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Ammonia losses from storage and land application of raw and chemical-mechanical separated slurry.

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Abstract

The effect of pig slurry chemical-mechanical separation on ammonia (NH_3) emissions was investigated with a field scale study. Ammonia volatilization during storage and after broadcast application to alfalfa (*Medicago sativa* L.) meadow of raw pig slurry and its liquid and solid separated fractions were determined in summer and winter conditions. The solid fraction was the main source of NH_3 losses during both storage and land application. Chemical-mechanical separation of raw pig slurry slightly (-2%) reduced NH_3 emissions during manure management (storage + broadcast application) in winter conditions. On the contrary, in summer conditions NH_3 emissions from storage and broadcast application of separated fractions (liquid + solid) resulted up to 17% higher compared to those obtained from raw pig slurry. Evidence from the present study suggests that environmental benefits can be achieved if the solid and liquid fractions are properly managed considering state of the art NH_3 mitigation options, such as coverage of manure stores and slurry application by band spreading.

Keywords:

ammonia volatilization, slurry separation, polyacrilamide, storage, land application.

1. Introduction

In Italy, pig farms produce approximately 17 million tons per year of liquid (slurry) manure (Colonna and Alfano, 2010), that are commonly recycled as fertilizer in crop production. Although they are a source of plant nutrients, they have to be managed and disposed with care due to their potential negative impacts on the environment and human health. In areas with a high livestock density, animal excreta might lead to eutrophication of streams and ground water resources due to increased nitrogen (N) and phosphorous (P) concentration (EEA, 2005). Storage and land application of manure also significantly contribute to increased emissions of ammonia (NH_3) and greenhouse gases (GHG), namely carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) (FAO, 2006).

To protect the environment, the European Union Nitrate Directive (91/676/EC) requires that animal manure nitrogen (N) spreading rate in ''nitrate vulnerable zones'' must not exceed 170 kg $ha^{-1}y^{-1}$. This implies that more land is needed and that the transport distance is farther. Therefore, improving the slurry handling by separation of the animal slurry into two fractions, one liquid and one rich in total solids (TS) and nutrients, seems to be a reasonable solution to reduce the cost and the management issue of untreated slurry transfer (Petersen and Sørensen, 2008). Several techniques have been developed to reduce the nutrient content of slurry by means of separation (Hjorth et al., 2010). Traditionally, solid-liquid separation of pig slurry has been performed using mechanical systems (e.g., sedimentation, filtration, centrifuge, drainage). However, most of the nutrient elements (such as N and P) found in pig slurry, are contained in small (<0.5 mm) suspended particles (Zhang and Westerman, 1997), which are not easily removed by mechanical separation (Hill and Tollner, 1980). The

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efficiency of the slurry separation can be improved by using combined chemical (e.g., additives such as bentonite or polyacrylamide - PAM) and mechanical techniques (Sievers et al., 1994; Hjorth et al., 2010). Pereira et al. (2005) reported a reduction of about 50% in total solids (TS) content when raw slurry was separated by screw press, whereas a 70% reduction was observed by combining mechanical treatment with PAM flocculant polymers addition. The addition of PAM polymers to raw pig slurry was found to increase the separation efficiency of TS, total N (TN) and P up to 92%, 47% and 91% respectively (Martinez-Almela and Barrera, 2005; Balsari et al., 2008a). This combination of treatment technology is nowadays meeting Italian farmers' approval and is rapidly spreading through 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 emission of NH_3, CO_2 and NO_2 during the storage of the separated raw slurry solid fraction. Moreover, Nyord et al. (2008) and Dinuccio et al. (2011) claimed that high losses of nitrogen as NH_3 might take place from the liquid fraction of separated slurry, especially during the land application. However, Balsari et al. (2008b) observed up to 26% reduction in NH_3 emissions after field application of the separated cattle slurry fractions, whereas Balsari et al. (2009) found that compared to raw pig slurry, application to cropland of the 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 was carried out to evaluate the effect of a chemical-mechanical separator (SELCO Ecopurin®) on NH_3 emissions from pig slurry under the most common italian manure management practices (e.g., uncovered solid and liquid manure storage; surface application by broadcast). Ammonia emissions were determined from the raw slurry and its

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liquid and solid fractions during storage and surface application by broadcast to alfalfa (*Medicago sativa* L.) meadow in 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) consisted of polyacrilamide (PAM) addition to raw slurry, a rotating screen, a filter press and an air flotation unit to further separate the residual solids. According to manufacturer's specifications, the dry PAM was activated with water in a dose of 5 kg m^{-3}, and mixed afterwards with the slurry for 20-30 minutes at a rate of 12 g PAM per 1.5 kg of total suspended solids (TSS) into the slurry. The flocculant polymer allows the aggregation of small (<0.5-1 mm) suspended particles contained in the effluent, increasing the separation efficiency to >90% (Martinez-Almela and Barrera, 2005) and the amount of materials available for the solids handling processes. Then, the obtained mix was mechanically conveyed to the rotary screen with 0.2 mm openings and then to the filter press to further dewater the separated solid fraction. Separated solids then exited the machine. Filter-pressed waste water was added to the liquid fraction separated 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 20m, walls height 5m) stored the raw pig slurry and the separated liquid fraction. The separated solid

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fraction was stored uncovered, in a static heap on a ferroconcrete platform. Ammonia emissions were measured for a period of 30 days from about 900 m^3 of raw slurry and from about 900 m^3 of separated liquid fraction, while the solid fraction was shaped on a 6.6 m^3 (4 Mg) truncated cone heap (W x L x H: 3.7 m x 4.2 m x 1.1 m). The available surfaces to monitor the 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 a week by a set of three wind tunnels (WT) (Schmidt and Bicudo, 2002; Balsari et al., 2007) per each 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 x 0.25 m height = 0.10 m^2), an expansion chamber and a sampling point. The WT were homogeneously distributed over the manure surface to obtain representative value of NH_3 emission. It is well know that gaseous emissions from the surface layer of stored manure may be very variable spatially, especially when considering solid manure. Indeed, NH_3 emissions at the top of the heap is expected to be higher than at the sides of the heap, due to an upward airflow generated by the high temperatures that generally occur during biodegradation of organic compounds (Petersen et al., 1998). During the storage of the raw slurry and of the liquid fraction the WT were equipped with two floating pontoons to buoy the device on the slurry surface. Each sampling lasted 24 hours. During measurement, a fan, linked to the tunnel through a flexible pipe, produced 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 meters, volumetric air meters, Teflon pipes and absorption flasks containing 80 mL of 1% (v/v) sulphuric 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, D-82362 211 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 to be analysed for TS, TN, total ammonium nitrogen (TAN), and pH. Total solids were determined by drying 100 g of fresh material in a heater at 105 ºC to constant weight; TN and TAN were analyzed by the Kjeldahl standard method (AOAC, 1990); pH was determined by pH-meter HI 9026 (Hanna Instruments, Italia).

2.3 Application trials

After storage, samples of the tested manures were manually broadcast-applied (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 a 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 WT were placed over the plots and measurements began. Each trial lasted for 96 h, with acid traps collected and replaced 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:

$$E_f = \frac{Mx_{solid}}{Mx_{slurry}} \, 100 \qquad (1)$$

where Mx_{slurry} and Mx_{solid} are the total amount (kg) of the compound in 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 leaving the WT (C, g L^{-1}) was calculated according to:

$$C = \frac{C_f}{V} \qquad (2)$$

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

Net flux rate (F, g NH_3 m^{-2} h^{-1}) at any sampling interval was then calculated as follows:

$$F = A \frac{(C_{out} - C_{in})}{S\Delta_t} \qquad (3)$$

where, A is the total air flow through the WT (L), C_{in} and C_{out} are the NH_3 concentrations of the air entering and leaving the WT calculated according to equation (2), S the area of the emitting surface covered by the WT (0.32 m^2), and Δ_t the duration of measurement (h).

Cumulative emissions from each manure (raw pig slurry, liquid fraction, solid fraction) over the storage period were estimated, by averaging net flux rates between two sampling points and multiplying by the time interval between sampling points.

To assess the effect of chemical-mechanical separation on NH_3 emissions, cumulative NH_3 losses recorded over the trials (storage, application) from each slurry fraction (liquid, solid) were corrected using the following formula:

$$T_n = T_{Ln} \times U_f/Q \qquad (4)$$

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where, T_n is the corrected cumulative NH_3 losses from fraction n expressed as g NH_3-N per Mg of treated raw pig slurry, T_{Ln} the cumulative NH_3 losses recorded over the trials (storage, application) from fraction n expressed as g NH_3-N per Mg of fresh manure (fm), U_f/Q the relative amount (%) of fraction n obtained after chemical-mechanical separation of the raw slurry.

2.5 Statistical Analysis

Analysis of variance (ANOVA) was performed for NH_3 emission data at each measurement point in the study. Data distribution normality was verified using the Kolmogorov–Smirnov test. Assumption of equal variance of different groups was tested using Bartlett's test. Before analysis some data were logarithmically transformed (natural logarithm) in order to fit a normal distribution. When significant, means were separated using a Sidak post-hoc test. Treatment differences were accepted as significant if $P<0.05$. Cumulative N losses as NH_3 emissions were analyzed by a two-way ANOVA using manure type (i.e., raw pig slurry, liquid fraction, solid fraction) and season (i.e., winter, summer) as fixed factors. All statistical analyses were performed with SPSS 12.0 for Windows (SPSS, 2006).

3. Results and discussion

3.1 Storage trials

Table 1 shows the chemical characteristics of the tested manures and the relative amount (U_f/Q) of each fraction obtained after chemical-mechanical separation of the raw slurry. The amount of produced solid fraction was dependent on the TS content of input slurry: compared to raw slurry at 3.93% TS, slurry at 5.18% TS produced more than twice the amount of solid fraction per mass unit of treated raw slurry. However, as water was added along with the PAM, the volume of the separated liquid was similar to that of the input raw

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slurry in both trials. On average, the concentration of TS and TN in the liquid fraction was, respectively, 63.7% and 39.6% lower than the concentration in the raw slurry. In contrast, the proportion of the TN present as ammonium nitrogen (TAN/TN) was up to 30% higher in liquid fraction than in raw slurry. The separation efficiencies, calculated according to Equ. 1, averaged 66.2%, 38.2% and 16.6% for TS, TN and TAN respectively.

During storage, the slurry surface temperature followed the ambient air temperature (Fig. 2). The recorded average air temperature was 6.08°C (range 3.81-7.40°C) and 18.7°C (range 13.0-23.5°C) in winter and summer conditions, respectively. Independent of trial conditions, the temperature of the solid fraction rose rapidly (Fig. 3) during the first days after the heap set up, followed by a dramatical decrease in the case of the winter conditions. The highest temperature (70.0 °C) was observed in winter conditions in the middle of the heap 3 days after its set up. During the summer trial the highest temperature reached by the middle of the heap was 45.7 °C, suggesting that the optimal oxygen concentration for aerobic micro-organisms activity was not achieved inside the solid fraction pile (Hong et al., 1997; Bernal et al., 2009). Ammonia flux rates from the raw slurries and from the liquid fraction (Fig. 4), followed a similar trend mainly influenced by the ambient air temperature. Ammonia volatilization from the solid fraction followed, instead, the temperature developed inside the heap itself (Fig. 3). This finding of positive relationship between NH_3 emission and temperature is consistent with the results of previous studies (e.g., Dewes, 1999; Chadwick, 2005; Hansen et al., 2006; Pagans et al., 2006; Balsari et al., 2007; Dinuccio et al., 2008). Specifically, the pattern of the NH_3 emissions from the solid fraction was characterised at the beginning (days 3-5) by a peak and later, by a progressive and regular decrease, which dropped to low levels after 30 days of storage. Peak flux rates observed from the separated solid fraction were 0.14 and 0.36 g NH_3 m^{-2} h^{-1} in summer and winter conditions, respectively. On average, NH_3 flux rates from the raw slurry and from the liquid fraction

stores were, respectively, 0.15 (range 0.10-0.20) and 0.14 (range 0.09-0.18) g NH_3 m^{-2} d^{-1} in winter, and respectively 0.60 (range 0.39-0.83) and 0.46 (range 0.35-0.56) g NH_3 m^{-2} d^{-1} in summer conditions. Cumulative NH_3-N, recorded from the solid fraction during winter and summer conditions were not different statistically ($P > 0.05$). During winter, the separated solid fraction produced the highest NH_3-N losses as a fraction of the initial mass of TAN, because exothermic oxidative processes were more active. The fast increase of the temperature inside the heap a few hours after the set up (Fig. 3) encouraged both a higher activity of micro-organisms which produce ammonium (NH_4^+) by hydrolysis of urea in urine, or by mineralisation of organic compounds in faeces, and higher water evaporation that consequently led NH_3 losses to increase (Møller et al., 2000; Petersen and Sørensen, 2008). Furthermore, Bernal et al. (2009) reported that temperature higher than 40 °C inhibits the activity of nitrifying bacteria, increasing the potential for NH_3 volatilization. The observed cumulative N losses as NH_3 (NH_3-N, Table 2) from the solid fraction are comparable with the overall losses of 3.5–3.7% of the initial TN content recorded by Gioelli et al. (2006) during storage of uncovered static heaps of solid fraction produced by mechanical separation of raw pig slurry. However, a greater proportion of TAN was found to be lost as NH_3 emission when composting of the stored cattle slurry solid fraction was enhanced by repeated turning (Amon et al., 2006). While not significant ($P > 0.05$), cumulative emissions recorded from liquid fraction, expressed as g NH_3-N Mg^{-1} of fresh manure (fm), resulted from 5.79% (winter trial) to 21.9% (summer trial) lower than those recorded from raw slurry (Table 2). In contrast, cumulative NH_3-N losses over the storage period, expressed as a fraction of initial TAN content, were up to 19.5% higher from liquid fraction than from raw slurry. This may be explained by the lower TS content of the liquid fraction (Table 1), which did not allow the development of a consistent crust layer on the slurry surface (Amon et al., 2006; Dinuccio et al., 2008; Fangueiro et al., 2008). The TS

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content was found to influence the formation of natural surface crust (Misselbrook et al., 2005a; Smith et al., 2007) which could limit the ammonia diffusion from the slurry to the atmosphere. During our storage trials, a consistent crust layer (up to about 1.0 – 1.5 cm) was observed to develop only on the raw slurry surface. Therefore, higher TAN losses as NH_3 emission from liquid fraction compared to raw slurry were expected. It is important to minimize such losses, as NH_3 has negative environmental impacts. In addition, reducing NH_3 losses from slurries and solid manures means more N is potentially available for grass and crop uptake. Ammonia emission from slurry storage tanks can be reduced up to >90% by covering the slurry surface with a floating cover (VanderZaag, 2008). The latter can be a layer of natural material (e.g., mineral based granules, wood chips, chopped straw), synthetic origin (e.g., geotextile, impermeable plastic), or combination of both (e.g., Hörnig et al., 1999; Bicudo et al., 2004; Balsari et al., 2006; Berg et al., 2006). Rodhe et al. (2010) suggested that covering the slurry surface with a synthetic material is a low-cost and effective options to reduce NH_3 emissions, without increasing emissions of CH_4 and N_2O. Chadwick (2005) also reported that compaction and covering of solid manure heaps with plastic sheet has the potential to reduce NH_3 emissions by 80–90%, while not increasing, or even reducing, those of N_2O and CH_4.

3.2 Application trials

The properties of the manures at the beginning of the application trials are listed in Table 1. The recorded average air temperature was 5.80°C (range 4.20-7.30°C) and 27.6°C (range 26.9-31.8°C) in late winter and summer conditions, respectively. In all cases, NH_3 emissions were higher in the first 3 hours after application, and quickly decreased to negligible values after 96 h (Fig. 5). Peak flux rates ranged between 0.04 and 0.11 g $NH_3\,m^{-2}\,h^{-1}$ in late winter and between 0.14 and 0.40 g$NH_3\,m^{-2}\,h^{-1}$ in summer. In both investigated conditions, the

highest NH_3 emissions flux in the first sampling step (3 h after application) were obtained after the application of the separated solid fraction, followed by the liquid fraction and the raw slurry. Differences in NH_3 emission flux rates, however, decreased after 6 h. Cumulative NH_3 losses recorded over the measurement period (96 h) were affected ($P<0.05$) by manure type and season (Table 2). Specifically, emissions from the broadcast applied manures were significantly ($P<0.05$) higher in summer than late winter conditions, confirming that NH_3 emissions and temperature are positively correlated (e.g., Moal et al., 1995; Balsari et al., 2008b). The solid fraction produced the largest NH_3-N losses both in late winter and summer conditions (Table 2), probably due to conservation of TAN during storage (Table 1) which increased the potential for NH_3 emissions after application to soil (Sommer et al., 2003). The study of Amon et al. (2006) reported lower NH_3 emission after spreading of the cattle slurry solid fraction. This was due to the high emissions caused by repeated turning during 80 day of storage which reduced to negligible value the TAN content of manure before spreading. The cumulative NH_3-N losses observed from the solid fraction (76.5% of TAN applied to soil, on average – Table 2) are in the same range to those reported from other types of broadcast-applied solid manure, which, depending on manure type and characteristics, and climatic conditions, have been determined to account for 30-104% of the initial TAN content (Chambers et al., 1997; Menzi et al., 1997; Hansen, 2004; Webb et al., 2004; Balsari et al., 2008b, Balsari et al., 2009). Averaged across the trials, the proportion of TAN lost as NH_3-N was 19.7% and 16.3% for the raw slurry and the liquid fraction, respectively. These values are in good agreement with those reported by Misselbrook et al. (2005b) for field application of pig slurry with low TS content. Our study also confirms the tendency of the separated liquid fraction to emit lower proportions of applied TAN as NH_3-N than raw slurry following land application, previously observed by other authors (e.g., Søgaard et al., 2002; Sommer et al., 2003; Misselbrook et al., 2005b; Balsari et al., 2008b; Balsari et al., 2009; Chantigny et

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al., 2009; Monaco et al., 2011). This was attributed to the low TS content in the liquid fraction, which permitted a more rapid infiltration of the TAN into the soil (Sommer and Hutchings, 2001). However, analysis of variance revealed that cumulative TAN losses (Table 2) obtained from raw slurry and from its separated liquid fraction were not significantly (P>0.05) different, suggesting a similar infiltration rate of the two types of slurry. In a study using cattle slurry, Sommer and Olesen (1991) reported that the influence of TS content on NH_3 emissions following broadcast application occurred in a range between 4% and 12%. However, when manure was surface applied in bands to permanent grassland, Amon et al. (2006) observed up to 60% lower NH_3 emissions from liquid fraction than raw cattle slurry. Probably, TS reduction of slurry by separation will show significant positive effect on NH_3 losses when slurry is applied by reduced-NH_3 emission application techniques, less so when slurry is broadcasted. It is well know that manure left on the surface rapidly volatilizes NH_3 (Fig. 5). On grassland, NH_3 emissions can be reduced up >90% by direct injection of slurry into soil (Rotz, 2004; Webb et al., 2010). Band spreading of slurry (e.g., by trailing shoe or trailing hose) places the manure in a series of narrow bands on the soil surface at spacings of 20 to 50 cm. This reduces the surface area of the manure and minimizes exposure to wind turbulence, resulting in NH_3 emission reductions between 29 and 83% compared to traditional surface broadcast application (Thompson et al., 1990; Smith et al., 2000; Pfluke et al., 2011). However, when reduced-NH_3 emission manure application techniques are used, the possible trade off with direct N_2O emissions needs to be addressed (Webb et al., 2010). VanderZaag et al. (2011) concluded from their review that under conditions that did not enhance N_2O emissions (e.g., well drained soil) there is no trade-off between NH_3 and N_2O production. Wulf et al. (2002a) and Wulf et al. (2002b) suggested band spreading as the best application method on grasslands, as both NH_3 and N_2O emissions can be minimized.

3.3 Effect of chemical-mechanical separation on NH_3 emissions

In Fig. 6 cumulative NH_3 losses recorded from liquid and solid fractions are compared to those obtained from raw pig slurry. These values, calculated on the basis of mass separation efficiency (U_f/Q, Table 1), allow comparison of emissions from the two fractions (liquid and solid) with those from raw slurry. Cumulative losses are disaggregated into emissions from storage and soil application of the manures. During storage, chemical-mechanical separation of raw pig slurry increased NH_3 emissions by 39% and 24% in winter and summer conditions, respectively. Ammonia emissions from application to alfalfa meadow were reduced (-14%) by chemical-mechanical separation in winter conditions only. Considering emissions as a whole (storage + application), chemical-mechanical separation of raw pig slurry slightly (approx. -2%) reduced NH_3 emissions during manure management in winter conditions. On the contrary, in summer conditions NH_3 emissions from storage and broadcast application of separated fractions (liquid + solid) resulted up to 17% higher compared to those obtained from raw pig slurry. This was due to the considerable amounts of NH_3 lost from the liquid fraction and to the addition of solid fraction as a sources of further NH_3 emission. Dinuccio et al. (2011) concluded that traditional management (uncovered storage + broadcast application) of mechanically separated fractions (solid + liquid) has the potential to increase up to 44% NH_3 emissions compared to raw cattle slurry. According to Amon et al. (2006) the overall negative environmental impacts from slurry separation are due to NH_3 emissions from composting of the solid fraction.

4 Conclusions

Results from this study confirmed the strong relationship between NH_3 emissions and temperature. The solid fraction was the main source of NH_3 losses during both storage and

land application. Chemical-mechanical separation of raw pig slurry in combination with non environmentally friendly manure management practices (e.g., uncovered stores, broadcasting) showed negative impact on NH_3 emissions to the atmosphere. Compared to raw pig slurry, storage and broadcast application to cropland of the liquid and solid fractions increased NH_3 emissions up to 17%. However, evidence from the present study suggests that environmental benefits can be achieved if the solid and liquid fractions are properly managed considering state of the art NH_3 mitigation options, such as coverage of manure stores and slurry application by band spreading.

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Figure Captions

Fig. 1. Schematic of the separator working principle

Fig. 2. Air and slurry surface temperature recorded during storage in winter and summer conditions

Fig. 3. Surface, middle and bottom temperatures of the solid fraction heap recorded during winter and summer trials

Fig. 4. Ammonia fluxes measured during the storage of the tested manures in winter and summer trials. Vertical bars represent standard deviation of the mean (n=3)

Fig. 5. Ammonia fluxes measured after application of the tested manures in late winter and in summer trials. Vertical bars represent standard deviation of the mean (n=3)

Fig. 6. Cumulative emissions recorded during storage and after soil application of the investigated manures, given in g NH_3-N per Mg of treated raw pig slurry.

Fig. 1

WINTER
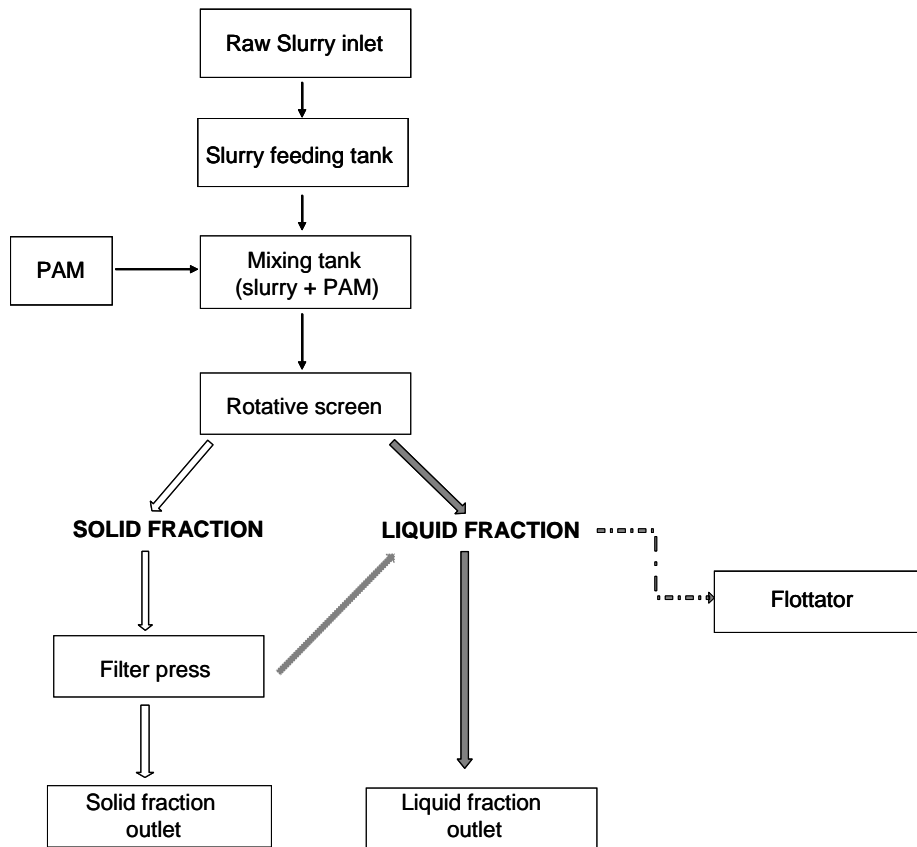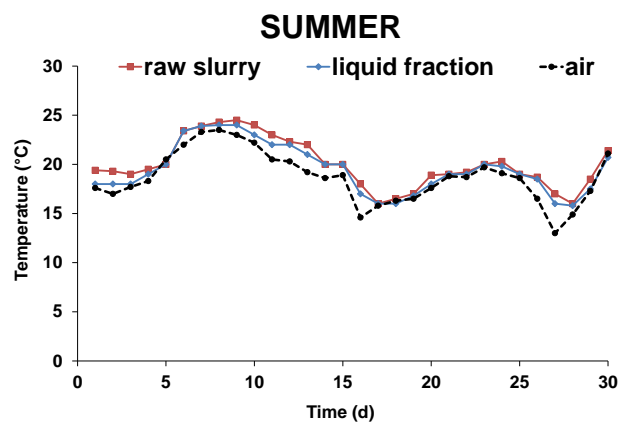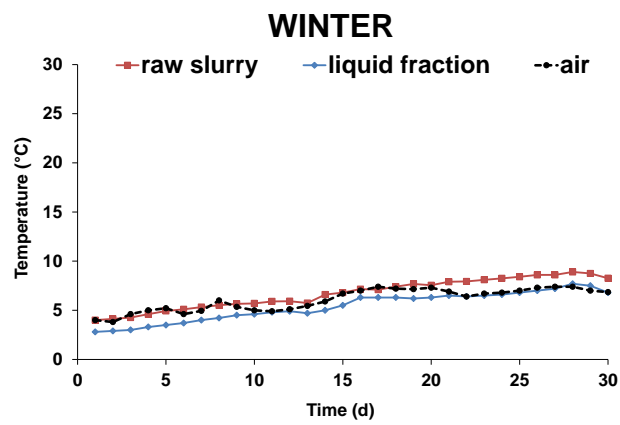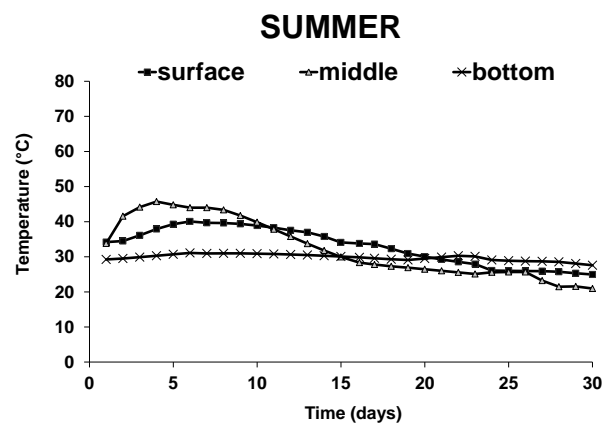
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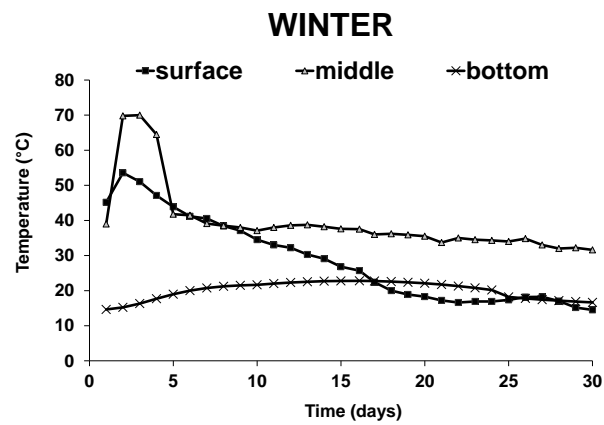
Fig. 2

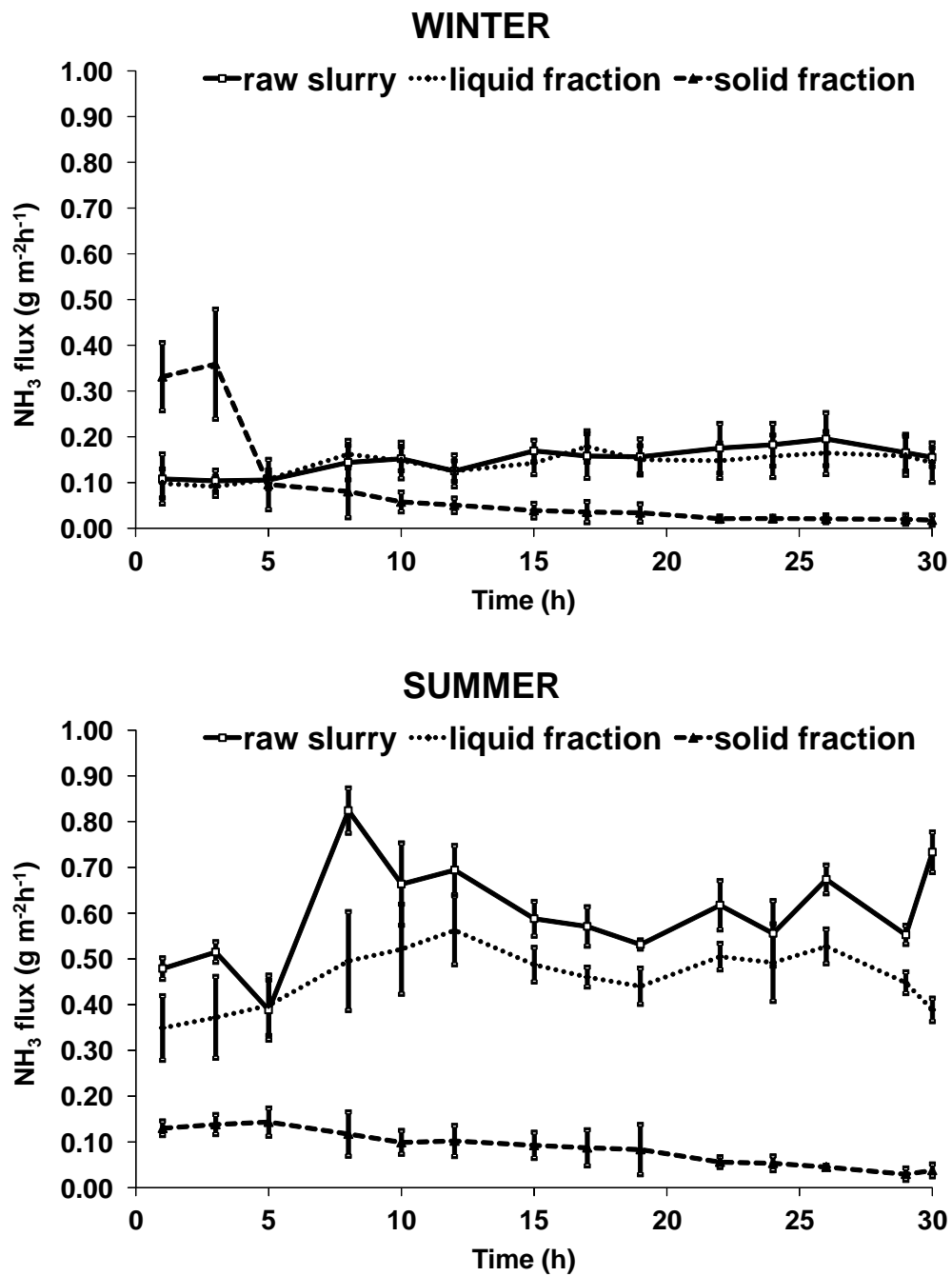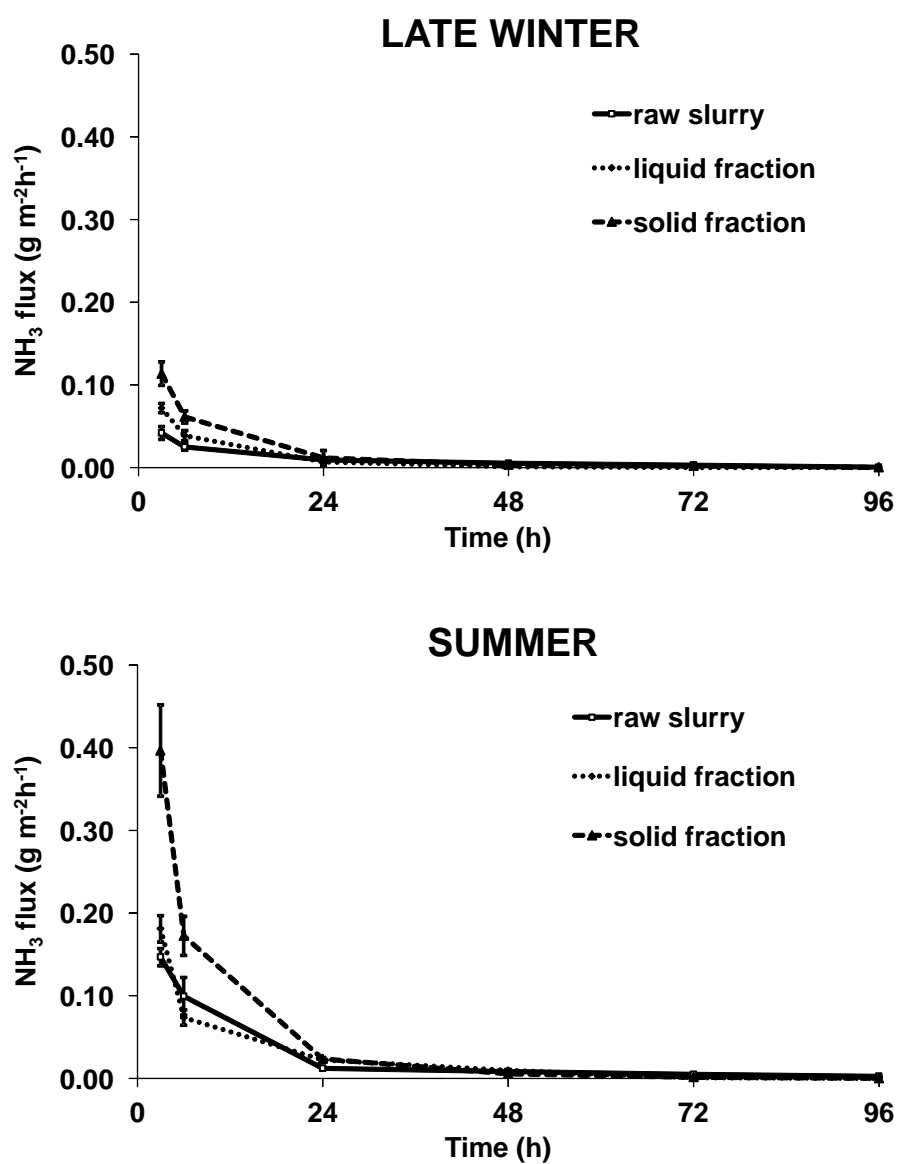WINTER

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Fig. 3

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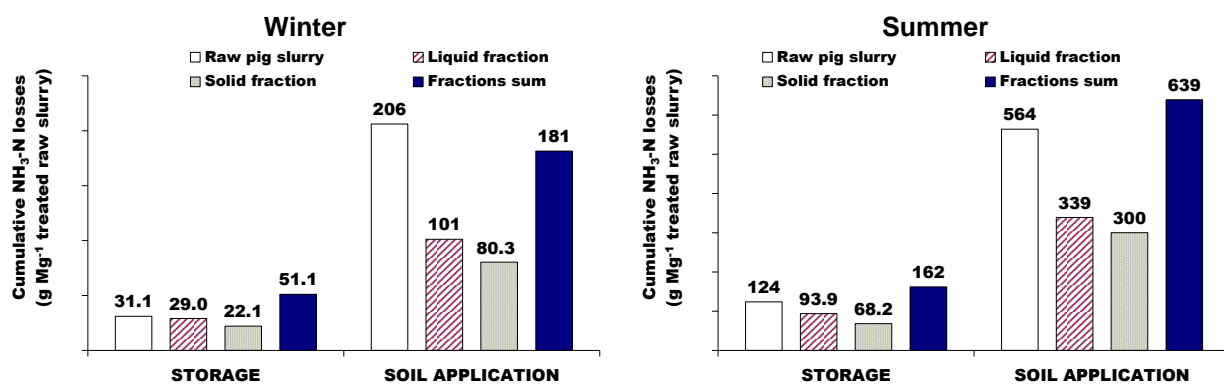
SUMMER

Fig. 4

Fig. 5

Fig. 6

Table captions

Table 1. Relative amount of solid and liquid fractions (U_f/Q) obtained after chemical mechanical separation of raw pig slurry and chemical characteristics of the tested manures at the beginning of each trial.

Table 2. Cumulative nitrogen losses as ammonia recorded from the tested manures during late winter (W) and summer (SA) trials.

	Manure	U_f/Q	pH	TS	TN	TAN	TAN/TN
		%		%fm*	%fm*	%fm*	
WINTER	Raw slurry						
	start	100	7.74	3.60	0.29	0.21	0.72
	end		7.94	3.03	0.30	0.23	0.77
	Liquid fraction						
	start	99	7.89	1.55	0.17	0.16	0.94
	end		8.05	1.09	0.18	0.15	0.83
	Solid fraction						
	start	11	8.06	18.1	0.97	0.20	0.21
	end		8.26	23.1	0.66	0.15	0.23
SUMMER	Raw slurry						
	start	100	7.54	5.18	0.37	0.29	0.78
	end		7.77	4.02	0.36	0.26	0.72
	Liquid fraction						
	start	97	7.88	1.65	0.23	0.20	0.87
	end		8.07	1.25	0.21	0.19	0.90
	Solid fraction						
	start	23	8.07	19.1	0.63	0.30	0.48
	end		8.30	22.9	0.53	0.19	0.36

* fm, fresh manure

Table 1

	Raw slurry		Liquid fraction		Solid fraction		SEM[†]
	W	SA	W	SA	W	SA	
STORAGE							
g NH_3-N Mg^{-1} fm*	31.1c	124b	29.3c	96.8b	244a	273a	32.1
NH_3-N/ TAN (%)	1.90c	5.49b	2.36c	6.22b	15.7a	11.7a	2.39
SOIL APPLICATION							
g NH_3-N Mg^{-1} fm*	204d	564b	102e	350c	670b	1430a	58.4
NH_3-N/ TAN (%)	11.4d	28.0c	8.79d	23.8c	56.7b	96.3a	3.83

* fm, fresh manure
[†] SEM, pooled standard error of mean.
a–d: data in a row followed by a different letter differ P<0.05.

Table 2