 for the HF and LF treatments, respectively (Table 2). Temperature was measured using a Type K thermocouple in the middle of the composting mass in each reactor. Temperature and air flow data were recorded every 15 min over the whole composting period using a data acquisition system (ADC-24 and TC-08 respectively, Pico Technology, UK).

### 2.3. Gas sampling system and calculation

For headspace gas sampling, the outlet port for releasing air from each reactor was connected via a Teflon tube (3 mm inner diameter) to an INNOVA model 1309 12-channel Multipoint Sampler combined with an INNOVA model 1412 Photoacoustic Field Gas Monitor (Innova AirTech Instruments, Ballerup, Denmark). To protect the gas analyser from water condensation, exhaust air from each reactor was conducted through a water trap before it entered the gas analyser. At the end of the composting period, the liquid in each trap was analysed for  $\text{NH}_4^+$ . The outlet from the water trap on

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