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Greenhouse gas and ammonia emissions from production of compost bedding on a dairy farm

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ABSTRACT

Recent developments in composting technology enable dairy farms to produce their own bedding from composted manure. This management practice alters the fate of carbon and nitrogen; however, there is little data available documenting how gaseous emissions are impacted. This study measured in-situ emissions of methane (CH_4), carbon dioxide (CO_2), nitrous oxide (N_2O), and ammonia (NH_3) from an on-farm solid-liquid separation system followed by continuously-turned plug-flow composting over three seasons. Emissions were measured separately from the continuously-turned compost phase, and the compost-storage phase prior to the compost being used for cattle bedding. Active composting had low emissions of N_2O and CH_4 with most carbon being emitted as CO_2-C and most N emitted as NH_3-N. Compost storage had higher CH_4 and N_2O emissions than the active phase, while NH_3 was emitted at a lower rate, and CO_2 was similar. Overall, combining both the active composting and storage phases, the mean total emissions were 3.9×10^{-2} g CH_4 kg^{-1} raw manure (RM), 11.3 g CO_2 kg^{-1} RM, 2.5×10^{-4} g N_2O kg^{-1} RM, and 0.13 g NH_3 kg^{-1} RM. Emissions with solid-separation and composting were compared to calculated emissions for a traditional (unseparated) liquid manure storage tank. The total greenhouse gas emissions ($CH_4 + N_2O$) from solid separation, composting, compost storage, and separated liquid storage were reduced substantially on a CO_2-equivalent basis compared to traditional liquid storage. Solid-liquid separation and well-managed composting could mitigate overall greenhouse gas emissions; however, an environmental trade off was that NH_3 was emitted at higher rates from the continuously turned composter than reported values for traditional storage.

1. Introduction

Recent technological advancements in the dairy sector have enabled dairy farms with liquid manure to use mechanical solid-liquid separation systems paired with active composting of the separated solids. This is desirable to farmers because liquid manure storage requirements are reduced, and composted solids are used as bedding material, avoiding the increasing cost of purchased bedding (Husfeldt et al., 2012). These commercially available in-vessel compost systems use a continuously turned rotating drum located in a small building near the dairy barn. Unlike other composting approaches (e.g. turned windrows, aerated static piles), the in-vessel composting approach is completely automated and requires minimal time from the farmer. Composting occurs rapidly under constant turning and aeration, enabling a high throughput of organic material within a small footprint. Moreover, the challenges of outdoor composting during winter are avoided.

Solid-separation and composting is a potential greenhouse gas mitigation practice for dairy farms; however, there is a lack of published measurements characterizing emissions from the process. Separation reduces carbon in the liquid fraction entering the manure storage, hence reducing the potential methane (CH_4) emissions, with a high global warming potential (GWP = 34, with climate-carbon feedback). Determining whether separation and composting has an overall greenhouse gas benefit requires considering all gases emitted during the processing stages. Nitrous oxide (N_2O) is a potent greenhouse gas (GWP = 298, with climate-carbon feedback)

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(IPCC, 2013, Table 8.7) emitted from solid manure and compost. Manure also emits ammonia (NH_3), which is an indirect greenhouse gas and has adverse health effects (USEPA, 2004; Harrison and Yin, 2000). Carbon dioxide (CO_2) is emitted but as part of the short (biogenic) carbon cycle it does not contribute to the net atmospheric concentration (e.g. Vergé et al., 2013; IDF, 2015).

Actively turned in-vessel composting in a rotating drum ensures consistent aerobic conditions, favoring CO_2 production instead of CH_4 (Lopez-Real and Baptista, 1996). A possible trade-off of mitigating CH_4 is the increased production and emission of NH_3 and N_2O. Composting increases the pH and temperature of the material, shifting the equilibrium between ammonium (NH_4^+) and NH_3 towards gaseous NH_3, which is rapidly lost to the atmosphere (Li et al., 2008, 2013; Tiquia, 2002; Wang and Zheng, 2017). Nitrous oxide is a by-product from the microbial processes of nitrification and denitrification, and can be produced and emitted during aerated composting of organic waste (He et al., 2001). Nitrification occurs in aerobic conditions (such as continuously turned composting), and is the process of oxidizing ammonia to nitrate by autotrophic bacteria (Alexander, 1977). Denitrification occurs if conditions become anaerobic (such as stored piles of compost), and involves the reduction of nitrate to di-nitrogen gas primarily by heterotrophic bacteria, if the reduction is incomplete, N_2O is released (Kebreab et al., 2006).

Past research on dairy manure emissions from small scale storage bins (2.6 m^3) filled with manure that was left to compost without active turning, but with passive aeration through pipes at the bottom of the bins, indicated that the combined emissions of N_2O + CH_4 (in CO_2-e) from composting were lower than when manure was stored as a slurry or in a stockpile (Pattey et al., 2005). Chambers have also been used to cover composting heaps of manure to estimate the emissions (Sommer et al., 1999). Amon et al. (2006) found that composting dairy manure (in piles 2 m high) after separation emitted 209 g NH_3 m^{-3}, an amount significantly higher than 41 g NH_3 m^{-3} emitted by untreated stored manure (the authors did not indicate compost conditions; presumably it was non-active). These data from small scale, infrequently mixed, compost studies are not transferrable to in-situ, farm scale, conditions where continuously-turned mechanical composters are used. These machines range in volume (8–57 m^3) with daily addition of fresh material and computer-controlled temperature and aeration to optimize compost production. A recent review (Pardo et al., 2015) highlighted the importance of turning compost piles to reduce CH_4 and N_2O emissions; however, they did not report any data from continuously turning compost drum systems which are becoming more common in the dairy industry. A study on aerated composting of liquid swine manure combined with wheat straw concluded aerated composting reduced N_2O and CH_4 emissions to as low as 30% when compared to storing the liquid swine manure without treatment, while non-aerated composting increased emissions, especially of CH_4 (Thompson et al., 2004).

This study aimed to address knowledge gaps regarding continuously-turned composting systems processing separated dairy manure solids and producing composted bedding material. Specific objectives were to determine the emission rates of four gases, CH_4, CO_2, N_2O, and NH_3, from solids separation, continuously turned composting, compost storage, and storage of the separated liquid fraction *vs* conventional storage of dairy slurry in anaerobic slurry tanks.

2. Materials and methods

2.1. Experimental site and manure management

The study was conducted on a commercial dairy farm with 150 milking cows and 30 non-milking cows near Ottawa, Ontario, Canada. Dairy slurry was pumped from the free-stall barn to a Screw-press Separator with 15 mm and 12.5 mm screens (EYS SP-600HD, Daritech Inc., Lynden, U.S.A.). The liquid fraction was pumped to an outdoor storage tank, while the solid fraction was directed to a continuously turned plug-flow composter with a rotating drum (BeddingMaster 6-32, Daritech Inc., Ontario, Canada). The continuously rotating drum was 9.75 m long × 1.83 m inner diameter with a 36 h retention time. A computer-controlled ventilation system maintained the temperature within the compost drum above 65 °C by drawing air into the composter through the compost outlet hole, and exhausting it from the other end outside the building. The farm produced compost continuously (24 h d^{-1}) amounting to approximately 35 m^3 wk^{-1}, while the farm used approximately 30 m^3 wk^{-1} as bedding for the cows on this farm (15 m^3 spread in the barn stalls twice per week). Surplus compost (5 m^3 wk^{-1}) was stored in piles until used as bedding, periodically compost was sold to other farms for bedding, and compost was applied to fields periodically during the growing season. The average retention time in the compost piles was approximately 5 wk, based on a typical surplus of 5 m^3 wk^{-1} and observed typical pile size of 25 m^3. A flowchart of this process is shown in Fig. 1. The building enclosing the separator, composter, and compost piles was 17.5 m long, 12.5 m wide, and 5.5 m high, and was passively ventilated through large windows and an overhead door.

2.2. Overall emission measurements

Emissions of four gases (CH_4, CO_2, N_2O, and NH_3) were measured from two sources: (1) emissions from both the separator and compost piles (released within the building); and (2) emissions from the compost drum (released through the exhaust pipe outside). Emissions from each source were determined separately as described in the following sections. Measurements were conducted over three seasons; summer, fall, and winter and we assumed that emissions in fall and spring are similar for annual analysis. Conducting these measurements on a commercial farm had the benefit that we measured emission from the real system which would be nearly impossible to replicate in a laboratory setting; however, it necessitated us to work within the farmer's schedule and preferences. Since the measurements required that we control the building ventilation and set-up our instrumentation within the building, we could only conduct measurements on specific Saturdays when the farmer granted us control of the building. Measurements were conducted a minimum of twice in each season in accordance with farmer's schedule.

2.3. Emissions measurements within the composting building (Stored Compost)

To analyze the emissions from the piles of stored compost, the building was sealed by closing the windows and door, and sealing all openings with plastic. Three open-path lasers (GasFinder 2, Boreal Laser Inc., Edmonton, Canada) were used to measure line-average concentrations of CH_4, CO_2, and NH_3 across a 15 m path adjacent to the compost piles within the building at 1.2 s intervals and averaged over 30 s. Measurement accuracy for individual 1.2 s measurements was given by the manufacturer as ±2% for CO_2 and CH_4 lasers, and ranged from ±10% (at low concentrations) to ±2% (at high concentrations) for the NH_3 laser. Nitrous oxide was measured by manually collecting 25 mL air samples at three locations (simultaneously by 3 people) across a 15 m transect within the building every five minutes (0, 5, 10, 15, 20, 25, 30 min), placed in 12 mL evacuated vials, and analyzed on a gas chromatograph (GC) (Varian CP-3800).

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