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Gaseous emissions from the storage of untreated slurries and the fractions obtained after mechanical separation

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Abstract

A laboratory scale study was set up to investigate the ammonia (NH_3), nitrous oxide (N_2O), carbon dioxide (CO_2) and methane (CH_4) emissions during storage of untreated pig and cattle slurry and the fractions (solid and liquid) obtained by mechanical separation. The solid and liquid fractions were obtained from the same untreated slurry by means of a lab scale mechanical separator.

The manures were stored for a period of 30 days in open vessels (1500 cm^3 capacity) in two temperature controlled rooms which were kept at 5±0.5 °C and 25±0.2 °C. Gaseous emissions were determined using a dynamic chamber method and Infrared Photoacoustic Detection (IPD).

Over the storage period, gaseous emissions from pig manures were significantly ($P<0.05$) higher than those from cattle manures. N_2O fluxes of up to 232 mg m^{-2} h^{-1} were measured but from pig solid fraction only. Between 40.8% (from pig liquid fraction stored at 25 °C) and 3.60% (from untreated cattle slurry stored at 25 °C) of the initial nitrogen content of the manures was lost as

NH_3. Over the 30-days storage period, the predominant emission of carbon was in the CO_2 form. Total C-CH_4 losses expressed as a percent of the carbon initially present in the volatile solids (C-VS) ranged from 0.60% to 12.8% for pig manures and from 0.23% to 1.56% for cattle manures. The mechanical separation of cattle slurry increased by up to 30% the emissions of CO_2 equivalents to the atmosphere during the storage of the separated fractions if compared with the slurries. Results indicated that NH_3, N_2O, CO_2 and CH_4 emissions were affected by the interaction between a number of variables, including storage temperature, chemical characteristics and type of manure. Results also indicated that mechanical separation does not reduce emissions but has the potential to increase the emissions of CO_2 equivalents to the atmosphere during the storage of the separated fractions.

Keywords: ammonia, greenhouse gas emissions, manure storage, slurry separation.

1. Introduction

Animal excreta can contribute to eutrophication of groundwater and surface waters as a result of nitrogen (N) and phosphorous (P) enrichment (EEA, 2005) and are considered an important source of ammonia (NH_3), nitrous oxide (N_2O), carbon dioxide (CO_2) and methane (CH_4) production (Van Der Hoek, 1998; Amon et al., 2001). While N_2O, CO_2, and CH_4 are greenhouse gases affecting the global environment and climate change, NH_3 contributes to eutrophication and acidification of soils and also indirectly contributes to N_2O emissions by increasing the N-cycling in natural ecosystems (Olesen, 2005). Modern intensive animal production methods have increased the volume of manure in the slurry form (Menzi et al., 2002). Several techniques have been developed to manage livestock slurries as cheaply and conveniently as possible and to reduce potential risks of environmental pollution. Among these techniques, solid-liquid separation is a technology that separates slurry into a larger liquid fraction and a minor solid fraction which has a greater concentration of nutrients than the liquid (Kroodsma, 1986; Møller et al., 2000). This could enable more cost-effective transfer of nutrients from areas of high livestock density where they may be in surplus to areas with a lower livestock density. Nevertheless, little data concerning NH_3, N_2O, CH_4 and CO_2 emissions during storage of both liquid and solid fractions are currently available.

In consequence a laboratory-scale trial was carried out to better characterize the main parameters affecting NH_3 and GHG emissions from the storage of untreated liquid manure and both the solid and liquid fractions derived from mechanical separation of slurry. The following aspects have been analyzed:

1) the NH_3, CO_2, CH_4 and N_2O emissions from the storage of:
    - A. cattle and pig untreated liquid manure
    - B. solid fractions obtained from both untreated liquid manure after solid-liquid separation
    - C. liquid fractions obtained from both untreated liquid manure after solid-liquid separation
2) the effects of temperature and chemical characteristics of the three products listed in point 1) on such emissions.

2. Materials and methods

The trials were carried out at Leibniz-Institute for Agricultural Engineering Potsdam-Bornim (ATB), Germany, in environmentally controlled conditions by means of two climatic rooms.

Fresh slurry was collected from commercial farms. The next day (cattle; pig two days after) it was separated and stored in vessels in the emission lab of the institute and measurements began.

The solid and liquid fractions (B and C) were obtained from the same pig and cattle untreated slurry (A) by means of a laboratory-scale mechanical separator. This latter was made up of (Fig. 1): a 1500 cm^3 bowl with handle; a stainless steel disc (screen) with circular holes 2.3 mm in diameter; a stainless steel blade integral with a crank; a container collecting the liquid fraction.

A press zone was created fitting the blade to the disc by means of a horizontal bar and a spring. After filling the bowl with the untreated slurry, the blade is manually rotated using the crank and the slurry separated in the press zone. The liquid fraction runs through the disc's holes into the container while the solid fraction remains in the bowl and is collected afterwards. The total input of each untreated slurry (100 kg), as well as the amounts of solid (18.1 kg for cattle and 7.80 kg for pig) and liquid (81.9 kg for cattle and 92.2 kg for pig) recovered, were weighed and recorded. The bulk density of the solid fractions (cattle and pig) was estimated to be 0.40 t m^{-3}.

Immediately after mechanical separation, samples of 1000 cm^3 of each of the investigated materials were stored for a period of 30 days in open vessels (1500 cm^3 capacity, 0.20 m height, 0.10 m base diameter and 0.095 m top diameter) in two temperature-controlled rooms which were kept at 5±0.5 and 25±0.2 °C. During the test period observations of crust formation and reduction of volume were carried out. Four replicates of each product were tested so that for each type of untreated liquid manure (pig or cattle) a total of 12 vessels were used per climate room.

The samples were analysed for pH, total solids (TS), volatile solids (VS), total Kjeldhal nitrogen (TKN), total ammoniacal nitrogen (TAN), and organic acids at the beginning and at the end of the investigation period. Initial and final slurry analyses are given in Table 1.

Flux measurements were carried out using infrared photoacoustic detection (IPD) and the dynamic chamber method described by Berg et al. (2006). This method allows the comparison of the effect of different treatments on gaseous emissions during manure storage, under standardized experimental conditions. Different conditions, such as volume to surface ratio of the manure stores, in the lab and on farms may yield different gas fluxes. Therefore, this fluxes cannot be used for calculating fluxes from on farm storage facilities without further validation. Accordingly, the slurries were stored in open vessels using the dynamic chamber method set up only during measurements. Before starting the measurements each vessel was closed with an air-tight lid provided with two ports for air inlet and outlet (Fig. 2). Air inlet port was connected in an airtight way with a flow meter and a compressor. The headspace (chamber) between the slurry surface and the lid was then ventilated with compressed air to create an airflow through the dynamic chamber. The air exchange inside the chambers was adjusted by the flow meters so that the air in the headspace was always changed once per minute. Measurements were carried out four times a week according to the following scheme:

1) lid closure at time t = 0 min;

2) between t=0 and t= 20 min the chamber was only ventilated to achieve steady conditions inside the chamber;

3) t= 20 min beginning of the exhaust air sampling;

4) t= 36 min end of the exhaust air sampling and vessel opening.

The gas concentrations in the inlet (atmospheric) and outlet (exhaust) air were analyzed by the INNOVA system 1312 Photoacoustic Multi-gas Monitor and Multipoint Sampler. The system provided a real time analysis of 4 gases (NH_3, N_2O, CH_4 and CO_2) plus water vapour. Measured data were related to standard conditions (25 °C and 100 kPa) and stored in a database. Exhaust air leaving each chamber was sampled for 16 min. The instrument needed 2 min to analyze one sample, thus, 8 values were recorded on each measurement occasion. The first 3 values were discarded and the mean of the remaining 5 recorded values was considered representative for the measurement. Gas fluxes F_j in mg m^{-2} h^{-1} were determined according to:

$$F_j = Q\frac{\left(C_{ex.j} - C_{in.j}\right)}{A} \tag{1}$$

where $C_{in.j}$ is the NH_3, N_2O, CH_4 or CO_2 concentration of air inlet the chamber in mg m^{-3}; $C_{ex.j}$ is the NH_3, N_2O, CH_4 or CO_2 concentration of air outlet the chamber in mg m^{-3}; Q is the air flow rate through the chamber in m^3 h^{-1}; A is the area of emitting surface covered by the chamber in m^2. Time evolution of the gas fluxes were approximated by spline approximation functions, and by integration of such approximations using adaptive Simpson quadrature formulas (Bronshtein et al.,

2003) cumulative losses φ_j in mg vessel^{-1} of each gas over the storage period (30 days) were estimated.

Since measurements were carried out with 1000 cm^3 of all substrates respectively, in order to assess the effect of mechanical separation on gaseous emissions, cumulative losses were corrected as follows:

$$\Phi_j = \varphi_j \ \rho \tag{2}$$

where Φ_j is the corrected cumulative loss of a specified gas in mg vessel^{-1}; ρ is a correction factor that takes into account the mass Sc (kg) of separated liquid and solid fractions obtained after separation of the untreated slurry Mc (kg), and the amount Me (kg) of untreated slurry, liquid and solid fractions used for emission trials:

$$\rho = \frac{Sc}{Mc}\frac{1}{Me} \qquad (3).$$

The ρ values used are summarized in Table 1.

During storage trials, volume and surface area in contact with the air were the same for all tested materials. Nevertheless, in practical conditions slurries are stored within tanks and solid fraction in heaps on platforms. The slurry NH_3 emitting area is the horizontal cross section of the storage tank, while for solid material it may be considered the surface area of a hypothetical frustum of cone representing the shape of the heap. Considering an angle of repose of $1^1/_2$: 1 (horizontal : vertical) (CNMP, 2002), the surface/volume ratio for the pig solid fraction was calculated to be 1.83 times as much as pig slurry and 2.44 times as much as cattle untreated slurry for the cattle solid fraction. Thus, to be able to assess the effect of mechanical separation on NH_3 emissions, measured NH_3 emissions from pig solid fraction and cattle solid fraction were therefore multiplied by 1.83 and by 2.44 respectively, assuming that the emissions per unit area were homogeneous. The emitting surface area of the liquid fraction was assumed to be that of the untreated slurry.

To consider the effect of slurry mechanical separation on GHG emissions as a whole, the lC_jl were converted into CO_2 equivalents by the Global Warming Potential (GWP) of the gases (NH_3: 3.1, N_2O: 310, CH_4: 21) (IPCC, 1997).

Significant differences in results and all possible interactions were investigated using the ANOVA procedure. Before analysis some of the parameters were log-transformed in order to fit a normal distribution. For all the statistics, a significant level of $P = 0.05$ was applied. Assumption of equal variance of different groups was tested using Bartlett's test. All statistical analyses were performed with SPSS 12.0 for Windows.

3. Results

3.1 Slurry properties

After mechanical separation the liquid fractions produced by mechanical separation showed significant reductions of TS and VS (Table 1). In contrast, the pH, TAN and TKN concentrations of the liquid fractions were very similar to those of the untreated slurries. As expected, the TS and VS content of the solid fractions were significantly greater than those for the untreated slurries. The TKN content of the pig solid fraction was almost double the TKN content of the pig untreated slurry, while the TKN content of the cattle solid fraction was approximately 1.4 times lower than the TKN content of the cattle untreated slurry.

Analysis of the manures at the end of each experiment are given in Table 2 together with volume reductions over the storage period.

Water evaporation occurred in all the samples throughout the storage period. As expected, evaporation was higher from materials stored at 25 °C than 5 °C and was responsible for volume reductions up to 45% of the stored slurries and of the relative increase of TS and VS amounts. Appreciable volume reduction (30.6%) occurred for cattle solid fraction stored at 25 °C, low reductions were observed for solid materials stored at 5 °C while no volume reduction occurred for pig solid fraction stored at 25 °C.

3.2 Gaseous emissions

3.2.1 N_2O emissions

Over the storage period (30 days), no N_2O fluxes were measured from any material stored at 5 °C. N_2O emissions from cattle and pig slurries stored at 25 °C occurred on a very few occasions only, e.g. when the crust dried up, but the overall amounts were negligible. Very low concentrations, sometimes slightly above the background concentration of N_2O, were also measured from the cattle solid fraction. Appreciable N_2O fluxes were measured only from the pig solid fraction stored at 25 °C (Fig. 3). N_2O emissions started 8 days after the beginning of the storage period and reached a peak of 232 mg m^{-2} h^{-1} at day 21. After that peak, the N_2O flux rapidly decreased to reach values close to zero at day 25. The total nitrogen loss via the N_2O pathway accounted for the 4.71% of the initial total Kjeldahl nitrogen (TKN) content of the solid manure (Table 3).

3.2.2 NH_3 emissions

Total losses of NH_3-N, expressed as a percentage of the initial TKN, (Table 3) ranged from 3.60% (from untreated cattle slurry stored at 25 °C) to 40.8% (from pig liquid fraction stored at 25 °C). Under the same storage conditions, there were no significant ($P>0.05$) differences between NH_3 fluxes from untreated pig slurry and from its liquid fraction (Fig. 4). In contrast, NH_3 fluxes from untreated cattle slurry were significantly less than from its liquid fraction. NH_3 emissions were higher at 25 °C than at 5 °C storage conditions, except when considering the pig solid fraction. From this, significantly ($P<0.05$) higher NH_3 fluxes at 25 °C than at 5 °C were measured only at the beginning of the storage period, while, after day 8 NH_3 fluxes were significantly lower at 25 °C than at 5 °C storage conditions.

3.2.3 CO_2 and CH_4 emissions

During pig and cattle manure storage, the predominant emission of carbon was as CO_2 (Fig. 5 and Table 3). Total losses of C-CO_2 expressed as a percentage of the carbon initially present in the volatile solids (C-VS) of the manures ranged from 7.76% (from cattle untreated slurry stored at 5 °C) to 33.4% (from pig liquid fraction stored at 25 °C). CO_2 losses were always higher at 25 °C and lower at 5 °C storage conditions.

Under the same storage conditions, CH_4 fluxes from the untreated slurries and from their liquid fractions were not different ($P>0.05$) (Fig. 6), but total C-CH_4 losses over the storage period, expressed as a fraction of initial C-VS content, were significantly ($P<0.05$) higher from liquid fractions than from untreated slurries (Table 3). Under all storage conditions, total C-CH_4 losses were higher from pig than from cattle slurries. C-CH_4 losses ranged from 0.60% to 12.8% for pig manures and from 0.23% to 2.19% of the initial C-VS content for cattle manures. C-CH_4 losses from pig manures were always consistently higher at 25 °C than those at 5 °C. However, the emissions of CH_4 were only observed to be significantly ($P<0.05$) higher from cattle slurries stored at 25 °C than at 5 °C during the first 3 days of storage. Thereafter, the emissions were lower from cattle slurries stored at 25 °C than at 5 °C. C-CH_4 losses from cattle and pig solid fractions were always significantly lower at 25 °C than at 5 °C storage.

3.2.4 Effect of slurry solid-liquid separation on gaseous emissions

Figure 7 shows the NH_3, CO_2 and CH_4 losses based on the corrected cumulative losses lC_jl and expressed as a percentage of the lC_jl calculated for the untreated slurries (pig and cattle). It can be seen that for pig slurry the combined emissions measured from the storage of the liquid and solid fractions resulted in reduced NH_3 losses compared to the storage of the untreated pig slurry. However for cattle slurry, the combined NH_3 losses measured from the storage of the liquid and solid fractions were 7% and 45% higher than those measured from the untreated cattle slurry stored at 25 C and 5 °C respectively.

The emissions from the storage of the two fractions increased the CO_2 emissions from 8% (when compared to untreated pig slurry stored at 5 °C) to 104% (when compared to untreated cattle slurry stored at 25 °C). During the storage of both liquid and solid fractions, CH_4 losses were 3% higher for pig untreated slurry stored at 25 °C and 4% higher for cattle untreated slurry stored at 5 °C. Instead, solid-liquid separation reduced CH_4 emissions by 8% for pig untreated slurry stored at 5 °C and by 9% for cattle untreated slurry stored at 25 °C.

Combining the emissions of CO_2 equivalents from both liquid and solid fractions (Fig. 8), they resulted in increased greenhouse gases emissions compared to the storage of the untreated slurries, except when considering the pig untreated slurry stored at 5 °C. In this latter case the mechanical separation had no effect in combined emissions of CO_2 equivalents.

4. Discussion

The small N_2O fluxes from cattle and pig slurries storage can be explained by the absence of crust during most of the storage period. N_2O may be emitted during storage of manure either as a by-product of incomplete ammonium oxidation or as a by-product of incomplete denitrification (Oenema et al., 2001). The condition in liquid manure is strictly anaerobic, and neither process occurs. In contrast, authors (e.g. Sommer et al., 2000; Berg et al., 2006) found N_2O production from stored slurries, but only when a dry crust formed on the surface. These emissions occurred since surface crust may contain a mosaic of anaerobic and aerobic micro–sites which are favourable for N_2O production. Dry conditions, together with air filled porosity, may explain the occurrence of N_2O production from pig solid fraction samples. On the other hand, separation of cattle slurry produced a fibrous solid fraction with a compacted structure, this might have created an environment with an oxygen concentration unsuitable for N_2O production.

Results confirm a positive relationship between ammonia emission and temperature found by other studies (e.g. Ni, 1999; Dewes, 1996), but not in the case of the pig solid fraction. Total losses from the pig solid fraction were 7.12 and 5.57% of the initial TKN content at 5 and at 25 °C storage conditions respectively. This may be explained by ammonium oxidation by nitrifying micro-organisms with N_2O production. NH_3 emission from manure decreased, therefore, as a greater proportion of the NH_4-N was oxidized by nitrifying micro-organisms.

CH_4 losses from pig slurries significantly increased with temperature (Table 3). This is confirmed by results of other studies (e.g. Husted, 1994), in which an increase of the CH_4 production with air storage temperature was also found. The lowest CH_4 emissions from cattle slurries stored at 25 °C with respect to those obtained at 5 °C were probably caused by the high water losses from the slurries over time. As a consequence, a relative increase in concentration of constituents, such as NH_3 and organic acids, which could be inhibitory to the methanogens (Kalle and Menon, 1984; Angelidaki et al., 1999), occurred. This was proved by the CH_4 fluxes from both untreated cattle slurry and liquid fraction stored at 25 °C which were observed to be high at the beginning of the storage and to gradually decrease over time (Fig. 6). Additionally, Table 2 shows for cattle slurries a relative increase in concentration of organic acids, which can be inhibitory to the methanogens, at the end of the storage compared to the beginning of the storage (Table 1). The combined effect of temperature and slurry concentration had no effect on CH_4 losses from pig slurries, probably due to a more active methanogens population. According to Massé et al. (2003), manure from different animals probably contains different species of anaerobic bacteria, which may be better adapted or acclimatized to inhibitive components such as organic acids.

CH_4 emission reductions from the cattle and pig solid fractions stored at 25 °C could also be explained by the high water losses over time. From the beginning of the storage period, when solid fractions started to dry, air entered the pores previously filled with water. The high water losses combined with low volume (1000 cm^3) of the samples in storage, resulted in a substantial reduction of the anaerobic zone inside the cattle and pig solid fractions stored at 25 °C. Methanogenesis is inhibited by low moisture content and oxygen availability in the manure. Furthermore, most studies show CH_4 emission reductions due to the methane oxidation during the passage through the porous surface layers of manure heaps (Olesen, 2005). Biological CH_4 oxidation is a process whereby methane is oxidised to carbon dioxide and water by methane oxidizing bacteria (methanotrophs) under aerobic conditions (Cicerone and Oremland, 1988; Kotsyurbenco, 2005). The substantial reduction of the anaerobic zone over time and the biological CH_4 oxidation in the outer layers could be the causes for lower CH_4 emissions from pig and cattle solid fractions stored at 25 °C.

5. Conclusion

Results from this study show that emissions of NH_3 and GHGs during the storage of animal manures are influenced by different factors. Since emissions of NO_2, NH_3, CO_2 and CH_4 are affected by microbiological, chemical, and physical processes, complex interactions exist. This requires a whole system approach when pollutant abatement technologies have to be adopted. Evidence from the present study suggests that mechanical separation of cattle and pig slurries does not reduce emissions but has the potential to increase the emissions of CO_2 equivalents to the atmosphere during the storage of the separated fractions by up to 30% if compared with the untreated slurries. The emission potential of pig slurry was up to 3 times higher than that of cattle slurry. It was determined under the laboratory conditions and assumptions as described. Thus, to confirm these results, experiments should be made under on-farm storage conditions.

Acknowledgements

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Figure legends

Fig. 1. Main components of the lab-scale mechanical slurry separator.

Fig. 2. Schematic diagram of the sampling system.

Fig. 3. Nitrous oxide (N_2O) fluxes from pig solid fraction stored at 25 °C. Error bars indicate standard error (number of observations = 4).

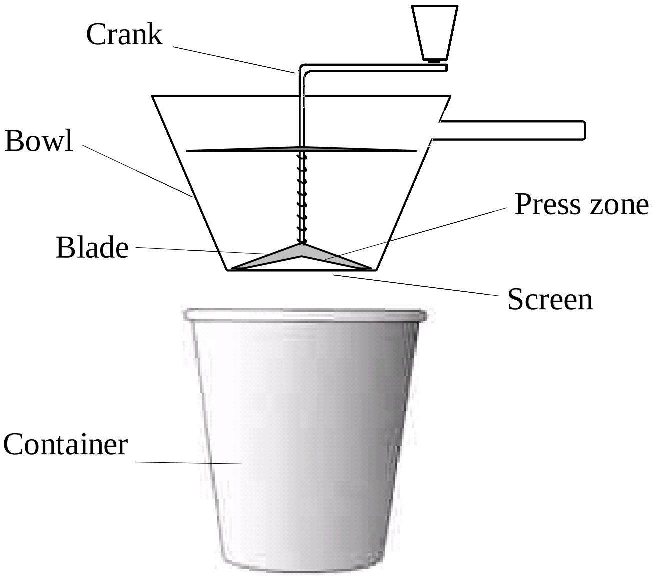
Fig. 4. Emission fluxes of ammonia (NH_3) during storage of the tested materials at 5 °C and 25 °C. Error bars indicate standard error (number of observations = 4).

Fig. 5. Emission fluxes of carbon dioxide (CO_2) during storage of the tested materials at 5 °C and 25 °C. Error bars indicate standard error (number of observations = 4).

Fig. 6. Emission fluxes of methane (CH_4) during storage of the tested materials at 5 °C and 25 °C. Error bars indicate standard error (number of observations = 4).

Fig. 7. Corrected cumulative loss Φ_j of NH_3, CO_2 and CH_4 of the investigated samples in relation to the Φ_j from untreated slurries (pig and cattle) samples.

Fig. 8. Climatic warm potential of untreated slurry (pig and cattle), liquid and solid fractions expressed as CO_2 equivalents calculated from the cumulated emissions of the single trace gases.



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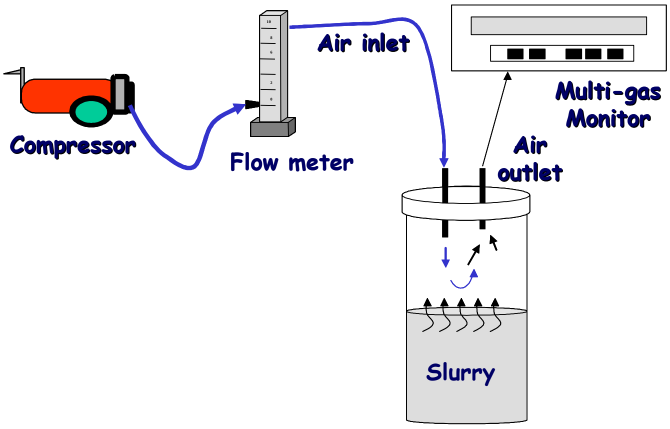


Fig. 2.

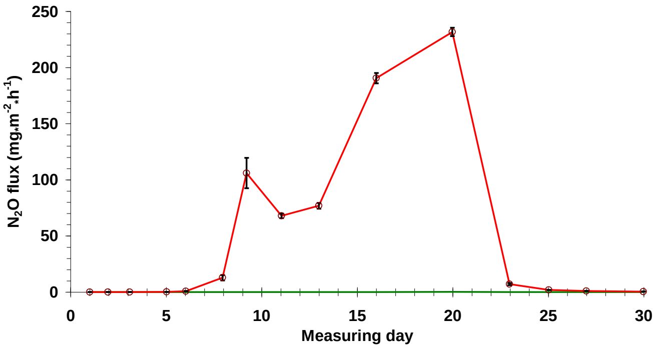


Fig. 3.

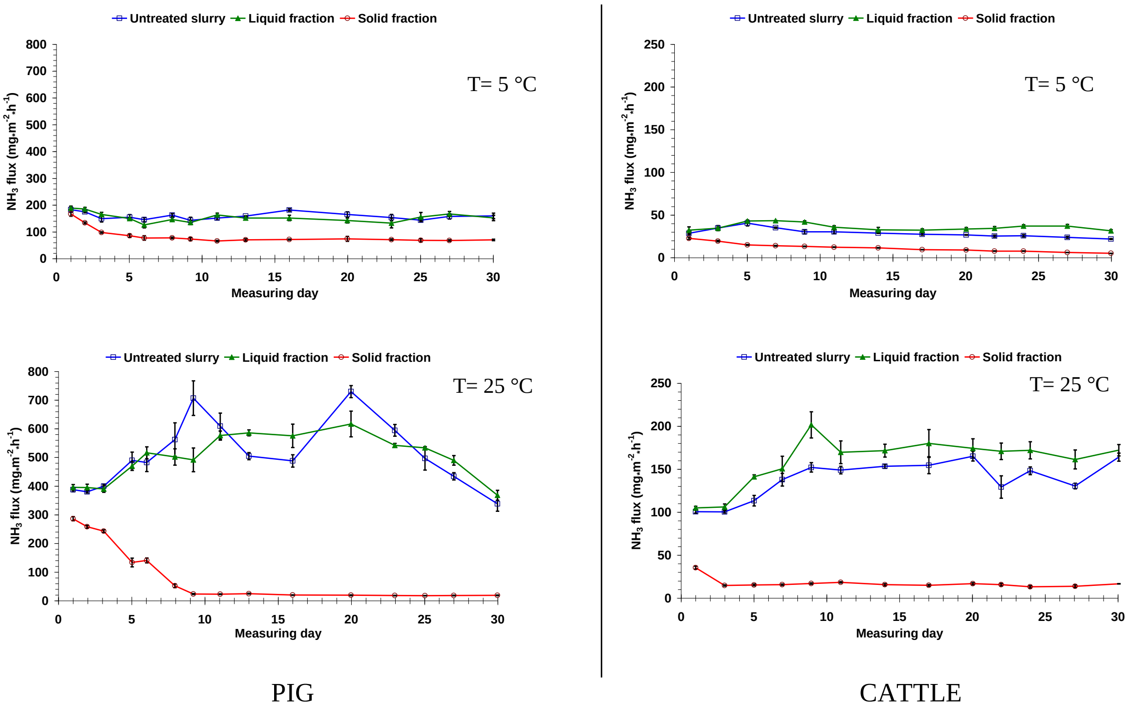

Untreated slurry
Liquid fraction
Solid fraction
T= 5 °C
T= 25 °C
NH_3 flux (mg.m^{-2}.h^{-1})
Measuring day
0
5
10
15
20
25
30
0
100
200
300
400
500
600
700
800
50
150
250
PIG
CATTLE

Fig. 4.

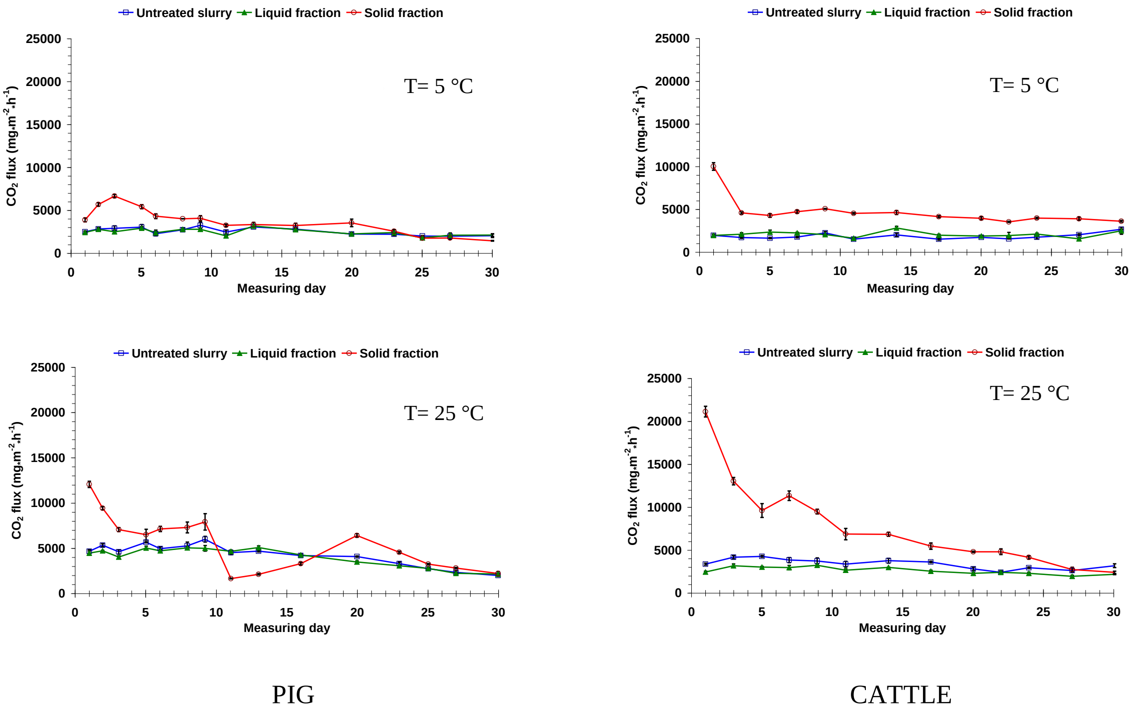

Untreated slurry
Liquid fraction
Solid fraction
T= 5 °C
T= 25 °C
CO_2 flux (mg.m^{-2}.h^{-1})
Measuring day
0
5
10
15
20
25
30
0
5000
10000
15000
20000
25000
PIG
CATTLE

Fig. 5.

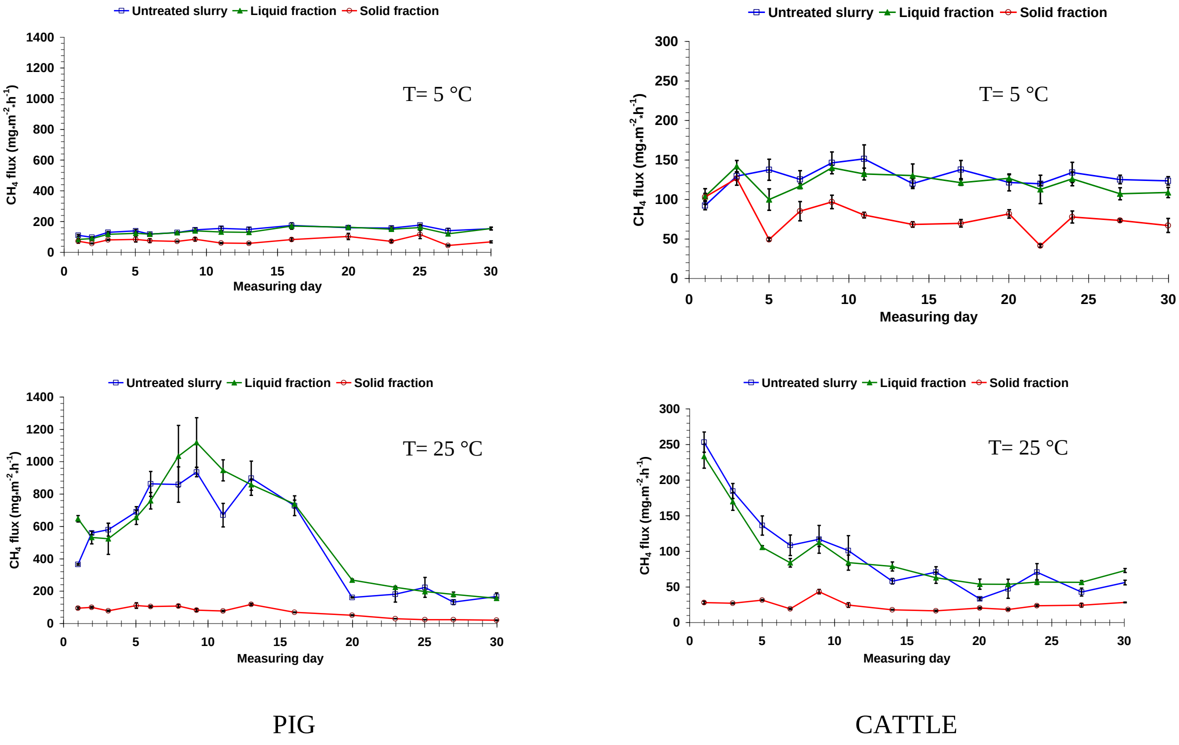
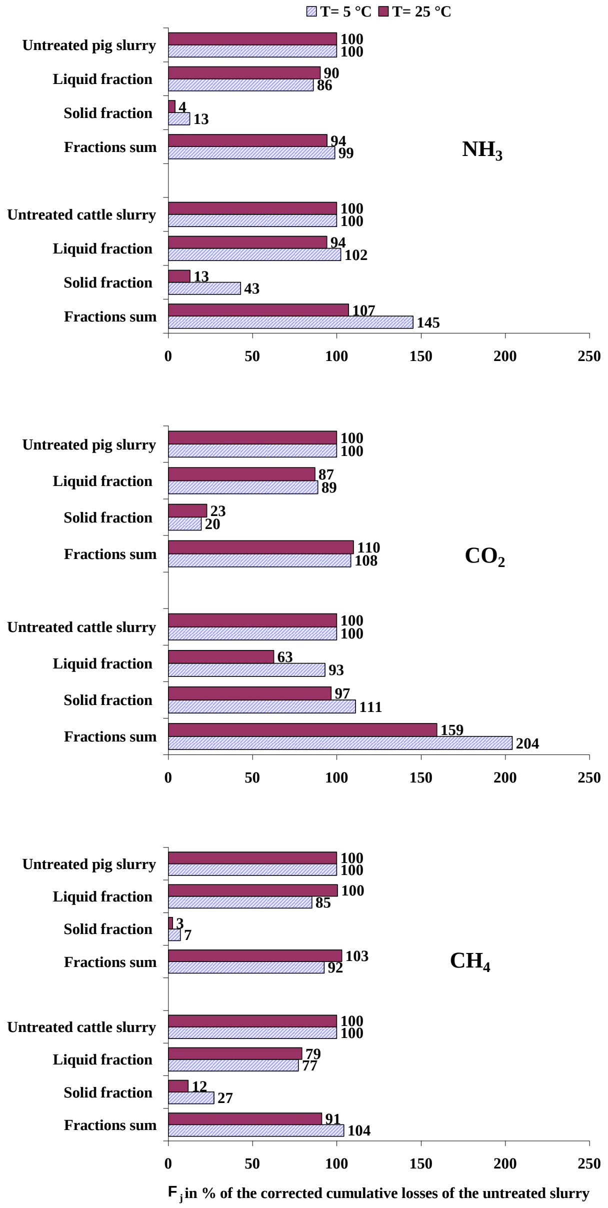

Untreated slurry
Liquid fraction
Solid fraction
T= 5 °C
T= 25 °C
CH_4 flux (mg.m^{-2}.h^{-1})
Measuring day
0
200
400
600
800
1000
1200
1400
0
50
100
150
200
250
300
0
5
10
15
20
25
30
PIG
CATTLE

Fig. 6.



▨ T= 5 °C ■ T= 25 °C
Untreated pig slurry
100
100
Liquid fraction
90
86
Solid fraction
4
13
Fractions sum
94
99
NH3
Untreated cattle slurry
100
100
Liquid fraction
94
102
Solid fraction
13
43
Fractions sum
107
145
0
50
100
150
200
250
Untreated pig slurry
100
100
Liquid fraction
87
89
Solid fraction
23
20
Fractions sum
110
108
CO2
Untreated cattle slurry
100
100
Liquid fraction
63
93
Solid fraction
97
111
Fractions sum
159
204
0
50
100
150
200
250
Untreated pig slurry
100
100
Liquid fraction
100
85
Solid fraction
3
7
Fractions sum
103
92
CH4
Untreated cattle slurry
100
100
Liquid fraction
79
77
Solid fraction
12
27
Fractions sum
91
104
0
50
100
150
200
250
F j in % of the corrected cumulative losses of the untreated slurry

Fig. 7.

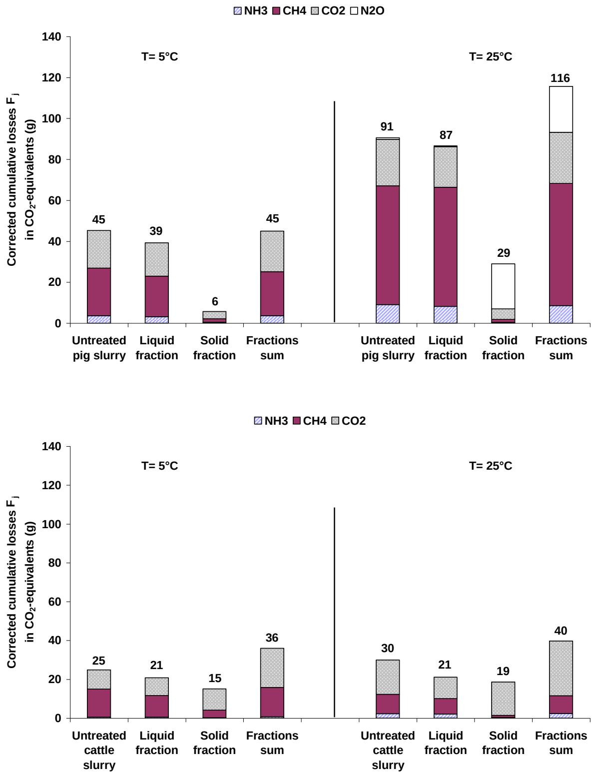

▨ NH3 ■ CH4 ▨ CO2 ☐ N2O
Corrected cumulative losses F$_j$ in CO$_2$-equivalents (g)
0
20
40
60
80
100
120
140
T= 5°C
T= 25°C
45
39
6
45
91
87
29
116
Untreated pig slurry
Liquid fraction
Solid fraction
Fractions sum
Untreated pig slurry
Liquid fraction
Solid fraction
Fractions sum
▨ NH3 ■ CH4 ▨ CO2
Corrected cumulative losses F$_j$ in CO$_2$-equivalents (g)
0
20
40
60
80
100
120
140
T= 5°C
T= 25°C
25
21
15
36
30
21
19
40
Untreated cattle slurry
Liquid fraction
Solid fraction
Fractions sum
Untreated cattle slurry
Liquid fraction
Solid fraction
Fractions sum

Fig. 8.

Table legends

Table 1. Main composition of the manures at the beginning of each experiment (n=2) and the correction factors ρ used for Φ_j calculation.

Table 2. Main composition of the manures at the end of each experiment (n=4) and volume reductions over the storage period.

Table 3. Mean gaseous losses from each of the tested material occurred at the different experimental conditions after 30 d of storage.

Table 1.

Type of slurry	Product	pH	TS %	VS %	TAN g kg^{-1}	TKN g kg^{-1}	Org. Acids %	ρ
Pig	Untreated slurry	7.79	5.90	4.21	4.31	6.40	4.78	1.00
	Liquid fraction	7.86	4.65	3.01	4.33	5.90	3.15	0.92
	Solid fraction	8.82	21.1	19.1	4.05	12.2	3.47	0.20
Cattle	Untreated slurry	7.11	7.46	6.02	1.47	3.58	4.48	1.00
	Liquid fraction	7.09	5.12	3.81	1.49	3.59	5.80	0.82
	Solid fraction	8.35	19.2	17.3	1.16	2.65	4.18	0.45

Table 2.

Type of slurry	Storage temperature °C	Product	pH	TS %	VS %	TAN g kg^{-1}	N Kjel. g kg^{-1}	Org. Acids %	Volume reduction %
Pig	25	Untreated slurry	8.43	8.38	5.31	1.55	4.10	1.46	46.3
	25	Liquid fraction	8.50	6.32	3.39	1.46	3.79	2.23	46.3
	25	Solid fraction	7.25	28.6	25.0	0.28	6.63	1.29	0.00
	5	Untreated slurry	7.92	5.98	4.16	3.65	5.76	3.26	3.72
	5	Liquid fraction	7.95	4.69	2.93	3.70	5.74	4.07	7.48
	5	Solid fraction	8.79	23.9	21.7	2.82	3.13	1.48	7.48
Cattle	25	Untreated slurry	6.96	8.63	6.76	1.51	3.22	8.48	38.4
	25	Liquid fraction	7.30	5.74	3.89	1.30	2.90	6.66	34.5
	25	Solid fraction	8.29	22.1	18.3	0.05	5.87	0.82	30.6
	5	Untreated slurry	6.79	7.67	6.17	1.40	3.32	6.37	3.72
	5	Liquid fraction	6.96	4.99	3.64	1.43	3.23	5.68	7.48
	5	Solid fraction	8.47	18.6	16.3	0.20	3.57	0.80	3.72

Table 3.

Type of slurry	Temperature °C	Untreated slurry				Liquid fraction				Solid fraction			
		N-NH_3 (%TKN)	N-N_2O (%TKN)	C-CH_4 (%VS)	C-CO_2 (%VS)	N-NH_3 (%TKN)	N-N_2O (%TKN)	C-CH_4 (%VS)	C-CO_2 (%VS)	N-NH_3 (%TKN)	N-N_2O (%TKN)	C-CH_4 (%VS)	C-CO_2 (%VS)
Pig	5	15.1 a	ND	3.34 a	20.0 a	15.0 a	ND	4.39 a	27.4 a	7.12 a	ND	0.68 a	11.1 a
		(0.34)		(0.05)	(0.41)	(0.61)		(0.17)	(0.68)	(0.04)		(0.02)	(0.37)
	25	37.8 b	ND	8.53 b	25.6 b	40.8 b	ND	12.8 b	33.4 b	5.57 b	4.71	0.60 b	16.3 b
		(0.57)		(0.43)	(0.64)	(0.22)		(0.47)	(0.35)	(0.11)	(0.12)	(0.02)	(0.26)
Cattle	5	3.60 c	ND	1.56 c	7.66 c	4.63 c	ND	2.19 c	13.7 c	5.21 c	ND	0.77 c	16.4 cb
		(0.09)		(0.05)	(0.19)	(0.14)		(0.10)	(0.42)	(0.10)		(0.01)	(0.36)
	25	16.5 d	ND	1.01 d	13.7 d	18.4 d	ND	1.55 d	16.7 d	6.03 db	ND	0.23 d	25.6 d
		(0.17)		(0.04)	(0.33)	(0.36)		(0.08)	(0.17)	(0.25)		(0.00)	(0.45)

Error standards are given in parentheses (n=4). Means with unequal letters in each column are significantly different ($P<0.05$).

ND = not detected