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Research article

Ammonia and greenhouse gases losses from mechanically turned cattle manure windrows: A regional composting network

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ABSTRACT

An on-farm composting network operates in the Basque Country (northern Spain), in which solid manure produced in livestock farms (mostly dairy and beef cattle) is composted through windrow turning. This network aims to produce a valuable resource (compost) for the farmers whereas the volume of the solid manure was reduced at farm level The objective of the study was to assess the gaseous losses (NH_3 and GHG) from 6 on-farm composting windrows (either deep litter systems or solid fraction after slurry separation) after turning operations. Monitored turning events occurred 1 to 4 months after establishing the heaps on the field. Ammonia and greenhouse gas (GHG) losses were estimated by the open and close chamber techniques, respectively. Results showed overall low emission rates related to the long degradation period of the windrows. Maximum NH_3 release was at 2.0 mg m^{-2} d^{-1} after the second/third turning events. Baseline N_2O losses were below 50 mg m^{-2} d^{-1}, with maximum rates close to 500 mg m^{-2} d^{-1} some days after turning works. Methane emissions were mostly below 100 mg m^{-2} d^{-1}, while CO_2 losses were lower than 25 g m^{-2} d^{-1}. Carbon dioxide peaks ($\approx$250 g m^{-2} d^{-1}) were reached after the second/third turnings. Overall, gaseous N and C losses accounted for 0.1 and 1% of the initial N and C content of the windrows, respectively. The present study concluded that two/three turning operations in aged solid manure-derived compost windrows do not have significant effects on NH_3 and GHG losses. The magnitude of the gaseous losses from on-farm composting systems is dependent on the manure management practices at farm level (e.g. moment of windrow stacking).

1. Introduction

The intensification of livestock production systems is associated with pollution problems leading to the deterioration of air, water and soil quality (Petersen et al., 2007). The accumulation of large amounts of manure may lead to nutrient surpluses at farm/regional level when nutrients exceed the fertilisation requirements of the croplands. The correct nutrient management planning should include the minimisation of manure volume and nutrients, properly designed fertilisation programs and the optimisation of manure transportation systems. Treatment technologies adapted to farm/regional requirements should also be included in the planning (Flotats et al., 2009). Under this paradigm, composting may comply with all these environmental issues when handling solid manure from animal husbandry (cattle, sheep, pig, poultry) becomes difficult at farm/regional scale. Composting reduces the volume of the raw manure through the biochemical mineralisation, and partial humification, of the organic compounds under aerobic conditions. As a result, a slow-release and useful end-product (compost) is achieved (Bernal et al., 2009; Onwosi et al., 2017). The use of the compost for crop fertilisation is associated to minimising the risk of spreading pathogens and weeds, and improving the soil quality and fertility (Larney and Hao, 2007).

Despite the environmental benefits of compost production and utilisation, this treatment is unfortunately linked to a couple of environmental drawbacks. Composting installations delivers greenhouse gases (GHG), such as nitrous oxide (N_2O), carbon dioxide (CO_2), methane (CH_4) and volatile organic compounds (VOC), into the atmosphere. Odorous compounds such as ammonia (NH_3), hydrogen sulfide (H_2S) and VOCs, which may induce social annoyances close to the facilities, are also emitted during the composting process. In addition, pollution of surface and groundwater is likely to occur if N and P losses via leaching/run-off pathways are not minimised (Bernal et al., 2009; Onwosi et al., 2017).

Composting process is primarily modulated by the C:N ratio of

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the piles (recommended ratio, 25–35), in which C is the energy source and N is required for microbial growth and activity. Compost piles with unbalanced C:N ratios may lead to either too slow compost production rates or composting processes with severe N losses. According to the literature, gaseous emissions may account for up to 60 and 75% of the initial N and C content in the raw manure, respectively (Bernal et al., 2009; Pardo et al., 2015). Ammonia volatilisation has been reported as the principal pathway for N losses, and mostly occurs within the first month of composting process (Martins and Dewes, 1992; Parkinson et al., 2004; Sommer, 2001). Nitrous oxide losses arise later after nitrification and denitrification processes during the mesophilic phase (Sommer, 2001), and may account for 10% of the initial N content (Maeda et al., 2011). Anaerobic/aerobic zones can also emerge into the piles during the composting process, and lead to CH_4 and CO_2 emissions due to the microbial and biochemical transformations. Carbon dioxide losses account for most of the total C mass loss whereas CH_4 emission may represent less than 10% (Hao et al., 2004; Mulbry and Ahn, 2014). The abatement of all these pollution sources becomes essential for producing composts with high agronomic value (Hao et al., 2004).

The extent of NH_3, N_2O, CH_4 and CO_2 losses from composting piles is influenced by the type of manure, nutrient balance, pH, particle size, porosity, moisture, temperature and aeration (Bernal et al., 2009). Aeration, which has been identified as the major contributor to gaseous emissions, is mostly conducted through mechanical turning (mixing) of the piles (Onwosi et al., 2017). The effect of turning events on gaseous losses have been mostly studied at pilot scale composting facilities (Ahn et al., 2011; El Kader et al., 2007; Hassouna et al., 2008; Mulbry and Ahn, 2014; Parkinson et al., 2004; Sommer, 2001). Nonetheless, little is known about turning events on compost windrows produced under real conditions (Chen et al., 2015). In this sense, a composting network is currently working in the Basque Country (northern Spain), in which solid manure produced by 68 conventional and organic farmers (mostly dairy and beef cattle) is on-farm composted through windrow turning. As Loyon et al. (2016) recently summarised, this initiative had to overcome the barriers associated to the implementation of environmental technologies at farm level: costs, fear of excessive action and doubts on the correct environmental performance.

The objective of the current study was to assess the gaseous losses (NH_3 and GHG) from on-farm composting manure after windrow turning operations.

2. Material and methods

2.1. Composting network

A composting network was started in 2009 in Araba province (the Basque Country, northern Spain) as an initiative of the local/regional administrations and a group of farmers (cattle, sheep, horse, poultry). This network aims to produce a valuable resource (compost) for the farmers whereas the volume of the solid manure was reduced at farm level (estimated up to 60%). The end-product is primarily used by the farmers themselves, although compost may be also sold to other farmers, crop producers and gardening companies in the region.

According to the regional best management practices (BMP) for solid manure composting, manure (either deep litter systems or solid fraction after slurry separation), must be stacked in long windrows (maximum height and width, 1.6 and 3.0 m, respectively) on the field. Windrows must be piled in sunny and wind-protected zones, searching non-permeable soils, warranting good accessibility for turning operations, and avoiding nearby water streams and high density population areas. All the windrows are mechanically turned by a self-propelled turner (4300 SP, Menart, Belgique) in order to promote their correct aeration. Turning events are always conducted in spring (Apr/May) and summer (Jul/Aug), and the windrows are turned twice (one month between the turning events). A third turning operation may occasionally be conducted if mature compost is required by some cultivars. Turning works are carried out according to a previously established calendar, which is arranged among the farmers, the technical advisors and the operators involved in the network.

2.2. Description of windrows and experimental setup

Six solid manure-derived composting windrows were included in the current study. Three deep litter-based windrows, which were produced in one beef and one dairy cattle farm, had been stacked on a bare soil in Kuartango (42°53′22.3″N, 2°54′31.8″W). All these windrows were built as semi-elliptic cylinders (initially 115 m long, 3 m wide and 1.3 m high). Cereal straw was used as bedding material in both farms (8 kg cow^{-1} d^{-1}). The suckler cow herd consisted of 102 cows (Pirenaica breed), which grazed in nearby mountain grassland areas from March to October. Solid manure was mostly produced in winter season and the corresponding composting windrow (BDL) used to be piled every 4 months. The dairy herd had 120 adult cows (Holstein breed), which were continuously confined at the stall. Deep litter was renewed every 2 months and subsequently heaped in the composting area. During the current experimental period (Table 1), windrows with different maturity were studied in relation to the dairy cattle farm (DDL_m and DDL_f).

The study of windrows heaped after slurry solid-liquid separation (SMS) was also performed. Three windrows had been stacked close to a dairy farm located in Arespalditza (43°05′31.4″N, 3°02′46.5″W), in which 148 Holstein cows were continuously confined. Slurry was daily separated using a screw press separator (Microfilter S.L., Reus, Spain), and the solid fraction was progressively heaped outdoors. The piles were also stacked as semi-elliptic cylinders (initially 30 m long, 3 m wide and 0.9 m high).

As Table 1 shows, monitored turning events in BDL, DDL_m and SMS windrows occurred 4 months after establishing the heaps on the field. DDL_f was turned 1 month after stacking the windrow. The first and second turning works were not monitored in SMS due to operational limitations.

2.3. Gas measurements

2.3.1. Ammonia measurements

Table 1 shows the monitoring period for NH_3 losses in all the windrows. Ammonia emissions were measured using the open chamber technique (Merino et al., 2008). Three polyvinyl chloride (PVC) chambers (6.75 L, 0.031 m^2) were randomly placed on BDL, DDL_m and DDL_f windrows, and on each SMS windrow. Inner walls were covered with a polytetrafluoroethylene film (PTFE) to ensure the minimal NH_3 uptake. Chambers fit tightly into a frame that was inserted 3 cm into the pile. An air flow produced by a compressor (ABAC FC2/24, Torino, Italy) was passed through orthophosphoric acid and distilled water, and delivered into each chamber through PTFE tubes. The flow rate was 2–3 L min^{-1}, which was fixed with a flow meter (2150/Inox, Tecfluid S.A., Barcelona, Spain). The outlet air stream was passed through a desiccant (Envirogel, Brownell Ltd., London, UK) to avoid interferences with the sample moisture. Ammonia measurements were monitored by a photoacoustic analyser (Bruel & Kjaer 1302, Nærum, Denmark; detection limit, 0.2 ppm NH_3). Gas sampling lasted 10 min in each chamber until the steady-state was reached. Ammonia concentrations were daily