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Ammonia losses from the storage and application of raw and chemo-mechanically separated slurry

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ABSTRACT

The effect of combined chemical–mechanical pig slurry separation on ammonia (NH_3) emissions was investigated in a field scale study. We determined the amount of volatized ammonia emitted from the solid and liquid fractions of raw pig slurry during its storage and after its broadcast to an alfalfa (*Medicago sativa* L.) meadow under summer and winter conditions. The solid fraction accounted for the largest NH_3 losses during both storage and land application. Chemical–mechanical separation of raw pig slurry under winter conditions caused a slight (−2%) reduction in NH_3 emissions during manure management (storage + broadcast application), as opposed to an emission increase of as much as 17% for separation under summer conditions. Evidence from this study suggests that environmental benefits are possible if solid and liquid fractions are managed using state-of-the-art NH_3 mitigation options, such as covered manure storage and band spread slurry application.

1. Introduction

Pig farms in Italy produce approximately 17 million tonnes per year of liquid (slurry) manure (Colonna and Alfano, 2010) that is commonly recycled into crop production as fertilizer. Although a good source of plant nutrients, slurry requires careful management, including disposal, to reduce its potential negative impacts on environmental and human health. In areas of high livestock density, animal excreta may lead to stream and ground water eutrophication from increased nitrogen (N) and phosphorous (P) concentrations (EEA, 2005). Manure storage and land application can also emit significant ammonia (NH_3) and greenhouse gases (GHG), namely carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) (FAO, 2006).

The European Union Nitrate Directive (91/676/EC), in an effort to protect the environment, mandates that the animal manure nitrogen (N) spread rate in “nitrate vulnerable zones” not exceed 170 kg ha^{-1} y^{-1}, which implies that land is limited and transport distances are greater than is actually the case. Therefore, improved slurry handling through its separation into two fractions, one liquid and one rich in total solids (TSs) and nutrients, presents a reasonable solution to the costs and management transfer issues of untreated slurry (Petersen and Sørensen, 2008). Several separation techniques have been developed to reduce the nutrient content of slurry (Hjorth et al., 2010). Traditionally, solid–liquid separation of pig slurry has been performed mechanically by sedimentation, filtration, centrifuge, or drainage. However, most of the nutrients (such as N and P) found in pig slurry are suspended in small (<0.5 mm) particles (Zhang and Westerman, 1997) and mechanical separation cannot remove them easily (Hill and Tollner, 1980). Slurry separation can be made more efficient by combining chemical (e.g., additives such as bentonite or polyacrylamide – PAM) with mechanical techniques (Sievers et al., 1994; Hjorth et al., 2010). Pereira et al. (2005) reported an approximate reduction of 50% in total solid (TS) content when raw slurry was separated by screw press; a 70% reduction was observed when PAM flocculant polymers were added/combined to the mechanical treatment. The addition of PAM polymers to raw pig slurry increased the separation efficiency of TS, total N (TN), and P as much as 92%, 47%, and 91%, respectively (Martinez-Almela and Barrera, 2005; Balsari et al., 2008a).

Combined treatment technologies like this have been met by Italian farmer approval and are rapidly spreading throughout the country. The effect of slurry separation on NH_3 and GHG emissions from the separated fractions compared to the raw slurry is controversial. Studies conducted by Amon et al. (2006), Dinuccio et al. (2008), and Fangueiro et al. (2008) found high NH_3, CO_2, and NO_2 emissions during solid fraction raw slurry storage. Moreover, Nyord et al. (2008) and Dinuccio et al. (2011) claimed that high nitrogen losses (as NH_3) might occur from the liquid fraction of

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separated slurry, especially during land application. Balsari et al. (2008b), however, found NH_3 emissions fell as much as 26% after field application of cattle slurry fractions. A year later, Balsari et al. (2009) observed that compared to raw pig slurry, cropland application of liquid and solid fractions reduced NH_3 emissions up to 48%. Little information is available on GHG and NH_3 emissions generated during handling (i.e., storage + land application) of the solid and liquid fractions obtained by chemical–mechanical separation of raw slurry.

This study evaluated the effect of a chemical–mechanical separator (SELCO Ecopurin®) on NH_3 emissions from pig slurry under the most common Italian manure management practices—uncovered solid and liquid manure storage and surface application by broadcast. Ammonia emissions were determined from the raw slurry and its liquid and solid fractions during storage and surface application by broadcast to alfalfa (*Medicago sativa* L.) meadow during winter and summer conditions.

2. Materials and methods

2.1. Slurry treatment

The SELCO Ecopurin® (SELCO MC, Advanced Engineering Services, Castellòn, Spain) system was used to separate raw pig slurry into a liquid and a solid fraction. The separator module (Fig. 1) had several components: a polyacrilamide (PAM) addition for the raw slurry, a rotating screen, a filter press, and an air flotation unit to further separate residual solids. According to the manufacturer's specifications, the dry PAM was activated in a dose of water of $5\,kg\,m^{-3}$, and then mixed with the slurry for 20–30 min until 12 g PAM per 1.5 kg of total suspended solids (TSSs) were measured in the slurry. The flocculant polymer aggregates the small (<0.5–1 mm) particles suspended in the effluent to increase separation efficiency to >90% (Martinez-Almela and Barrera, 2005) and the materials available for the solid-handling processes. The resultant mix was mechanically conveyed through the rotary screen with 0.2 mm openings and then through the filter press to further de-water the separated solid fraction. Separated solids then exited the machine. There after, filter-pressed waste-water was added to the liquid fraction separately through the rotating screen. The total input of raw slurry (Q), as well as the amounts of recovered solid and liquid fractions (U_f), were weighed and recorded.

2.2. Storage trials

The trials were carried out in summer and in winter seasons at a pig-fattening farm in Cuneo, Piemonte (Italy). Two identical 1600 m^3 uncovered cylindrical tanks (diameter 20 m, wall height 5 m) stored the raw pig slurry and the separated liquid fraction. The separated solid fraction was stored uncovered in a static heap on a ferro-concrete platform. Emitted ammonia was measured for 30 days from approximately 900 m^3 of raw slurry and from approximately 900 m^3 of separated liquid fraction while the solid fraction was shaped into a 6.6 m^3 (4 Mg) truncated cone heap (W × L × H: 3.7 m × 4.2 m × 1.1 m). The available surface area to monitor for NH_3 emissions were 314 m^2 for the liquid slurries and 21 m^2 for the solid fraction. Ammonia emission measurements were carried out three times each week by a set of three wind tunnels (WT) (Schmidt and Bicudo, 2002; Balsari et al., 2007) per manure type. Each WT (1.80 m total length) consisted of a mixing chamber, the tunnel body (0.80 m length; cross-sectional area: 0.40 m width × 0.25 m height = 0.10 m^2), an expansion chamber, and a sampling point. The WTs were evenly distributed over the manure surface to obtain representative NH_3 emission values as gaseous emissions from the surface layer of stored manure may vary spatially, especially in the case of solid manure. Indeed, NH_3 emissions at the top of the heap are expected to be higher than those at the sides of the heap, due to the airflow from the temperature gradient generated during organic compound biodegradation (Petersen et al., 1998).

During storage of the raw slurry and liquid fraction, the WTs were equipped with two floating pontoons to buoy the devices on the slurry surface. Each sampling lasted 24 h. During measurement a fan was linked to the tunnel through a flexible pipe to produce an air flow of about $0.6\,m\,s^{-1}$ over the emitting surface. The ingoing and outgoing air streams were sampled simultaneously at a rate of $4\,L\,min^{-1}$ using a suction pump, flow metres, volumetric air metres, Teflon pipes, and absorption flasks containing 80 mL of 1% (v/v) sulfuric acid (H_2SO_4) solution. The amount of NH_3 (C_f, g) trapped in the absorption flasks during each sampling interval was determined by an ammonium selective electrode (Inolab 2, Wissenschaftlich-Technische Werkstätten GmbH, Weilheim, Germany), and followed the method described by ISO TC 147/6778 (ISO, 1984).

The slurry surface temperature was continuously measured at 10-min intervals by temperature probes dipped into the first 10 cm of the stored slurry. Probes were connected to a logging system (HOBO® U12 Thermocouple Data Logger). The surface, middle, and bottom temperatures of the solid fraction heap were also automatically measured and recorded by HOBO® U12 Thermocouple Data Loggers at 10-min intervals. At the beginning and at the end of each trial, samples of each manure type were collected for TS, TN, total ammonium nitrogen (TAN), and pH analysis. Total solids were determined by drying 100 g of fresh material in a oven at 105 °C to a constant weight; TN and TAN were analysed by the Kjeldahl standard method (AOAC, 1990), and pH was determined by pH-metre HI 9026 (Hanna Instruments, Italy).

2.3. Application trials

After storage, samples of the tested manures were manually broadcasted (summer, just after second cut; late winter, before spring regrowth) to 3-year-old alfalfa (*Medicago sativa* L.) plots at a rate of $70\,kg\,N\,ha^{-1}$. The soil was loamy sand (3.1% clay, 10.6% silt and 86.3% sand) with 0.9% organic carbon, 0.11% TN, and pH 8.2. The experiment was set up as a randomised block design with three replicates. Immediately after manure application, the WTs were placed over the plots and measurement began. Each trial lasted for 96 h, with acid traps collected and replaced at 3, 6, 24, 48, 72, and 96 h after manure application. Air temperature was measured and recorded by HOBO® U12 Thermocouple Data Loggers at 10-min intervals.

2.4. Calculations

2.4.1. Separation efficiency of chemical–mechanical separator

The separation efficiency (E_f) of a specific compound (x; e.g., TS, TN, TAN) was calculated as follow:

$$E_f = \frac{Mx_{solid}}{Mx_{slurry}} \times 100 \tag{1}$$

where Mx_{slurry} and Mx_{solid} are the total amount (kg) of the compound under consideration, respectively, in the slurry treated by the chemical–mechanical separator and in the solid fraction produced.

2.4.2. Ammonia emission

The concentration of NH_3 in the air entering and exiting the WT (C, $g\,L^{-1}$) was calculated according to:

$$C = \frac{C_f}{V} \tag{2}$$

where V is the volume (L) of air sampled.