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Ammonia, Methane and Nitrous Oxide Emissions During Storage of Cattle and Pig Slurry and Influence of Slurry Additive „Effective Micro-Organisms (EM)“

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On Behalf of Multikraft Gesellschaft mbH., A - 4631 Haiding / Wels

1 Introduction

The slurry additive “Effective Micro-Organisms (EM)” is delivered in Austria by Multikraft Ltd. In animal manures, EM is applied to reduce odour, ammonia and greenhouse gas emissions. Highly accurate trials at pilot scale were conducted to investigate the influence of EM addition to cattle slurry, pig slurry, and pig feed on emissions of methane (CH_4), nitrous oxide (N_2O), ammonia (NH_3) and total organic carbon (TOC) emissions from slurry stores.

2 Experimental Design

2.1 Research station "Gross Enzersdorf"

Emission measurements were carried out in Gross Enzersdorf, Lower Austria, near the city of Vienna at the research station of the University of Natural Resources and Applied Life Sciences. Climate and soil at Gross Enzersdorf are typical for a Pannonian region. During summer, hot and dry conditions prevail. Winters are cold with only little snowfall. Mean air temperature is 9.8 °C, mean precipitation is 547 mm per year, mean relative humidity is 75 % for the years 1960 – 2000.

Data on climate prevailing during emission measurements are essential for data interpretation and analysis. ZAMG[1] supplied hourly means of air temperature, relative humidity, precipitation and air pressure. Figures 1 and 2 give monthly means of air temperature and precipitation, respectively, during emission measurements (March to June 2003) and mean values for the years 1960 – 2000. In 2003, temperature from March to June was slightly above mean temperature of the period 1960 – 2000. Precipitation was slightly lower than the average.

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[1] Central Institute of Meteorology and Geodynamics

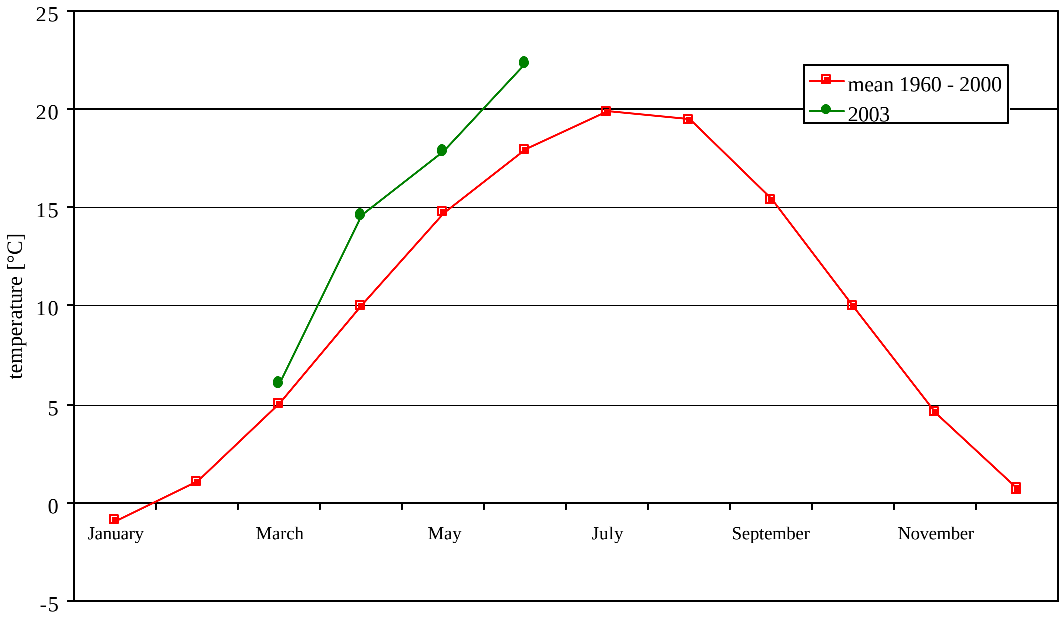


Figure 1 Temperature at research site Gross Enzersdorf: mean temperature 1960 – 2000 and temperature during the emission measurements in 2003.

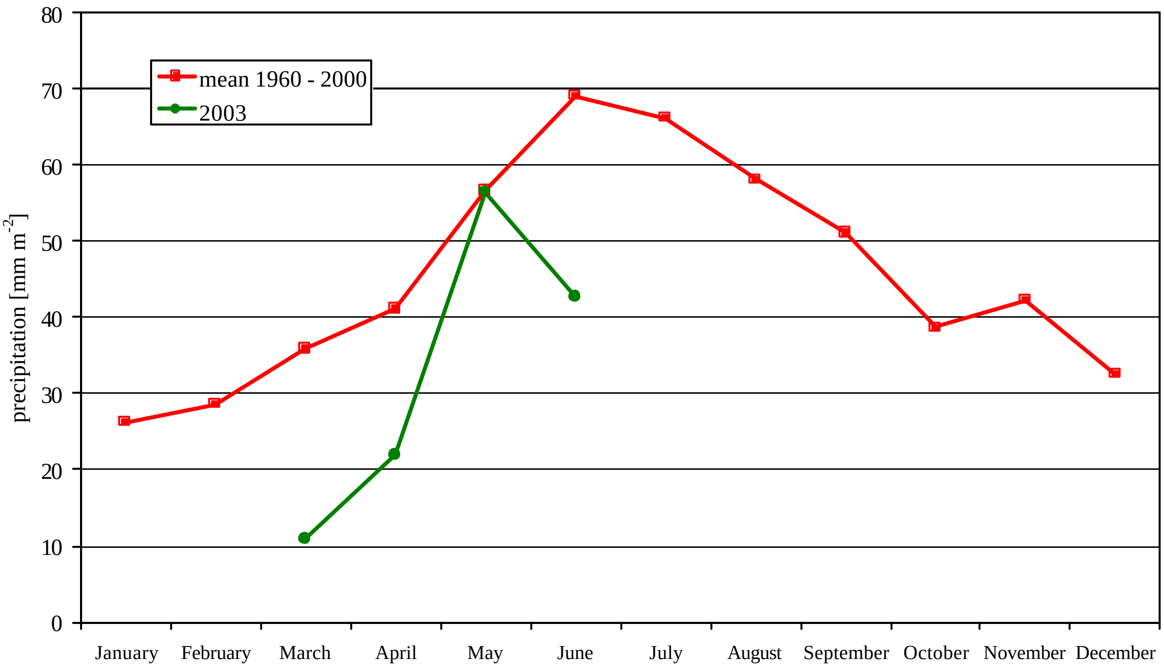


Figure 2 Precipitation at research site Gross Enzersdorf: mean precipitation 1960 – 2000 and precipitation during the emission measurements in 2003.

2.2 Slurry tanks

In March 1999 five slurry tanks and a concrete area for composting were built at the research site Gross Enzersdorf. Slurry tanks were 2.5 m deep and had a diameter of 2.5 m. They were made from concrete and buried into the ground, with 5 cm of the wall above the soil surface. Adjacent to the slurry tanks, a concrete area was installed, where solid manure can be stored and/ or composted. The concrete area covers an area of 4 * 10 m. Figures 3 and 4 show the design of the experimental facility by which emissions from manure storage were quantified. Concrete area and slurry tanks are situated side by side with an interspace of 0.5 m. Parallel to the slurry tanks a wooden rail was installed on which the large open dynamic chamber can easily be moved from one tank to the other.

The slurry tanks were filled with about 10 m^3 slurry. Emissions of NH_3, N_2O and CH_4 were quantified by moving the large open dynamic chamber on a slurry tank and collecting the emissions. Due to variability in emissions it was necessary to have small sampling intervals. Emissions of each variant were measured twice a week for 8 – 12 hours. The open dynamic chamber was installed on a base by which the chamber could be rolled from one slurry tank to the next. The experimental facility was constructed in such a way that it was possible to move the large open dynamic chamber from one variant to the other with only little effort.

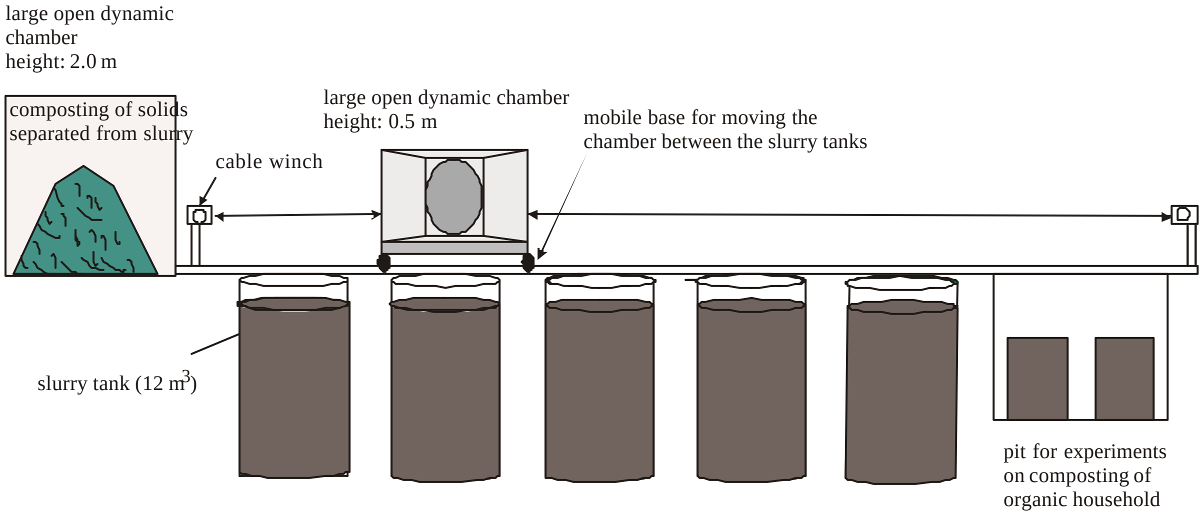


Figure 3 Design of the experimental facility for quantifying emissions from manure storage (side view)

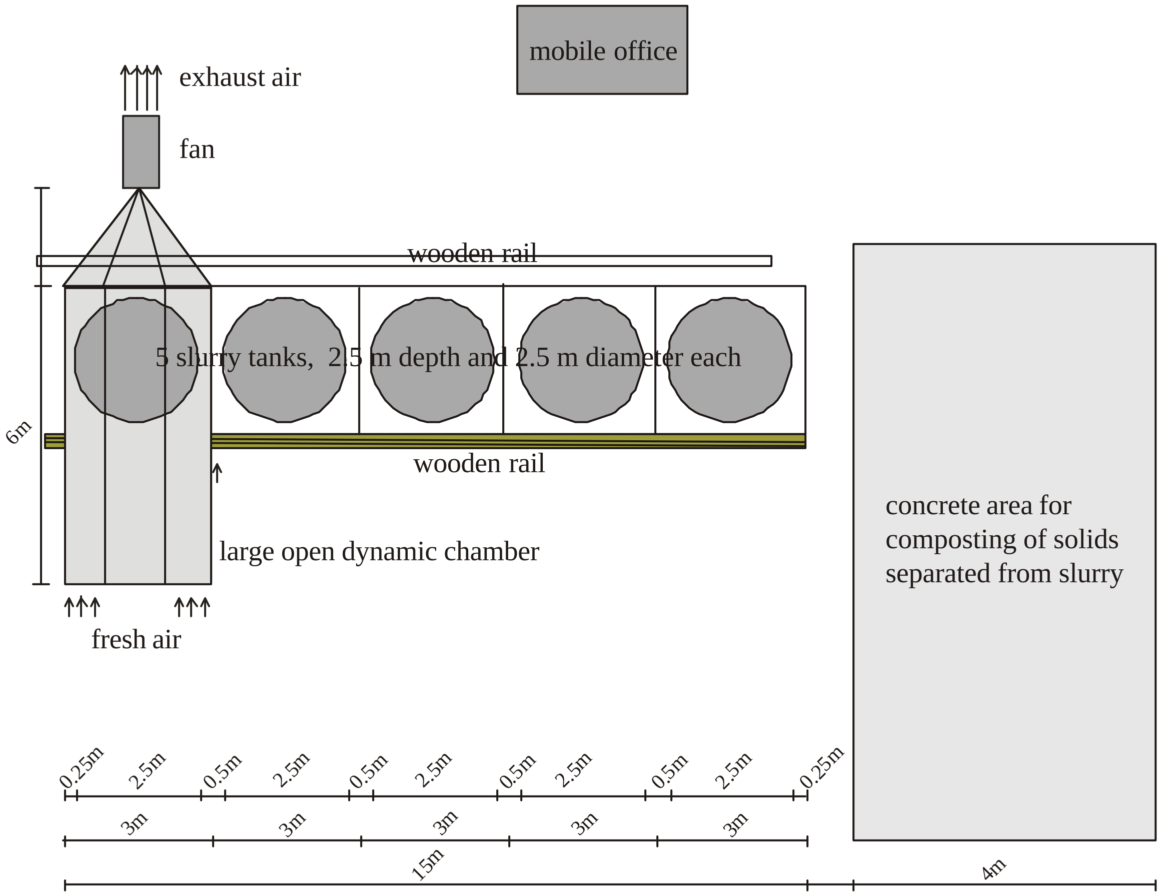


Figure 4 Design of the experimental facility for quantifying emissions from manure storage (plan view)

Slurry temperature was continuously measured at two heights. Slurry samples were taken bi-weekly during the whole period of emission measurements. Samples were taken from 5 different heights of the slurry tank and mixed to one sample that was immediately frozen until the laboratory analysis started. A total of 41 samples was analysed for

- dry matter content
- organic dry matter content
- ash content
- pH
- NH_4-N content
- total nitrogen content
- total carbon content.

2.3 *Large open dynamic chamber developed by ILUET*

For the determination of emission rates, gas concentration and air flow must be known. The emission rate is calculated as follows:

Emission rate [g h^{-1}] = gas concentration [g m^{-3}] * air flow [m^3 h^{-1}]

For the determination of the air flow over stored manure ILUET has developed a large open dynamic chamber (figure 5). The mobile chamber covers an area of 27 m^2 and can be built over emitting surfaces in the animal housing, on manure stores and over spread manure. Two different chamber side wall heights are available: 2 m and 0.5 m. Fresh air enters the chamber at the front. In the chamber the fresh air accumulates the emissions and leaves the chamber on the far side. Gas concentrations are measured alternately in the incoming and in the outgoing air. The differences in concentration of specific gases between the incoming and the outgoing air represent the emissions from the substrate inside the chamber. The air flow is recorded continuously by a fan-based flow meter.

The open dynamic chamber does not alter the conditions inside the chamber compared to ambient air conditions. The continuous air flow prevents heating up inside the chamber. The air flow can be adjusted between 1,000 and 11,000 m^3 h^{-1} which results in an air speed between 0.05 and 0.51 m s^{-1}. The open dynamic chamber is made from polycarbonate. Light can penetrate inside the chamber. The material does not adsorb ammonia. For emission measurements during slurry storage and after manure application the mobile chamber was slightly modified: its height was reduced from 2.0 m to 0.5 m. Thus the air speed inside the chamber could be adjusted between 0.18 and 2.04 m s^{-1}.

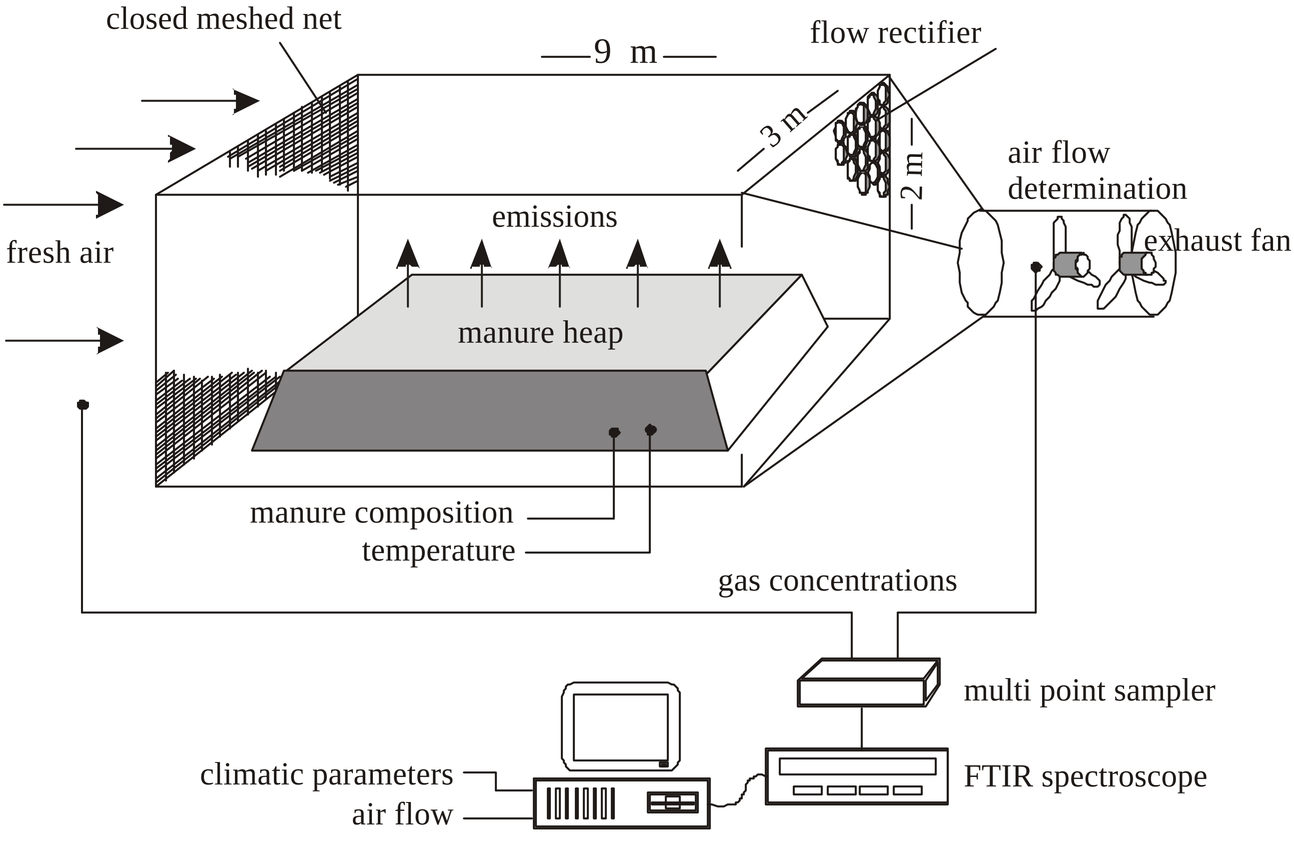


Figure 5 Design of the large open dynamic chamber developed by ILUET

2.4 Gas concentration analysis

FTIR spectroscope. If environmental impacts of manure management systems are to be assessed, it is important to follow a whole-systems-approach. This means, that gaseous compounds that have negative environmental impacts have to be measured simultaneously. FTIR spectroscopy offers a reliable possibility for continuous online detection of NH_3, N_2O, CH_4 and CO_2 in the field. Operating costs of the instrument are low.

FTIR spectroscopy is based on the principle that individual gases have distinct infrared absorption features. This enables the simultaneous measurement of several gases with one instrument since every IR spectrum contains the information of all IR radiation absorbing gases between a radiation source and a detector.

Exhaust air from animal houses or manure stores is a mixture of up to 200 different gaseous components. In order to avoid cross-sensitivities that would result in wrong concentration values, the spectral resolution of the FTIR spectroscope has to be high. The applied FTIR spectroscope has a spectral resolution of $0.25\ cm^{-1}$. It operates with a white cell with 8 m light path. The detection limit is 0.5 ppm for ammonia and ambient air level for carbon dioxide, methane, and nitrous oxide. Gas concentrations in absorption spectra collected by the FTIR spectroscope are quantified by multivariate calibration methods.

Volatile Organic Carbons Analyser. Concentration of volatile organic carbons (VOC) in the chamber outlet was quantified. VOC concentration was analysed by a flame ionisation detector. Gas samples are pumped into the analyser and burned at 190 °C. Organic carbon is oxidised and detected as carbon ion. VOC concentration was measured every 5 minutes. Every second day, the VOC analyser was calibrated with zero gas (N_2) and 50 ppm CH_4. VOC emissions are expressed as CH_4 equivalents.

The VOC content can give a hint on potential odorous emissions from substrates. The higher the VOC content the higher the potential for odorous emissions. However, it is at the moment not possible to quantitatively correlate VS emissions with odour emissions.

2.5 PC based programme for data collection

Continuous gas concentration analysis was enabled by a computer based programme. The programme controls the multi-point sampler and the FTIR spectroscope. It starts with the collection of inlet air. Inlet air is continuously sucked through the FTIR gas cell at a rate of $1\,l\,min^{-1}$. Three absorption spectra are collected for gas concentration analysis of inlet air. Then the PC based programme opens the exhaust air valve of the multi-point sampler. The FTIR gas cell is purged with exhaust air for ten minutes before collection of three absorption spectra starts. When three exhaust air spectra have been collected, the inlet air valve of the multi-point sampler is opened again. The FTIR gas cell is purged for 10 minutes with inlet air and then the cycle starts again from the beginning. The cycle is continuously repeated until the PC based programme is stopped by hand.

2.6 Calculation of the emission rate

The emission rate $g\ h^{-1}$ is calculated by multiplying gas concentration ($g\ m^{-3}$) and ventilation rate ($m^3\ h^{-1}$). FTIR spectroscope and VS analyser give gas concentrations in ppm. Gas concentrations given in ppm can be transferred to gas concentrations in $mg\ m^{-3}$, if molecular weight and molar volume are known. Molar volume depends on atmospheric pressure and on temperature. Temperature in gas tubes and gas cell was constantly kept at 45 °C. Atmospheric pressure was measured on an hourly basis and included in the calculation of gas concentrations.

Gas concentrations were alternately measured in the chamber inlet and outlet. Inlet concentrations were measured three times and then outlet concentrations were measured three times. Emission rate is calculated from the mean outlet gas concentration minus the mean inlet concentration multiplied by the air flow rate that is measured by the fan based flow meter.

2.7 Mobile office

Online measurements in the field require measurement instruments and PC to be installed in the field. ILUET constructed a "mobile office" in a trailer that can be moved near the emitting sources. The trailer contains a writing desk, a PC, the FTIR spectroscope, the VS analyser, the multi-point sampler, and the automatic data logging for slurry temperature and air flow rate (figure 6).

The FTIR spectroscope is securely situated in the back corner of the trailer and sheltered from dust and dirt by a wooden cover. Gas cell and sampling tubes are constantly heated at 45 °C by a heater that stands near the FTIR spectroscope. The multi-point sampler is installed close to the FTIR spectroscope. The FTIR spectroscope has to be continuously purged with dry, CO_2 free air. An adsorption drier that is connected to a compressor filters water and CO_2 from ambient air and purges the FTIR spectroscope with the clean air. The VS analyser stands beside the FTIR spectroscope. Calibration gas and N_2 needed for calibrating the VS analyser are fixed to the wall of the trailer.

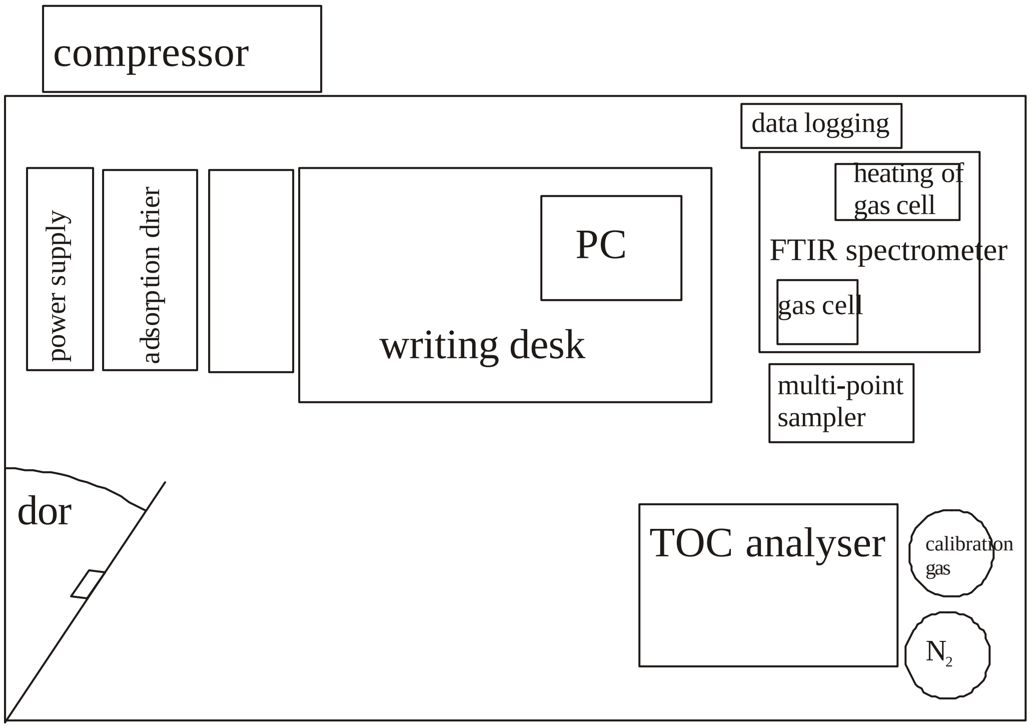


Figure 6 Mobile office for quantification of NH_3, N_2O and CH_4 emissions in the field

2.8 *Statistical data analysis*

Statistical data analysis was carried out with the software package SPSS, version 10.0. Regression curves were fitted to cumulative emissions. Regression equation and coefficient of determination are given in the respective figures. Differences in regression equations were tested with a pairwise comparison of regression parameters by the t-test.

2.9 Slurry treatments

The following manure treatments were included in the experiments:

- cattle slurry without addition of EM (cattle_untreated)
- cattle slurry with addition of EM (cattle_EM)
- pig slurry without addition of EM (pig_untreated)
- pig slurry with addition of EM (pig_EM)
- pig slurry that was received from pigs that were fed EM (pig_EMfeed)

Table 1 gives an overview in the measurement campaigns. Slurry tanks were filled with *c.* 10 m^3 of slurry on 3rd March 2003.

Table 1 Emission measurements to investigate the influence of EM on NH_3, N_2O, CH_4 and VS emissions from slurry stores

treatment	*measurement period*	*length [days]*	*length of emission measurements [h]*	*amount of slurry in the tank [m^3]*
cattle_untreated	3rd March – 2nd June 2003	122	467	8.84
cattle_EM	3rd March – 1st June 2003	121	465	10.31
pig_untreated	3rd March – 6th June 2003	96	381	9.18
pig_EM	3rd March – 5th June 2003	95	401	8.79
pig_EMfeed	3rd March – 5th June 2003	95	312	10.46

2.10 Slurry origin

Cattle slurry. Cattle slurry was received from the farm of Johann Schibich in Laaben/ Neulengbach – Lower Austria. 36 suckling cows (Simmental, Limousine and Murbodner) are kept according to the regulations of organic farming. The farm is member of “Bio Ernte Austria”. The cattle are fed grass silage, hay and some barley straw. Replacement heifers are kept in a house with a slatted floor in the feeding area and lying boxes. The house is equipped with an outside pen. The slurry that was used in the experiments was mainly received from replacement heifers.

C. 20 m^3 of fresh cattle slurry from the farm „Johann Schibich“ were filled in two of the slurry tanks at the research station in Gross Enzersdorf. To the treatment “cattle_EM” 10 l EM were added immediately after filling the slurry tank. This amounts to c. 1 l EM per m^3 of slurry. The EM solution was prepared by Ms. Mag. Hader of Multikraft Ltd. Slurry tanks with and without EM were not covered.

Pig slurry. Pig slurry for the treatments “pig_untreated“ and “pig_EM“ were received from the farm of Josef Ollinger in Laa/ Thaya, Lower Austria. 300 fattening pigs are kept on partly slatted floors. Slurry is diluted with rain and wash water and is stored in a below ground store outside the pig house. The pigs receive dry feed that consists of soya, peas, potato protein, barley, triticale, and maize. It is fed ad libitum. During the fattening period two different ratios are fed. The first until pigs reach a life weight of 70 – 80 kg and the second until they reach a life weight of 120 – 130 kg. The first ratio has a crude protein content of 19 %, the second has 18 % crude protein.

C. 20 m^3 of fresh pig slurry from the farm “Josef Ollinger“ were filled in two of the slurry tanks at the research station in Gross Enzersdorf. To the treatment “pig_EM” 9 l EM were added immediately after filling the slurry tank. This amounts to c. 1 l EM per m^3 of slurry. The EM solution was prepared by Ms. Mag. Hader of Multikraft Ltd. Slurry tanks with and without EM were not covered.

Pig slurry for the treatment “pig_EMfeed” was received from the farm of Thomas Halbmair in Aschbach-Markt/ Lower Austria. 35 breeding sows and 230 fattening pigs are kept on partly slatted floors. The slurry is stored outside the house in a covered store. The pig feed consists of wheat, soya, CCM and a mixture of active agents. EM is added to the active agents mixture. CCM is conserved with EM. The farm is member of the programme "N reduction in pig feed". Up to a life weight of 65 kg, pre-fattening feed is fed. Afterwards, pigs receive feed with a reduced protein content of 17.5 % crude protein.

C. 10 m^3 of pig slurry from the farm "Thomas Halbmair" were filled in one slurry tank at the research station in Gross Enzersdorf and stored without additional treatment.

2.11 Quantification of the maximum methane production potential at lab scale

Maximum methane production potential of the pig slurry that was received from pigs that were fed EM was quantified at lab scale. Slurry was anaerobically digested in an eudiometer apparatus at 40 °C. Methane production was followed for 60 days. Anaerobic digestion in the lab shows the maximum amount of methane that can be produced from the pig slurry "pig_EMfeed". The experiments at pilot scale (measurement of CH_4 emissions from slurry stores) show, how much methane is actually produced if slurry is stored under field conditions. From the comparison of both values, the "methane conversion factor (MCF)" can be calculated. It says which percentage of the maximume methane production potential is built under field conditions. The MCF is important for the compilation of national emission inventories according to the IPCC guidelines.

3. Results

3.1 Cattle slurry

3.1.1 Slurry composition

Table 2 and figure 7 show the composition of cattle slurries at the start and at the end of the storage experiments. The cattle slurry contained 9.39 % dry matter at the beginning of storage. Slurry without EM addition had 5.73 % dry matter after 120 days of storage. EM amended slurry had 5.03 % dry matter when experiments were finished. During storage, the volatile solids content (= organic dry matter) was reduced from 6.85 % to 4.06 % (cattle_untreated), and 3.30 % (cattle_EM), respectively. Total N content declined from 3.82 g (kg fresh matter)$^{-1}$ to 2.97 (cattle_untreated), and 3.26 (cattle_EM), respectively. Without EM addition, the pH value was lowered from 7.79 to 7.48. EM addition resulted in an increase in pH value to 7.93.

Table 2 Slurry composition at the start and at the end of the storage period.

		N_t [g (kg FM)$^{-1}$]	NH_4-N [g (kg FM)$^{-1}$]	C [g (kg FM)$^{-1}$]	C : N	TS [% FM]	VS [% FM]	pH
cattle_untreated	start	3.82	1.93	35.80	9.38	9.39	6.85	7.79
	end	2.97	1.80	19.77	6.65	5.73	4.06	7.48
cattle_EM	start	3.82	1.93	31.51	8.25	9.39	6.85	7.79
	end	3.26	1.92	17.02	5.23	5.03	3.30	7.93

FM = slurry fresh matter

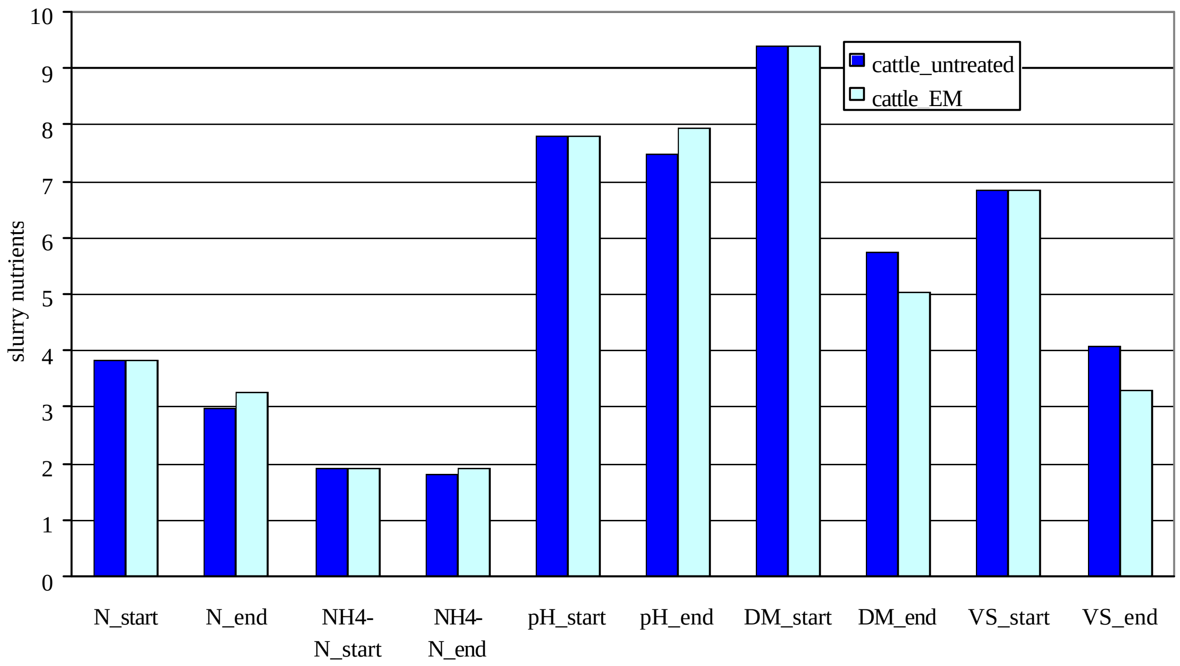


Figure 7 Composition of cattle slurry with and without EM addition at the start and at the end of the storage period.

3.1.2 Emissions during slurry storage

The following chapter gives results from the emission measurements from untreated and EM amended cattle slurry. Daily emission rates and slurry temperature from March to June 2003 are shown. Daily emission rates are given as g per m^3 of slurry and day. The sum of daily emissions gives cumulated emissions that are shown in separate figures. From the cumulated curve net total emissions can be taken. Cumulated emissions are given as g per m^3 of slurry fresh matter.

Regression curves were fitted to cumulated emissions. Regression equation, and coefficient of determination are given in the respective figures. Differences in regression equations were tested with a pairwise comparison of regression parameters by the t-test.

There were only little differences in daily methane emissions between cattle slurry with and without EM addition (Fig. 8). Cumulated emissions did not differ significantly (Fig. 9). Methane emissions were low at the start of the storage period. Air temperature and slurry temperature rose between March and June. This resulted in an increase in daily methane emission rates.

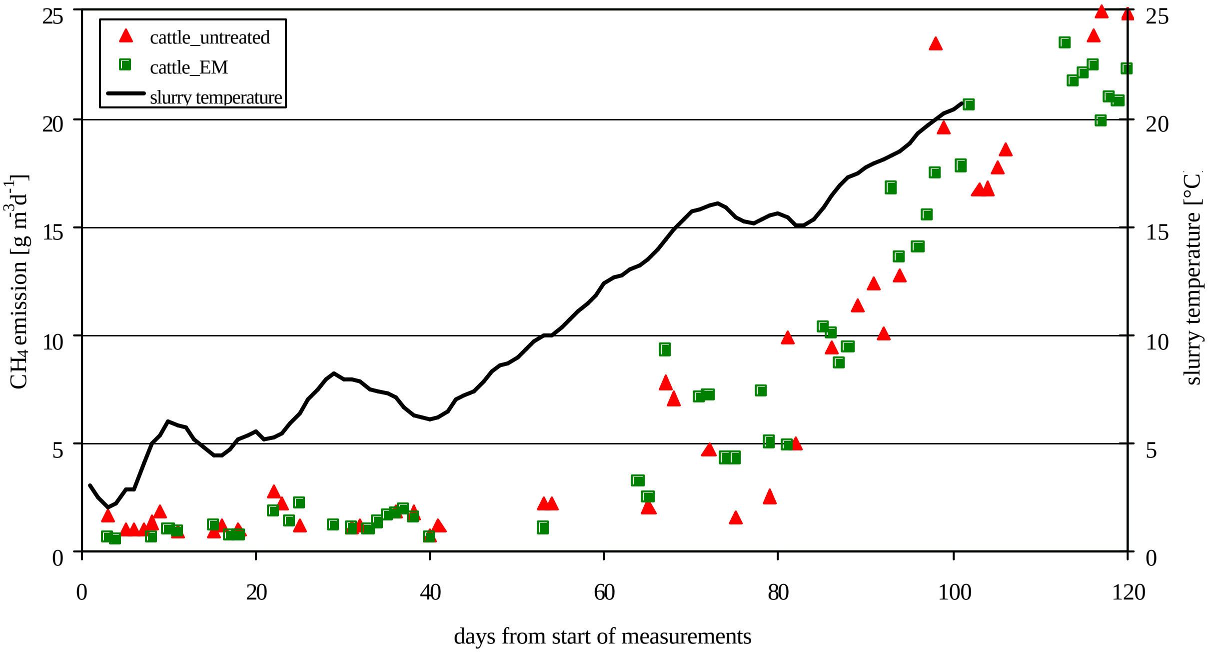


Figure 8 Daily methane emissions from cattle slurry with and without addition of EM.

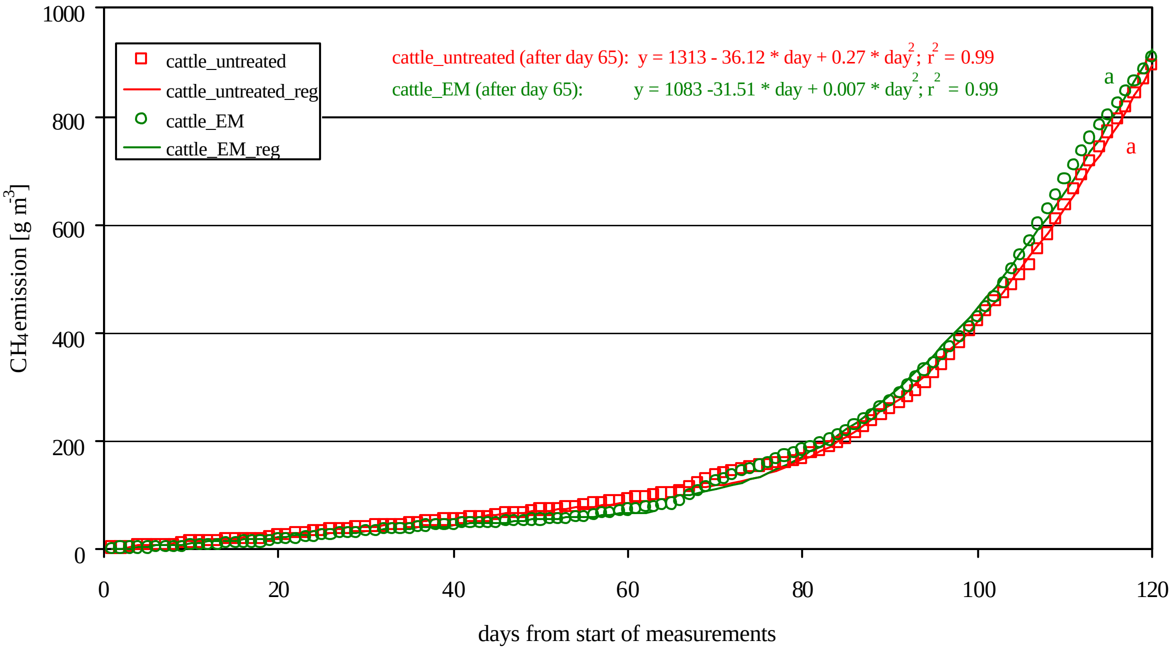


Figure 9 Cumulated methane emissions from cattle slurry with and without addition of EM.

Slurry temperature had a significant influence on methane emissions. Figure 10 gives an example of the correlation between slurry temperature and daily methane emission rates from the treatment cattle_EM. The exponential correlation has a coefficient of determination of 0.9.

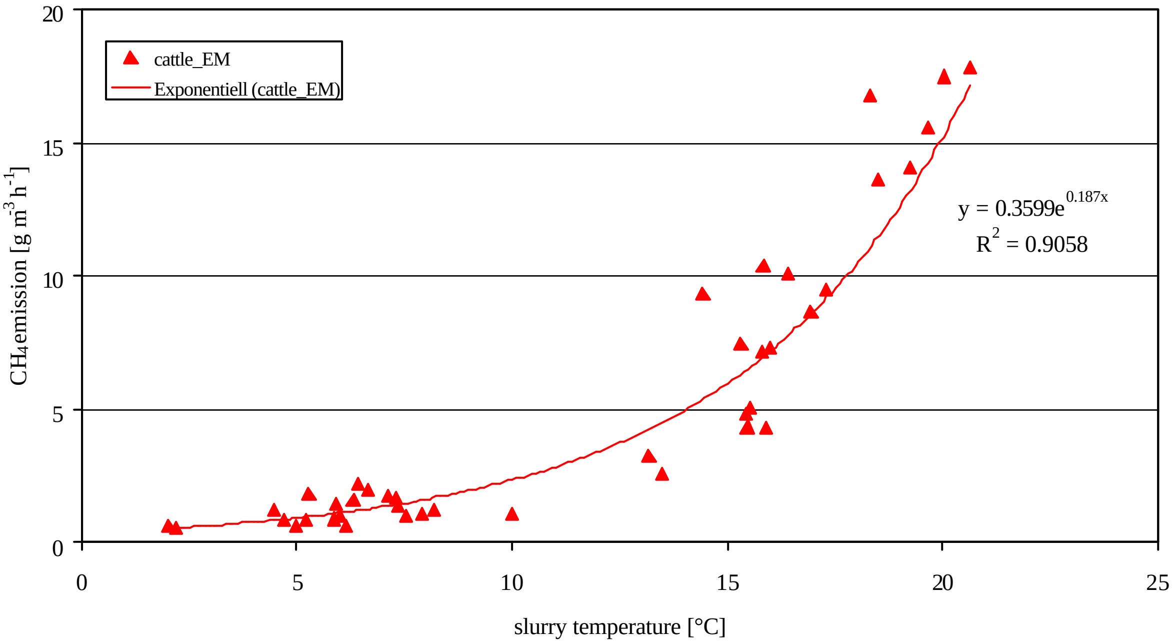


Figure 10 Correlation between daily methane emissions and slurry temperature (treatment: cattle slurry with EM addition).

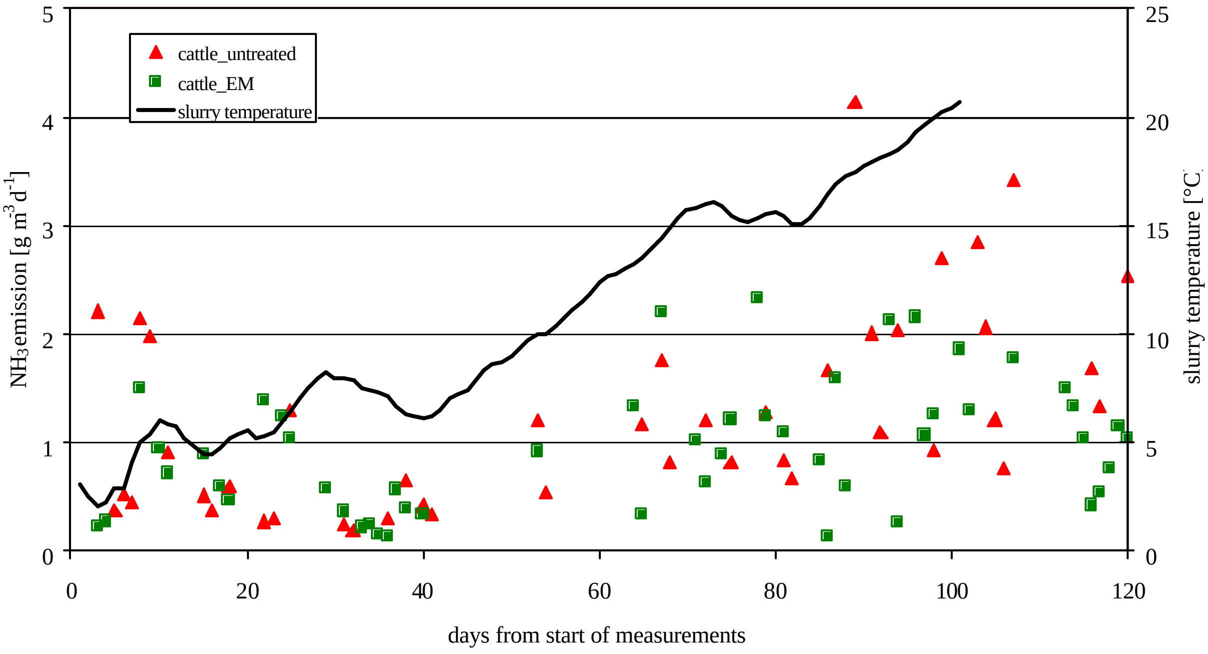


Figure 11 Daily ammonia emissions from cattle slurry with and without addition of EM.

The daily ammonia emission rates rose in course of the storage period – parallel to the rise in slurry temperature (fig. 11). Especially in the beginning and at the end cattle slurry without EM addition had higher ammonia emissions that cattle slurry where EM was added. The difference in cumulated emissions was statistically significant (fig. 12). Addition of EM reduced ammonia emissions during storage of cattle slurry.

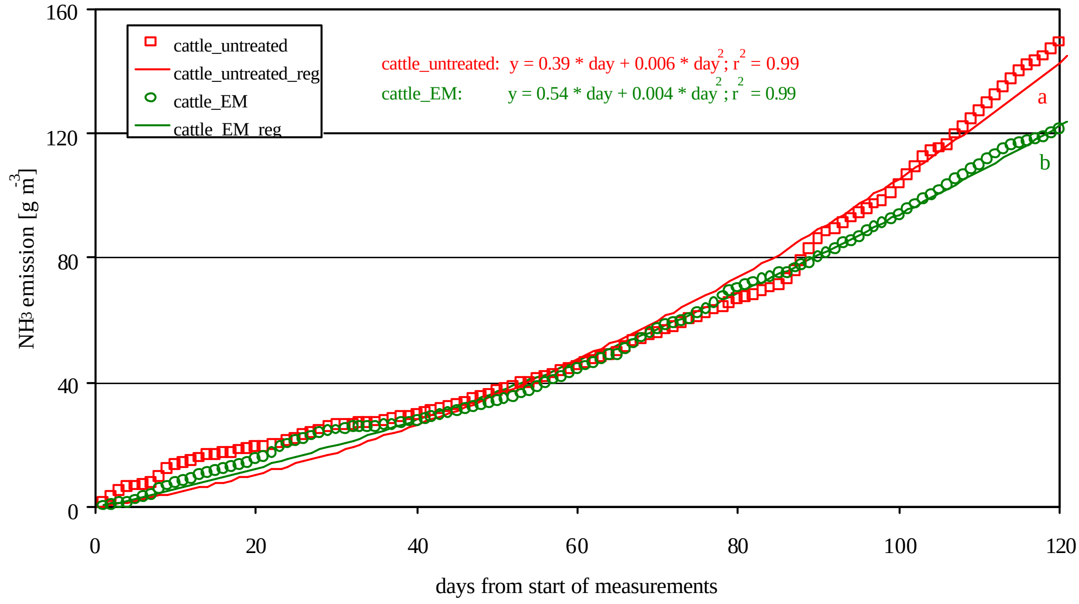


Figure 12 Cumulated ammonia emissions from cattle slurry with and without addition of EM.

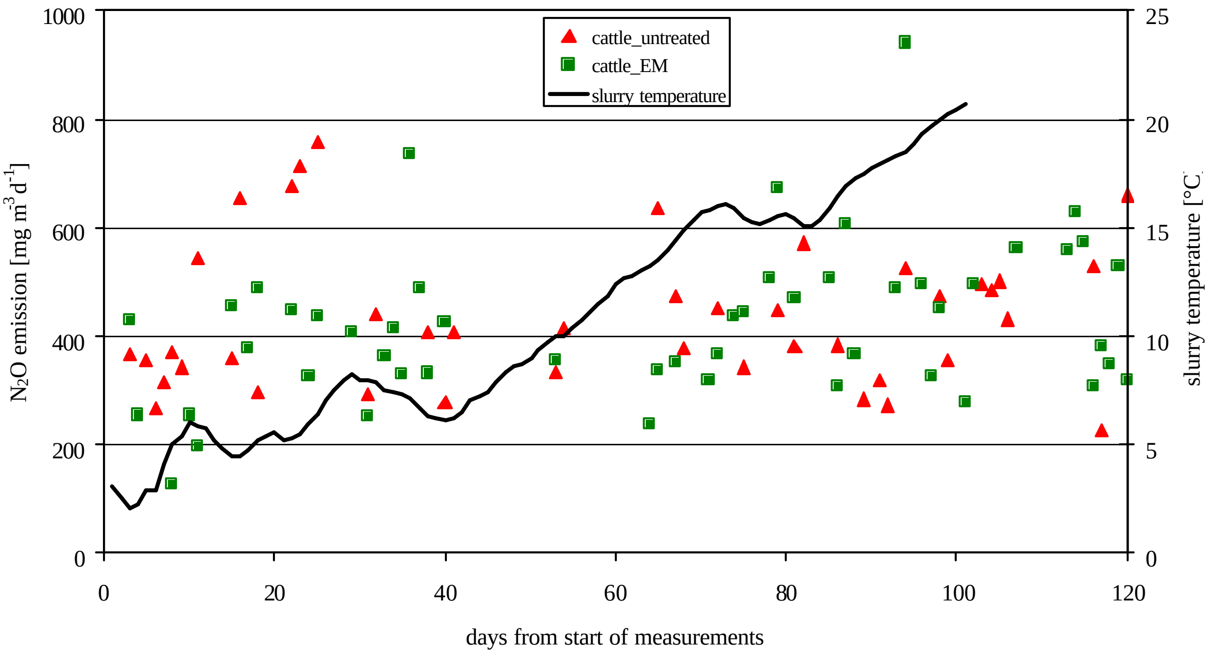


Figure 13 Daily nitrous oxide emissions from cattle slurry with and without addition of EM.

The daily emission rate of nitrous oxide stayed on a realtively constant level throughout the whole storage period (fig. 13). No trend or correlation with the slurry temperature could be observed. Cumulated emissions showed a constant linear increase during the 120 day storage (fig. 14). Cumulated nitrous oxide emissions from cattle slurry with EM were significantly lower than those from cattle slurry without EM addition.

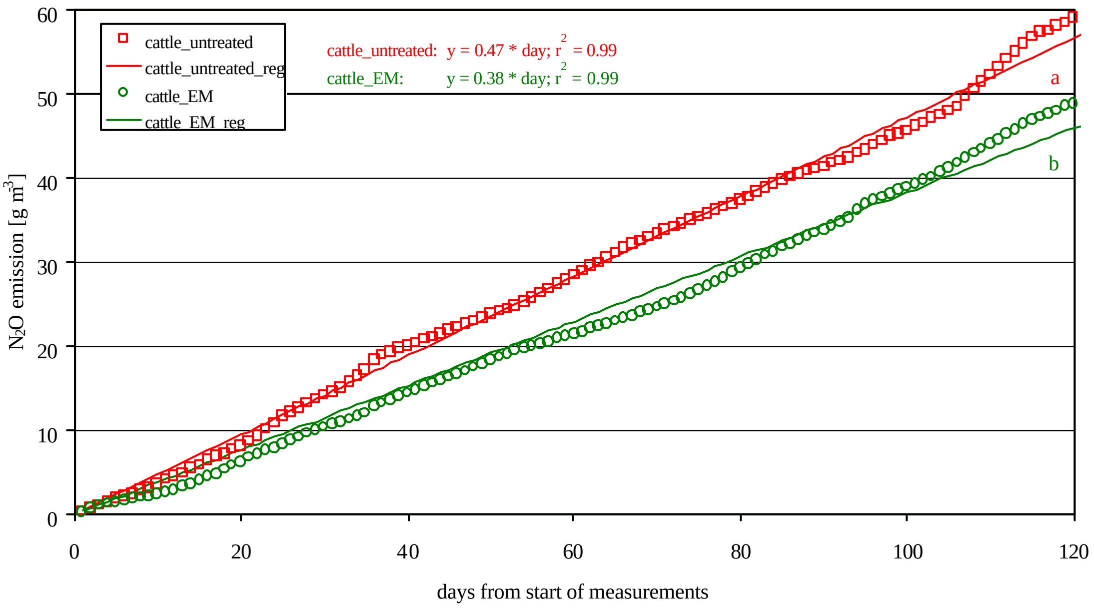


Figure 14 Cumulated nitrous oxide emissions from cattle slurry with and without addition of EM.

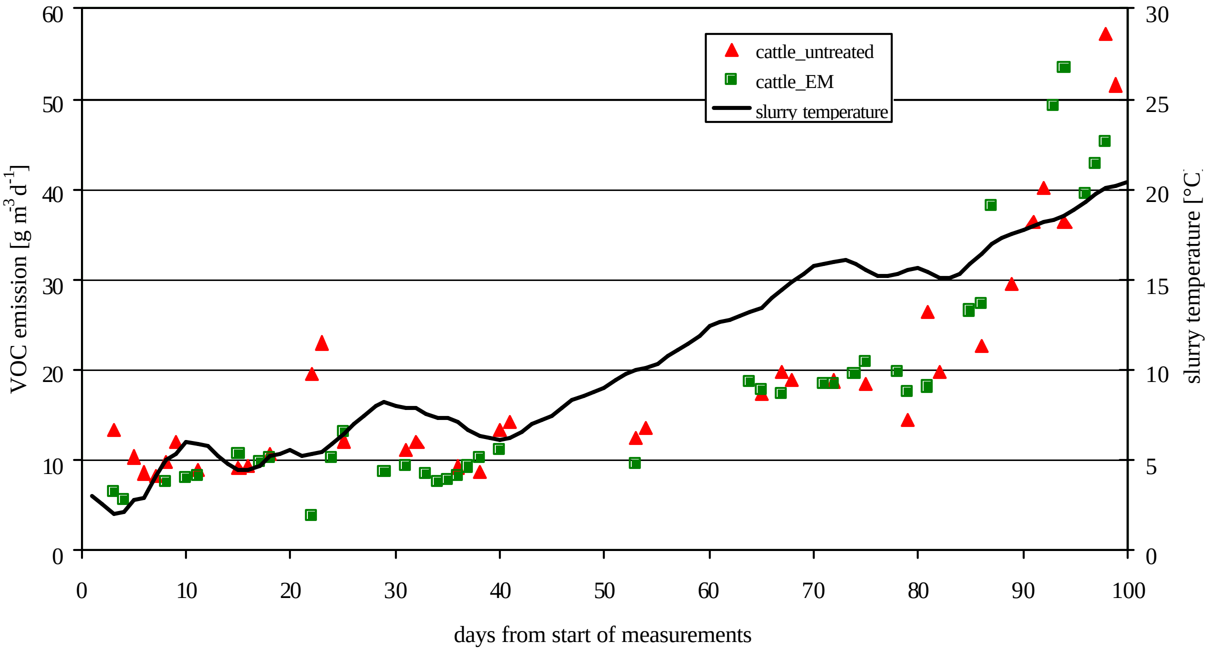


Figure 15 Daily VOC emissions from cattle slurry with and without addition of EM.

The daily VOC emission rate showed a slight increase in course of the storage period (fig. 15). At the beginning – when slurry and air temperature were low – daily VOC emissions were around 10 g m^{-3} d^{-1}. With the rise in slurry temparture in course of the experiments, daily VOC emissions increased to *c.* 50 g m^{-3} d^{-1}.

Cumulated VOC emissions from untreated cattle slurry were significantly higher than from cattle slurry with EM addition (fig. 16). EM is able to reduce the potential for odour emissions during storage of cattle slurry.

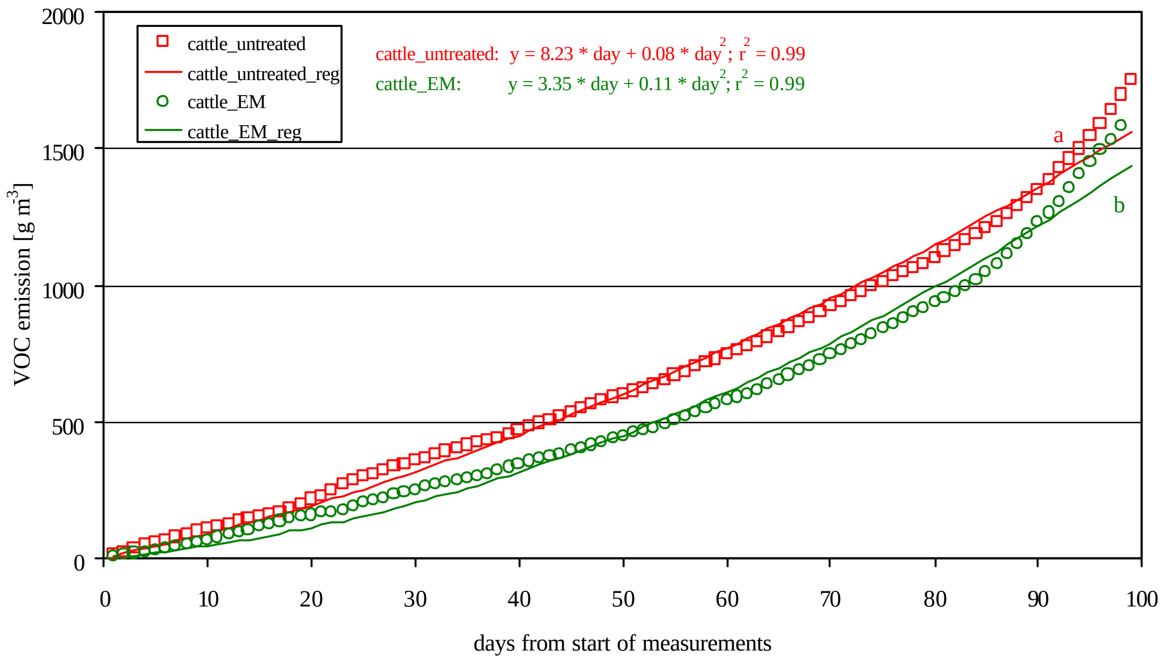


Figure 16 Cumulated VOC emissions from cattle slurry with and without addition of EM.

3.1.3 Cumulated emissions from cattle slurry with and without addition of EM

Table 3 gives net total methane emissions during storage of cattle slurry. Untreated cattle slurry emitted 894.18 g CH_4 which corresponds to 670.63 CH_4-C per m^3 of slurry. When EM was added, emissions amounted to 910.11 g CH_4, and 682.58 CH_4-C per m^3 of slurry, respectively. The difference between the two treatments is not statistically significant. Per kg of volatile solids (= organic dry matter), 97.9 g CH_4-C (cattle_untreated) and 99.6 g CH_4-C (cattle_EM) were lost.

Table 3 Cumulated methane emissions during storage of cattle slurry with and without addition of EM.

treatment	*cumulated emissions of…*		
	CH_4 [g (m^3 FM)$^{-1}$]	CH_4-C [g (m^3 FM)$^{-1}$]	CH_4-C [g (kg VS)$^{-1}$]
cattle_untreated	894.2 [a]	670.6	97.9
cattle_EM	910.1 [a]	682.6	99.6

FM = slurry fresh matter

Table 4 summarises cumulated ammonia emissions. Cattle slurry without EM addition lost 152.7 g NH_3, which corresponds to 125.74 g NH_3-N per m^3 of slurry. Addition of EM resulted in a significant decrease in NH_3 emissions of *c.* 20 %. NH_3-N emissions per kg of total N content were 32.9 g (cattle_untreated), and 26.3 g (cattle_EM), respectively. NH_3-N emissions expressed as g NH_3-N per kg of total ammoniacal N content amounted to 65.1 (cattle_untreated), and 52.0 (cattle_EM), respectively.

Table 4 Cumulated ammonia emissions during storage of cattle slurry with and without addition of EM.

treatment	*cumulated emissions of*			
	NH_3 [g (m^3 FM)$^{-1}$]	NH_3-N [g (m^3 FM)$^{-1}$]	NH_3-N [g (kg N_t)$^{-1}$]	NH_3-N [g (kg NH_4-N)$^{-1}$]
cattle_untreated	152.7 [a]	125.7	32.9	65.1
cattle_EM	121.9 [b]	100.4	26.3	52.0

FM = slurry fresh matter

EM addition to cattle slurry at the beginning of slurry storage significantly reduced N_2O emissions (table 5). Without EM addition, a net total of 60.0 g N_2O was lost, which corresponds to 38.2 g N_2O-N. EM addition reduced N_2O emissions by *c.* 16.5 %. Per kg of total nitrogen content, 10.0 (cattle_untreated) and 8,3 (cattle_EM) g N_2O-N were lost. Cumulated N_2O-N losses per kg of total ammoniacal N were 19.8 g (cattle_untreated), and 16.5 g (cattle_EM), respectively.

Table 5 Cumulated nitrous oxide emissions during storage of cattle slurry with and without addition of EM.

treatment	*cumulated emissions of…*			
	N_2O [g (m^3 FM)$^{-1}$]	N_2O-N [g (m^3 FM)$^{-1}$]	N_2O-N [g (kg N_t)$^{-1}$]	N_2O-N [g (kg NH_4-N)$^{-1}$]
cattle_untreated	60.0 [a]	38.2	10.0	19.8
cattle_EM	50.1 [b]	31.9	8.3	16.5

FM = slurry fresh matter

Table 6 summarises CH_4, NH_3, N_2O, VOC and greenhouse gas emissions during storage of cattle slurry with and without EM addition. Greenhouse gas emissions are given as CO_2 equivalents. Net total CO_2 eq. result from the addition of methane emissions * 21 and nitrous oxide emissions * 310.

EM addition did not significantly alter methane emissions. N_2O emissions were significantly lowered through EM. Net total greenhouse gas emissions (CH_4 and N_2O) were lower from EM amended cattle slurry than from untreated cattle slurry.

Ammonia emissions and thus nitrogen losses during slurry storage were reduced when EM was added to cattle slurry at the beginning of the storage period. VOC emissions, an indicator for the potential for odour emissions, were lower in the treatment cattle_EM.

Addition of EM showed a positive effect on the reduction of N_2O, NH_3, VOC and greenhouse gas emissions. Negative effects were not observed.

Table 6 Cumulated emissions during storage of cattle slurry with and without addition of EM.

treatment	*cumulated emissions of…*				
	CH_4	NH_3	N_2O	VOC	CO_2 eq. [kg (m^3 FM)$^{-1}$]
	[g (m^3 FM)$^{-1}$]				
cattle_untreated	894.2 [a]	152.7 [a]	60.0 [a]	1.75 [a]	37.4
cattle_EM	910.1 [a]	121.9 [b]	50.1 [b]	1.58 [b]	34.6

FM = slurry fresh matter

3.2 Pig slurry

3.2.1 Slurry composition

Table 7 and figure 17 show the composition of pig slurries at the start and at the end of the storage experiments. The farm that delivered the slurries “pig_untreated” and “pig_EM” diluted them with water prior to storage outside the pig house. This resulted in a relatively low dry matter content of 1.97 %, and 1.95 %, respectively. During storage, dry matter content of both treatments was further reduced. Slurry from pigs that were fed EM (“pig_EMfeed”) had a dry matter content of 5.40 % at the beginning of storage. After the 100-days storage period, a dry matter content of 3.71 % was measured. Due to the lower dry matter content, volatile solids content (= organic dry matter) in “pig_untreated” and “pig_EM” was lower than in “pig_EMfeed”. PH values at the beginning of storage were similar with all treatments (8.12 – 8.17). At the end, pH values ranged from 7.85 (“pig_EMfeed”) to 8.08 (“pig_untreated”). Total N content of all slurries was reduced in course of slurry storage.

Table 7 Slurry composition at the start and at the end of the storage period.

		N_t [g (kg FM)$^{-1}$]	NH_4-N [g (kg FM)$^{-1}$]	C [g (kg FM)$^{-1}$]	C : N	TS [% FM]	VS [% FM]	pH
pig_untreated	start	5.36	5.04	6.30	1.17	1.97	1.09	8.17
	end	4.65	4.42	6.68	1.44	1.72	0.91	8.08
pig_EM	start	4.97	4.40	6.70	1.35	1.97	1.14	8.12
	end	4.70	4.34	6.52	1.39	1.68	0.88	7.91
pig_EMfeed	start	6.96	5.94	19.31	2.78	5.40	3.64	8.15
	end	6.80	5.20	7.45	1.10	3.71	1.38	7.85

FM = slurry fresh matter

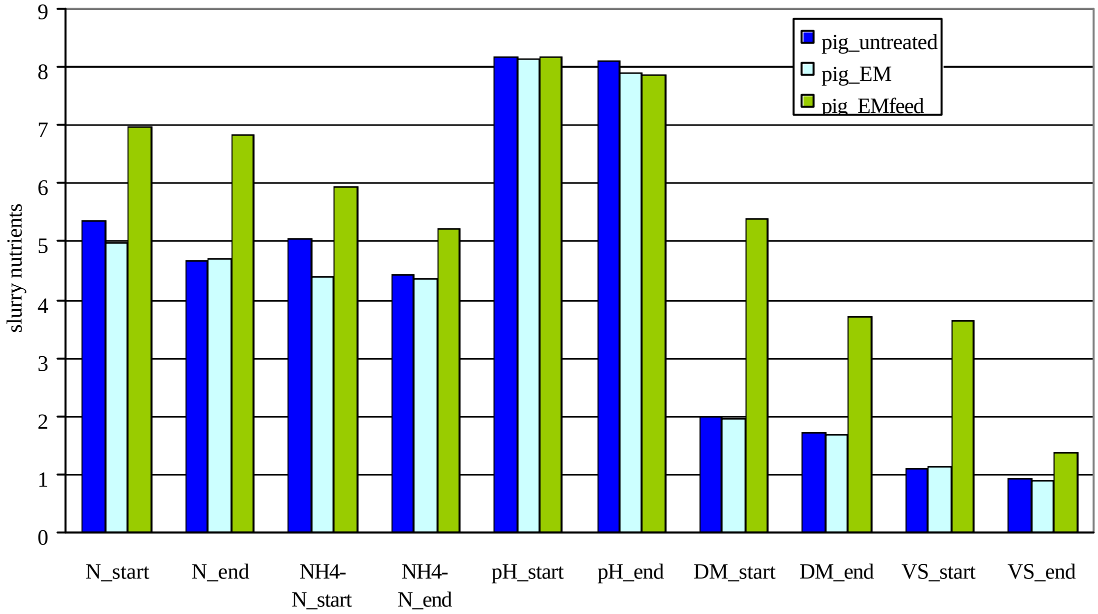


Figure 17 Composition of pig slurry with and without EM addition and of slurry from pigs that were fed EM at the start and at the end of the storage period.

3.2.2 Emissions during slurry storage

The following chapter gives results from the emission measurements from untreated and EM amended pig slurry and from slurry where pigs were fed EM. Daily emission rates and slurry temperature from March to June 2003 are shown. Daily emission rates are given as g per m^3 of slurry and day. The sum of daily emissions gives cumulated emissions that are shown in separate figures. From the cumulated curve net total emissions can be taken. Cumulated emissions are given as g per m^3 of slurry fresh matter.

Regression curves were fitted to cumulated emissions. Regression equation, and coefficient of determination are given in the respective figures. Differences in regression equations were tested with a pairwise comparison of regression parameters by the t-test.

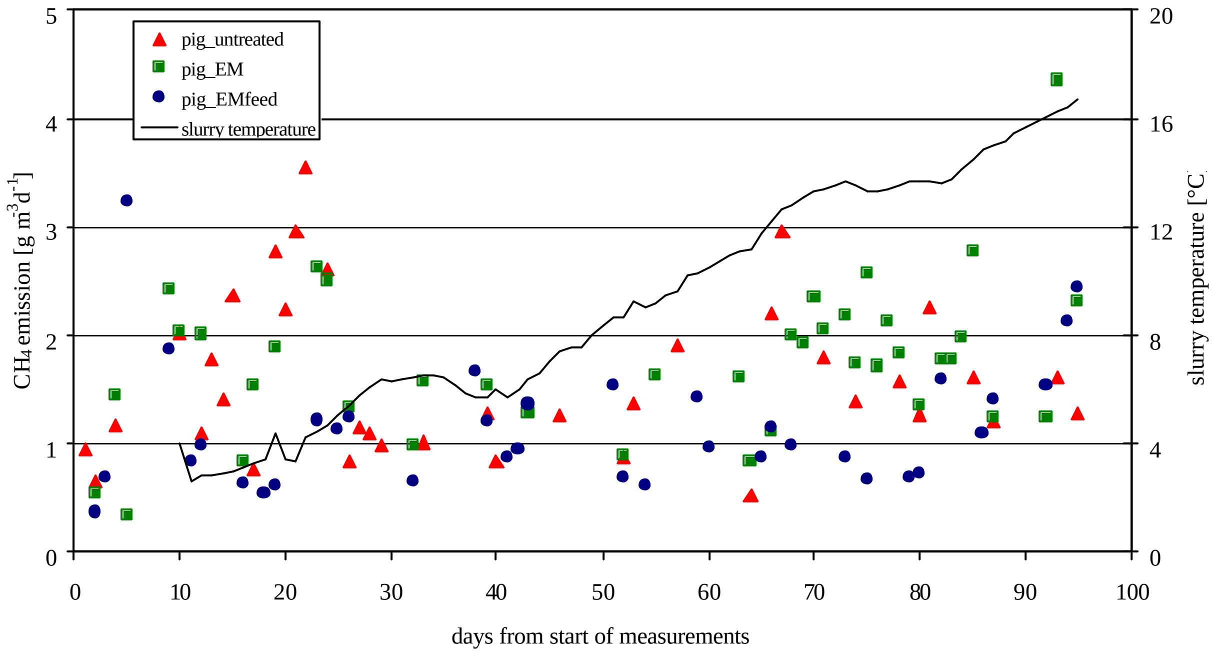


Figure 18 Daily methane emissions from pig slurry with and without addition of EM and from slurry from pigs that were fed EM.

With pig slurry, daily methane emissions did not correlate with slurry temperature (fig. 18). In the first 20 days of storage, emissions were relatively high compared to the rest of the storage period. After day 20, methane emissions stayed fairly constant.

Cumulated emissions increased linearily during the experiments (fig. 19). No significant difference was measured between the treatments “pig_untreated” and “pig_EM”. Feeding EM to pigs resulted in an significant decrease in cumulated methane emissions.

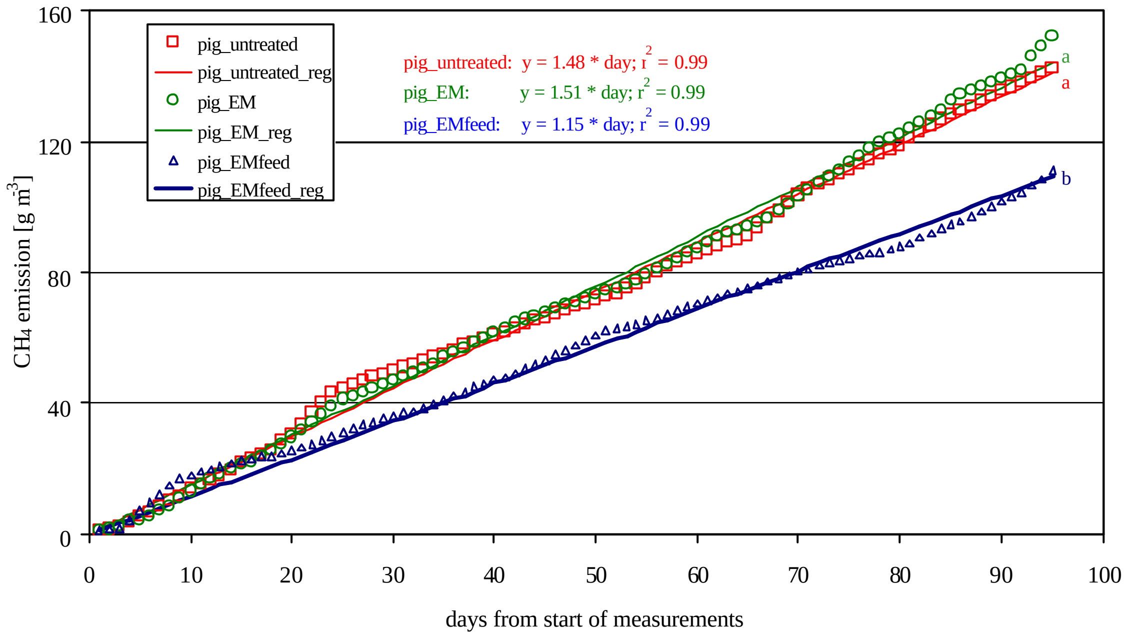


Figure 19 Cumulated methane emissions from pig slurry with and without addition of EM and from slurry from pigs that were fed EM.

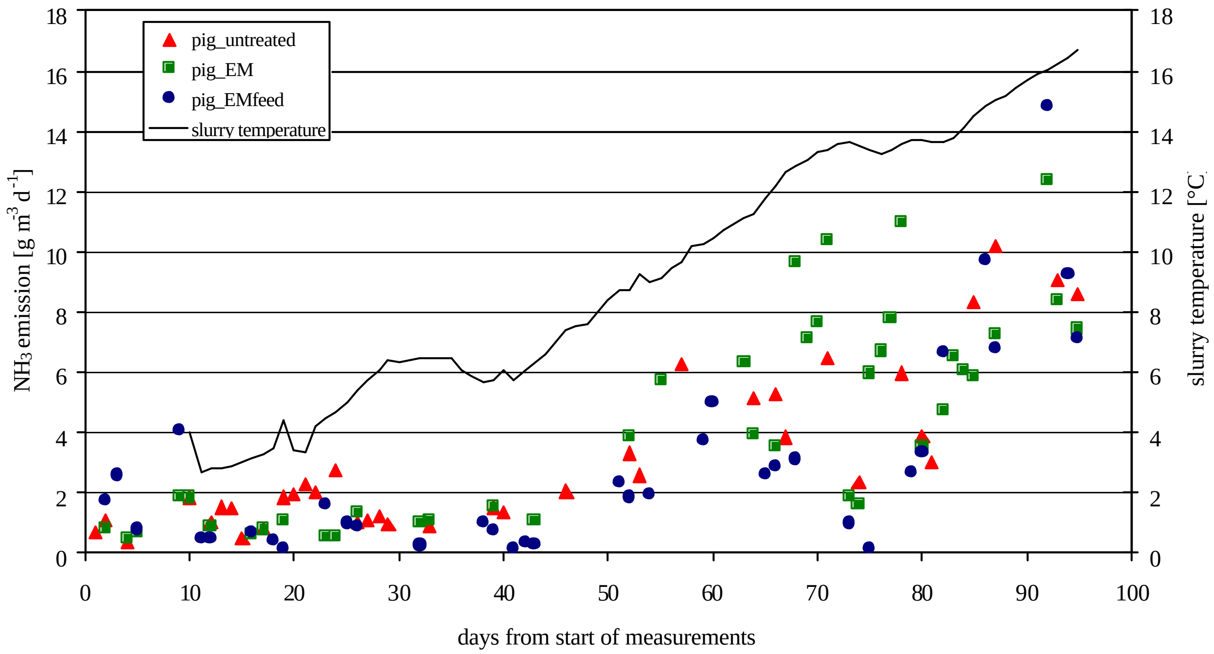


Figure 20 Daily ammonia emissions from pig slurry with and without addition of EM and from slurry from pigs that were fed EM.

Daily ammonia emissions rose in course of the storage period (fig. 20). Slurry temperature significantly influences the daily ammonia emission rate (fig. 21). The regression equation that quantifies the correlation between slurry temperature and daily ammonia emission has a coefficient of determination of 0.75.

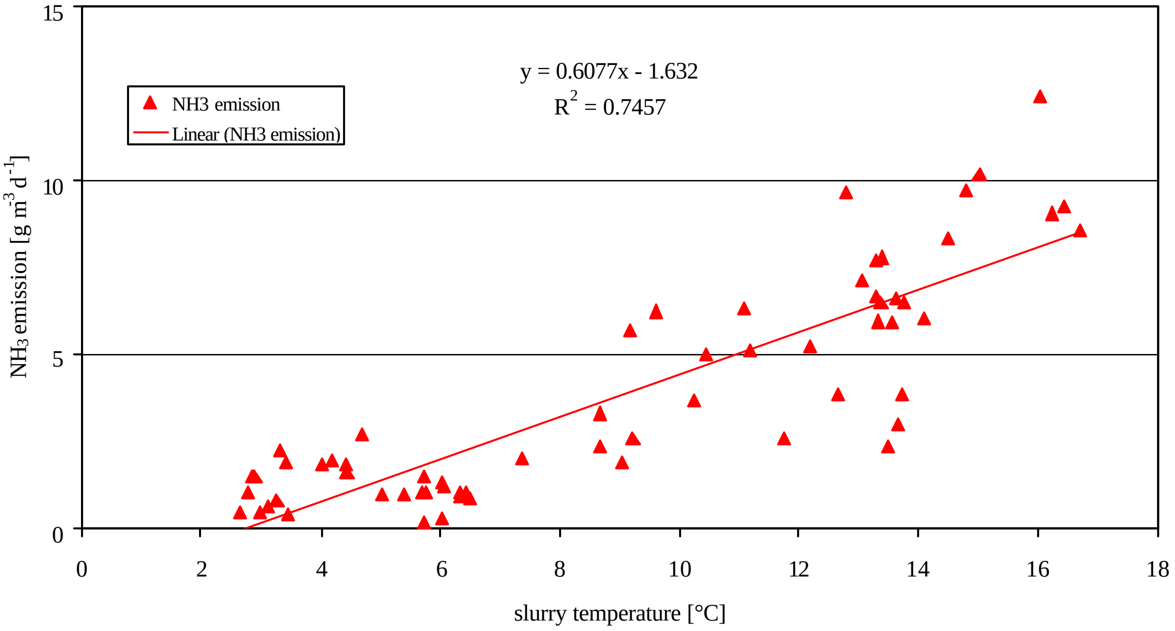


Figure 21 Correlation between ammonia emissions from pig slurry (all treatments) and slurry temperature

There was a small, but significant difference in cumulated ammonia emissions between pig slurry with and without EM addition (fig. 22). Addition of EM at the beginning of slurry storage slightly increased net total ammonia emissions. When EM was added to the pigs` feed, ammonia emissions during slurry storage were considerably lower than from untreated slurry and from slurry where EM was added only at the beginning of slurry storage. Addition of EM to the pigs` feed is a means to reduce ammonia emissions during slurry storage.

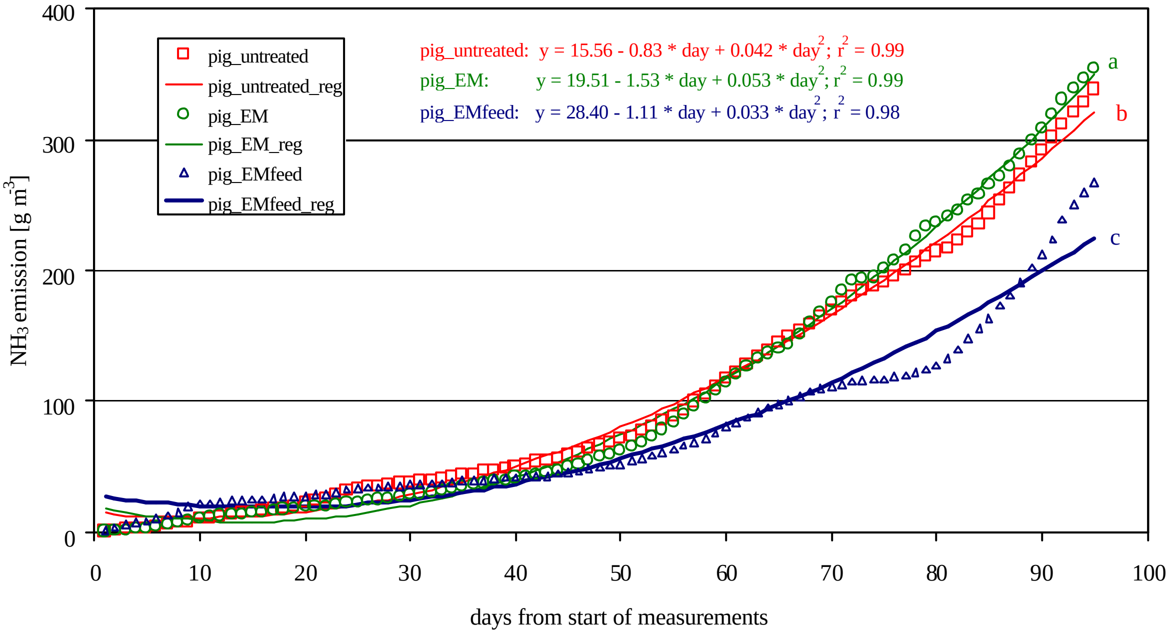


Figure 22 Cumulated ammonia emissions from pig slurry with and without addition of EM and from slurry from pigs that were fed EM.

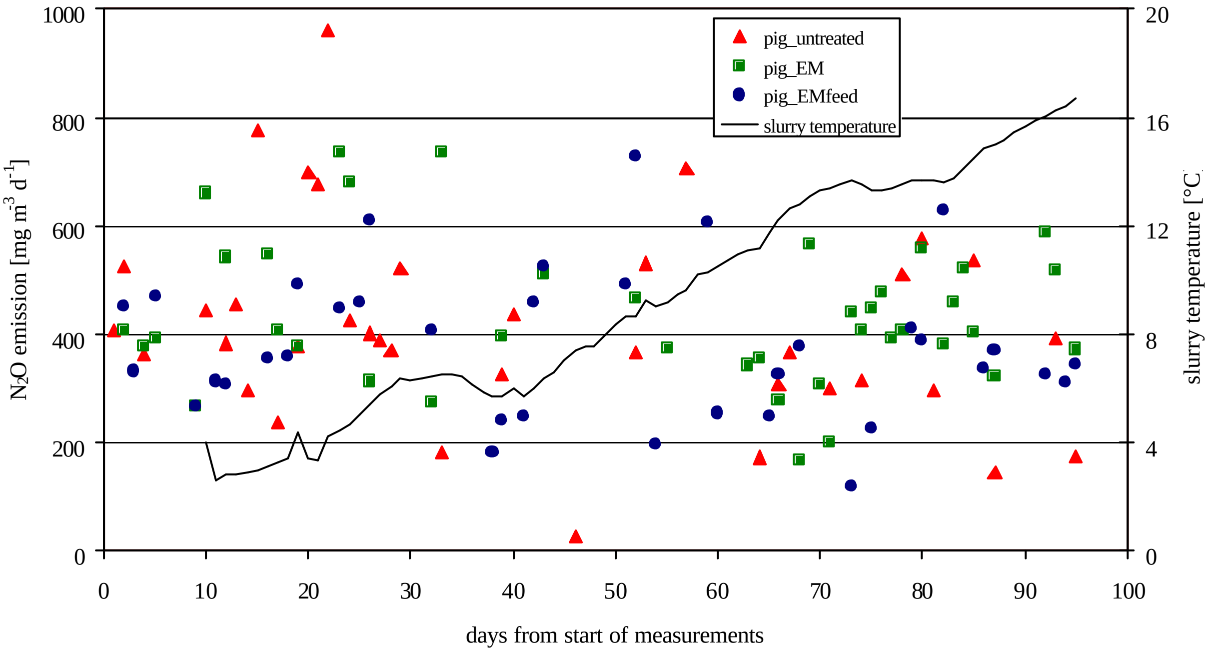
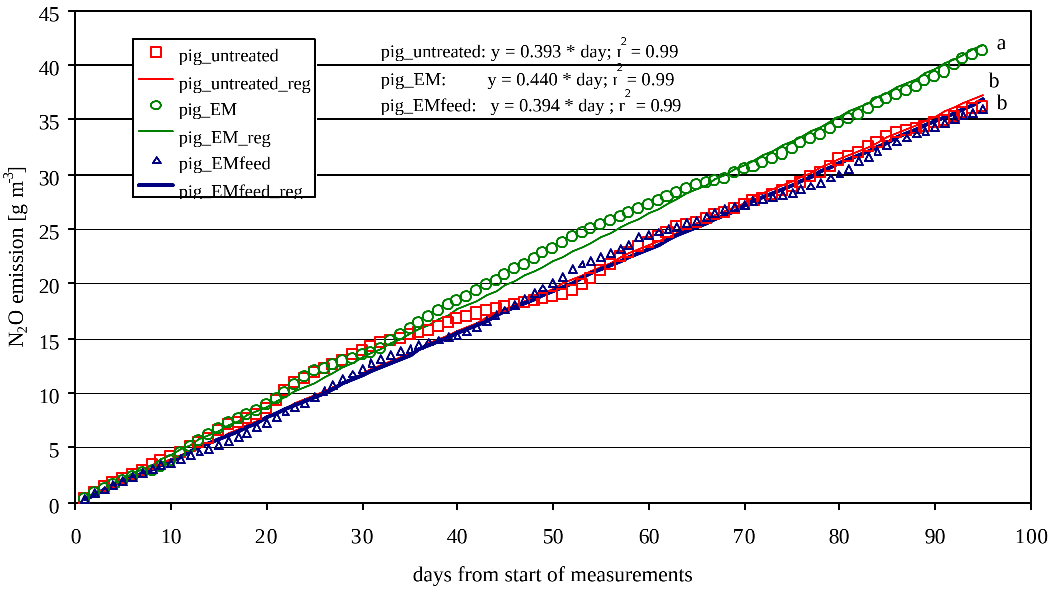


Figure 23 Daily nitrous oxide emissions from pig slurry with and without addition of EM and from slurry from pigs that were fed EM.

Daily nitrous oxide emissions did not show a trend in course of the storage period. There was no correlation with slurry temperature (fig. 23). Cumulated nitrous oxide emissions linearly increased throughout the whole storage period (fig. 24). EM addition at the beginning of slurry storage (“pig_EM”) led to a significant increase in net total nitrous oxide emissions. There was hardly any



difference in nitrous oxide emissions between untreated slurry and slurry from pigs that were fed EM.

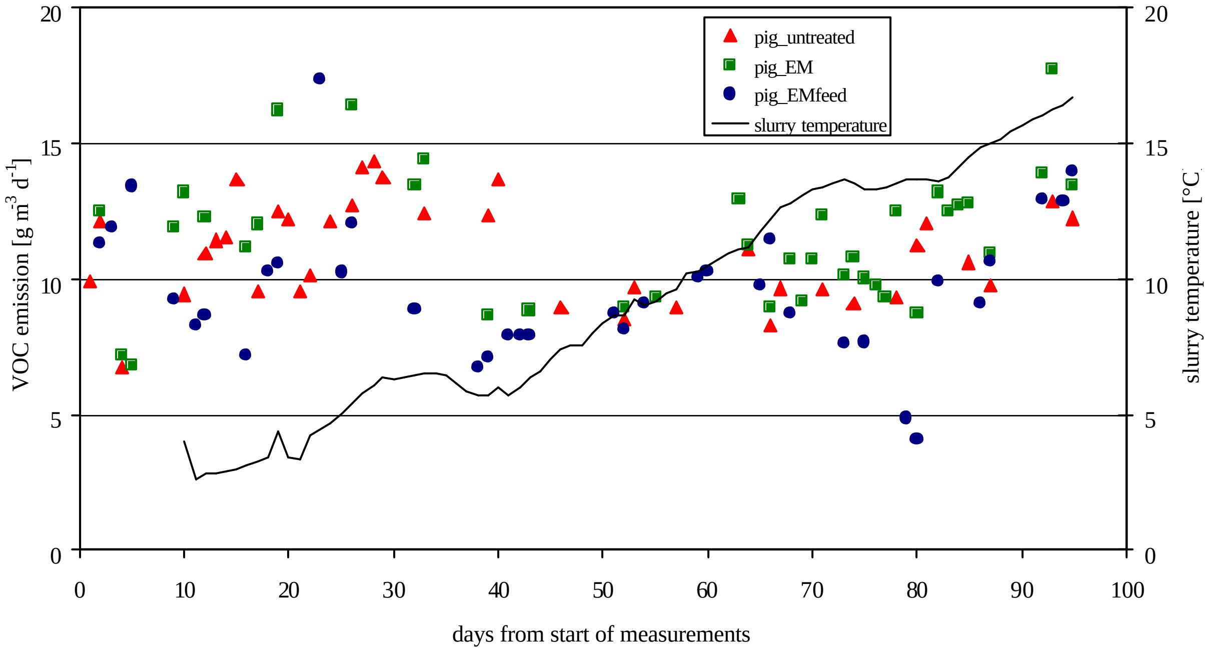
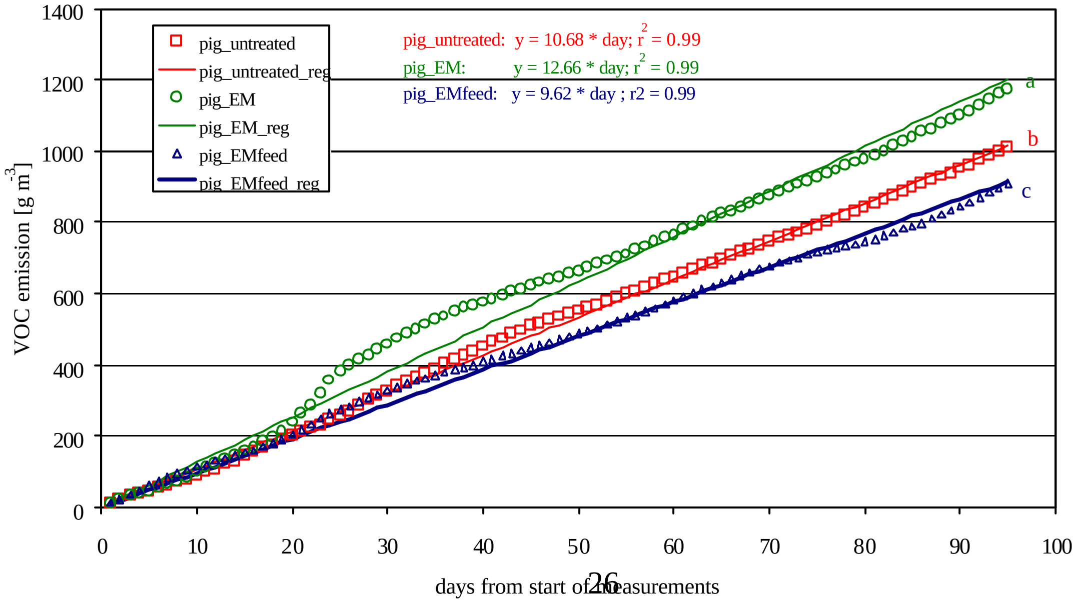


Figure 24 Cumulated nitrous oxide emissions from pig slurry with and without addition of EM and from slurry from pigs that were fed EM.

Figure 25 Daily VOC emissions from pig slurry with and without addition of EM and from slurry from pigs that were fed EM.

Daily VOC emissions stayed relatively constant throughout the whole measurement period (fig. 25). Cumulated emissions showed a linear increase (fig. 26). EM addition at the beginning of slurry storage (“pig_EM”) significantly increased net total VOC emissions. This means, that EM amended slurry had a higher potential for odour emissions. When EM was added to the pigs` feed (“pig_EMfeed”), net total VOC emissions during storage were significantly lowered compared to



slurry without EM addition (“pig_untreated”).

Figure 26 Cumulated VOC emissions from pig slurry with and without addition of EM and from slurry from pigs that were fed EM.

3.2.3 Cumulated emissions from pig slurry with and without addition of EM and from slurry from pigs that were fed EM

Table 8 gives net total methane emissions during storage of pig slurry. Untreated pig slurry emitted 142.3 g CH_4 per m^3 of slurry which corresponds to 106.7 g CH_4-C m^{-3}. When EM was added at the beginning of slurry storage, CH_4 emissions rose to 151.6 g CH_4 / 113.7 g CH_4-C per m^3 of slurry. The difference between both treatments was not statistically significant. Per kg of volatile solids in the slurry, 97.9 g CH_4-C ("pig_untreated") and 99.8 g CH_4-C ("pig_EM") were lost. EM addition to the pig´s feed drastically reduced methane emissions during slurry storage. The difference in CH_4 emissions per m^3 of fresh slurry is statistically significant. As shown in table 7, the treatment "pig_EM feed" had a much higher VS content than the two other treatments. Methane is formed from volatile solids in the slurry. According to the IPCC Guidelines, national inventories are required to estimate methane emissions from slurry stores from the volatile solid content of slurries. When net total methane emissions are expressed as g CH_4-C per kg of VS, the positive effect of feeding EM reveals even more clearly. The treatment "pig_untreated" and "pig_EM" emitted c. 100 g CH_4-C per kg VS, whereas methane emissions from "pig_EMfeed" amounted only to 22.8 g CH_4-C per kg VS.

Table 8 Cumulated methane emissions during storage of pig slurry with and without EM addition and of slurry from pigs that were fed EM.

treatment	*cumulated emissions of…*		
	CH_4 [g (m^3 FM)$^{-1}$]	CH_4-C [g (m^3 FM)$^{-1}$]	CH_4-C [g (kg VS)-1]
pig_untreated	142.3 [a]	106.7	97.9
pig_EM	151.6 [a]	113.7	99.8
pig_EMfeed	110.8 [b]	83.1	22.8

FM = slurry fresh matter

Table 9 summarises net total ammonia emissions from storage of pig slurry. From untreated slurry, 337.9 g NH_3 and 278.2 g NH_3-N per m^3 of slurry were lost. EM addition at the beginning of slurry storage slightly increased NH_3 emissions by *c.* 2 %. Per kg of total nitrogen in the slurry, 51.9 g NH_3-N ("pig_untreated"), and 58.7 g NH_3-N ("pig_EM"), respectively, were lost. NH_3-N losses per kg of total ammoniacal nitrogen amounted to 55.2 g ("pig_untreated"), and 66.3 g ("pig_EM"), respectively.

When pigs were fed EM, ammonia emissions during slurry storage significantly decreased. The treatment "pig_EMfeed" emitted *c.* 21 % less NH_3 than untreated pig slurry. Emission inventories estimate NH_3 emissions during slurry storage either as g NH_3-N per kg of N_t or per kg of NH_4-N. Both, N_t and NH_4-N content were higher in the slurry that was received from pigs that were fed EM than in the untreated slurry. Reduction of ammonia emissions through feeding EM revealed even more clearly when NH_3-N emissions were expressed as per kg of N_t or per kg of NH_4-N. The treatment “pig_EMfeed” emitted 31.6 g NH_3-N (kg N_t)$^{-1}$, and 37.0 g NH_3-N (kg NH_4-N)$^{-1}$.

Table 9 Cumulated ammonia emissions during storage of pig slurry with and without EM addition and of slurry from pigs that were fed EM.

treatment	*cumulated emissions of…*			
	NH_3 [g (m^3 FM)$^{-1}$]	NH_3-N [g (m^3 FM)$^{-1}$]	NH_3-N [g (kg N_t)$^{-1}$]	NH_3-N [g (kg NH_4-N)$^{-1}$]
pig_untreated	337.9 ^{a}	278.2	51.9	55.2
pig_EM	354.3 ^{b}	291.8	58.7	66.3
pig_EMfeed	266.9 ^{c}	219.8	31.6	37.0

FM = slurry fresh matter

Addition of EM at the beginning of slurry storage led to an increase in net total nitrous oxide emissions (table 10). Untreated pig slurry emitted 36.1 g N_2O / 23.0 g N_2O-N per m^3 of slurry. When EM was added, cumulated emissions of 41.3 g N_2O / 26.3 g N_2O-N per m^3 of slurry were measured. Per kg of total nitrogen content, 4.3 g N_2O-N ("pig_untreated"), and 5.3 g N_2O-N ("pig_EM") were lost. Cumulated nitrous oxide emissions per kg of total ammoniacal nitrogen were 4.6 g N_2O-N ("pig_untreated"), and 6.0 g N_2O-N ("pig_EM").

Feeding EM did not result in differences in net total N_2O emissions per m^3 of slurry compared to untreated slurry. However, as mentioned before, total N content in the treatment "pig_EMfeed" was higher than in untreated pig slurry. N_2O-N emissions per kg of total nitrogen content were *c.* 23 % lower than from untreated slurry. EM addition to the pigs´ feed reduces N_2O-N emissions during slurry storage.

Table 10 Cumulated nitrous oxide emissions during storage of pig slurry with and without EM addition and of slurry from pigs that were fed EM.

treatment	*cumulated emissions of…*			
	N_2O [g (m^3 FM)$^{-1}$]	N_2O-N [g (m^3 FM)$^{-1}$]	N_2O-N [g (kg N_t)$^{-1}$]	N_2O-N [g (kg NH_4-N)$^{-1}$]
pig_untreated	36.1 ^{a}	23.0	4.3	4.6
pig_EM	41.3 ^{b}	26.3	5.3	6.0
pig_EMfeed	36.0 ^{a}	22.9	3.3	3.9

FM = slurry fresh matter

Table 11 summarises CH_4, NH_3, N_2O, VOC and greenhouse gas emissions during storage of pig slurry with and without EM addition and of pig slurry that was received from pigs that were fed EM. Greenhouse gas emissions are given as CO_2 equivalents. Net total CO_2 eq. result from the addition of methane emissions * 21 and nitrous oxide emissions * 310.

EM addition to pig slurry at the beginning of slurry storage resulted in an increase of all gaseous emissions. With pig slurry, EM addition at the beginning of the storage did not show positive effects.

EM addition to the pigs´ feed, however, reduced the emission of all gaseous compounds that were measured and has thus very positive environmental effects. There was a distinct reduction in methane emissions. Net total greenhouse gas emissions were lowered by *c.* 50 %. Nitrogen losses and the potential for odour emissions was lower when pigs were fed EM compared to untreated slurry.

Table 11 Cumulated emissions during storage of pig slurry with and without EM addition and of slurry from pigs that were fed EM.

treatment	*cumulated emissions of …*				
	CH$_4$-C [g (kg VS)$^{-1}$]	NH$_3$-N [g (kg N$_t$)$^{-1}$]	N$_2$O-N [g (kg N$_t$)$^{-1}$]	VOC [kg (kg VS)$^{-1}$]	CO$_2$-Äquiv. [kg (kg VS)$^{-1}$]
pig_untreated	97.9	51.9	4.3	928.3	4.83
pig_EM	99.8	58.7	5.3	1029.5	5.37
pig_EMfeed	22.8	31.6	3.3	249.9	2.24

3.2.4 *Comparison of maximum methane production potential and methane emissions during slurry storage in pilot scale slurry tanks*

Slurry from the treatment “pig_EMfeed“ was anaerobically digested in lab scale eudiometers with the aim to quantify the maximum methane production potential. Figure 27 gives the course of methane production during anaerobic digestion. Methane production was high in the first 25 days. Afterwards, methane production declined. After 50 days hardly any additional methane was formed.

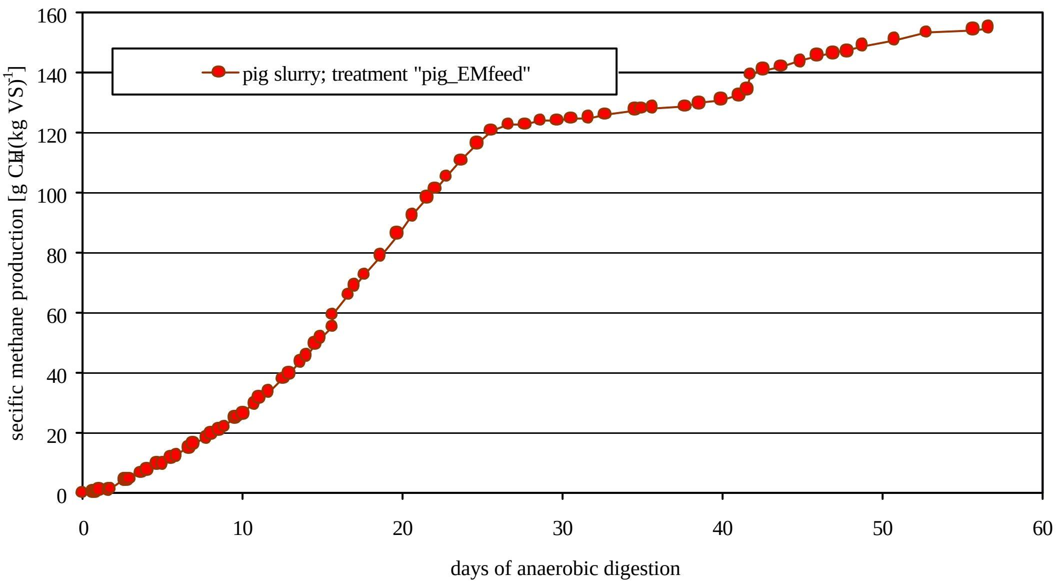


Figure 27 Maximum methane production from anaerobic digestion of pig slurry in an eudiometer.

A net total of 154.73 g CH_4 (kg VS)$^{-1}$ was formed. This is the maximum amount of methane that can be built during anaerobic digestion of the slurry “pig_EMfeed”. In the pilot scale slurry tanks at the research station Gross Enzersdorf, 30.45 g CH_4 (kg VS)$^{-1}$ were lost during the 100 day storage period. This value corresponds to methane emissions that can be expected during storage of slurry on commercial farms. 30.45 g CH_4 (kg VS)$^{-1}$ correspond to 19.7 % of the maximum methane production potential that was measured in the lab.

4 Conclusions

- Addition of “Effective Micro-Organisms (EM)“ at the beginning of dairy cattle slurry storage (dry matter 9.39 %) had positive environmental effects. Methane emissions were only to a small extent influenced by EM addition. A significant reduction in ammonia and nitrous oxide emissions and in the potential for odour emissions was observed. Net total greenhouse emissions were lower with EM addition.
- EM addition at the beginning of dairy cattle slurry storage can be recommended.
- In further experiments the impact of EM addition to dairy cattle feed on emissions during slurry storage should be clarified.
- With pig slurry, EM addition at the beginning of slurry storage had no or negative effects on the emissions of CH_4, NH_3, N_2O, VOC and greenhouse gas emissions. The very low dry matter content of the pig slurry is very likely the reason for this phenomenon. Dry matter content was only 1.97 %, which is unusually low. Pig slurry was received from a commercial farm at very low outside temperatures. The solids had formed a frozen surface crust on the commercial slurry store. The liquid slurry under this surface crust was deficient of solids.
- Effective Micro-Organisms can not optimally develop in slurry with a very low dry matter content. Thus, the experiment should be repeated with pig slurry that has a higher dry matter content. Only then reliable information on the effect of EM addition on emissions during pig slurry storage can be given.
- EM addition to the pigs´ feed significantly reduced emissions of CH_4, NH_3, N_2O, VOC and greenhouse gas emissions. EM addition to the feed has positive environmental effects on emissions during pig slurry storage.