University of Natural Resources
and Applied Life Sciences
Department for Sustainable Agricultural Systems
Division of Agricultural Engineering

Ammonia, Nitrous Oxide, Methane and VOC Emissions During Storage of Pig Slurry and Pig Farmyard Manure and Influence of the Additive „Effective Microorganisms (EM)“

Final report
August 2005

Dr. Barbara Amon
Dr. Vitaliy Kryvoruchko
Dipl.-Ing. Martina Fröhlich
Ao.Univ.Prof. Dipl.-Ing. Dr. Thomas Amon

On behalf of Multikraft Ltd.

Table of Contents

1 Introduction

Animal welfare and environmental protection are increasingly important. Housing systems must be found that offer animal welfare and emit little ammonia and greenhouse gases. The environmental impact of housing systems can only be assessed if the whole manure management continuum is considered. This means, that emissions from the animal house, during manure storage and after manure application must be included in the evaluation procedure. The housing system not only influences emissions from the animal house, but as well has a considerable impact on emissions from the subsequent manure storage.

The influence of the application of “Effective Microorganisms (EM)” in a straw flow system for fattening pigs has been investigated and is documented in AMON ET AL. (2004a). The research project presented in this report goes one step further and measures emissions during the storage of pig slurry and pig solid manure received from two straw flow systems.

The straw flow system can be operated as a liquid or as a solid manure system. When the pigs are offered 50 – 100 g non chopped straw per pig and day, is produced that due to its low dry matter content can be handled as slurry. ZALUDIK (1997) wanted to find the optimum amount of straw that has to be littered down in a straw flow system. She littered down 50 and 100 g non-chopped straw per pig and day and she observed the pigs` reaction to the different amounts of straw. No difference in the length of straw directed behaviour was found between the two treatments. It may be concluded that 50 g non-chopped straw per pig and day are sufficient to allow the pigs to show their innate explorative behaviour. When more straw is used, solid manure is produced from a straw flow system.

The research project quantified emissions of ammonia (NH_3), nitrous oxide (N_2O), methane (CH_4) and volatile organic carbons (VOC) from pig slurry and pig farmyard manure with and without the addition of “Effective Microorganisms (EM)”.

2 Experimental Design

2.1 ILT experimental facility at Gross-Enzersdorf

In course of the research project “Methane, Nitrous Oxide and Ammonia Emissions from Management of Liquid Manures“ the Division of Agricultural Engineering (Institut für Landtechnik, ILT) developed an experimental facility for the quantification of emissions from slurry and farmyard manure stores (AMON ET AL. 2002).

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. ZAMG[1] supplied hourly means of air temperature, relative humidity, precipitation and air pressure at Gross-Enzersdorf.

---

[1] Central Institute of Meteorology and Geodynamics

Slurry tanks and farmyard manure storage. In March 1999, five slurry tanks and a concrete area for farmyard manure storage were built at the research site Gross-Enzersdorf. Slurry tanks are 2.5 m deep and have a diameter of 2.5 m. They are 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 is installed, where solid manure can be stored and / or composted. The concrete area covers an area of 4 * 10 m. Figures 1 and 2 show the design of the experimental facility. 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 is installed on which the large open dynamic chamber can easily be moved from one tank to the other.

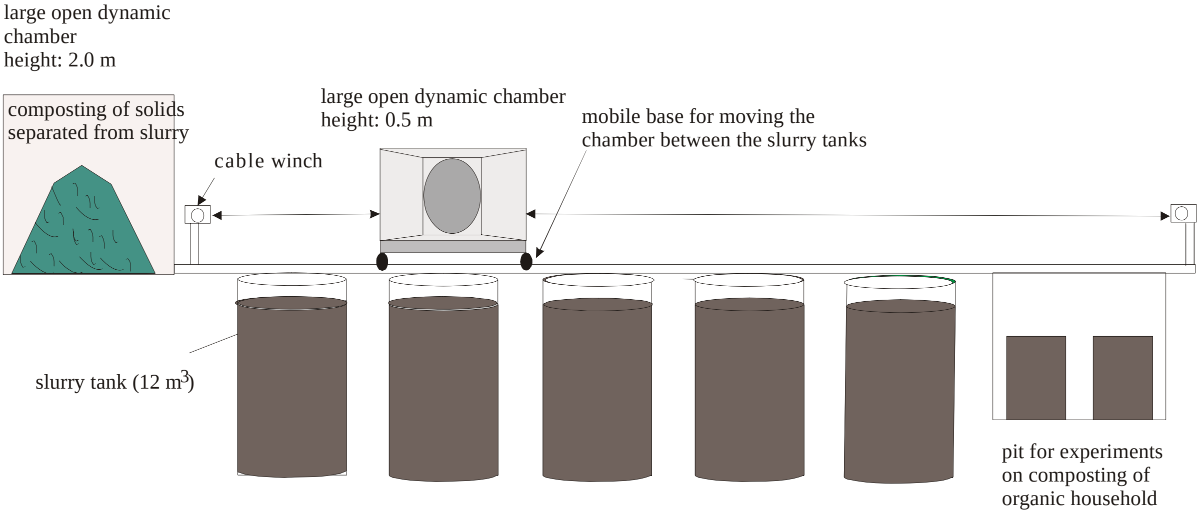

Figure 1. Design of the experimental facility for quantifying emissions from manure storage (side view) (after AMON ET AL. 2002)

The slurry tanks were filled with about 10 m^3 slurry. Emissions of NH_3, N_2O, CH_4 and VOC 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.

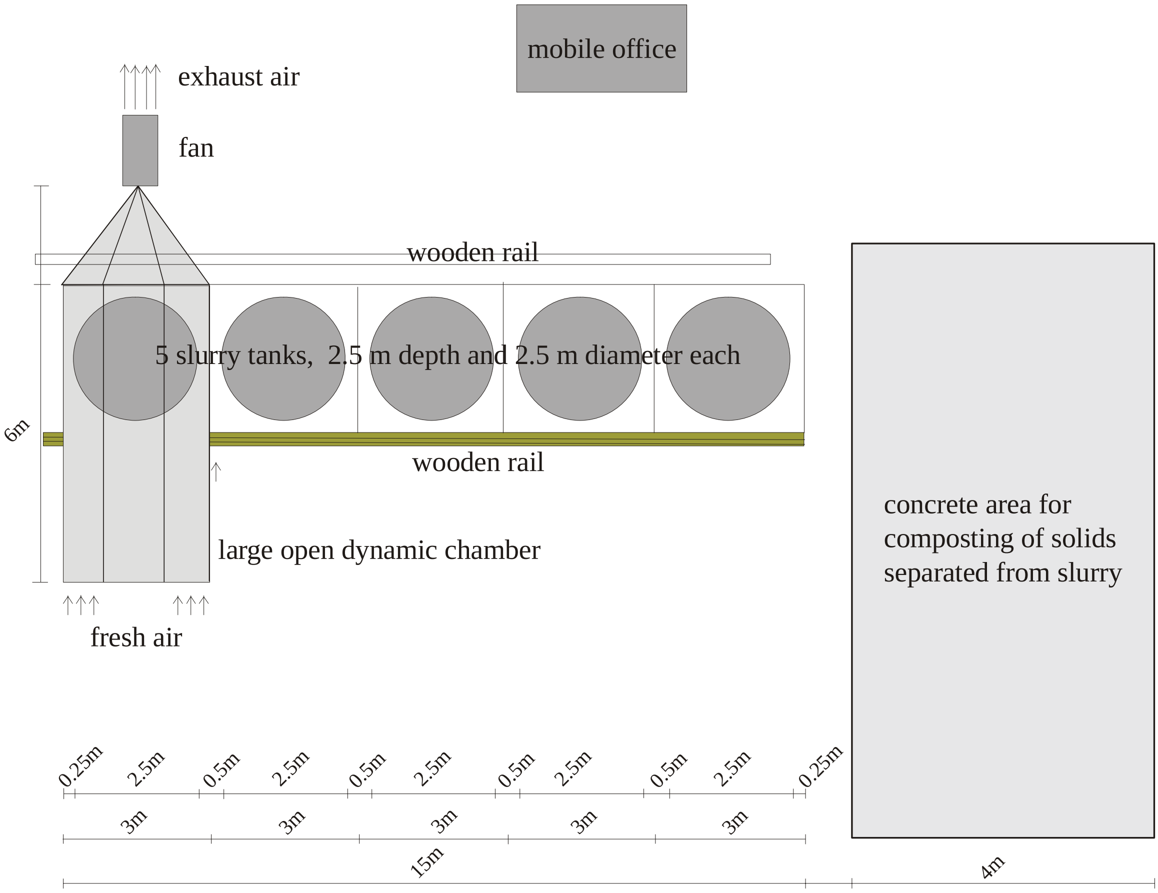

Figure 2. Design of the experimental facility for quantifying emissions from manure storage (plan view) (after AMON ET AL. 2002)

Large open dynamic chamber. 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 ILT developed a large open dynamic chamber (figure 3). 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}. The open dynamic chamber is made from polycarbonate. Light can penetrate inside the chamber. The material does not adsorb ammonia.

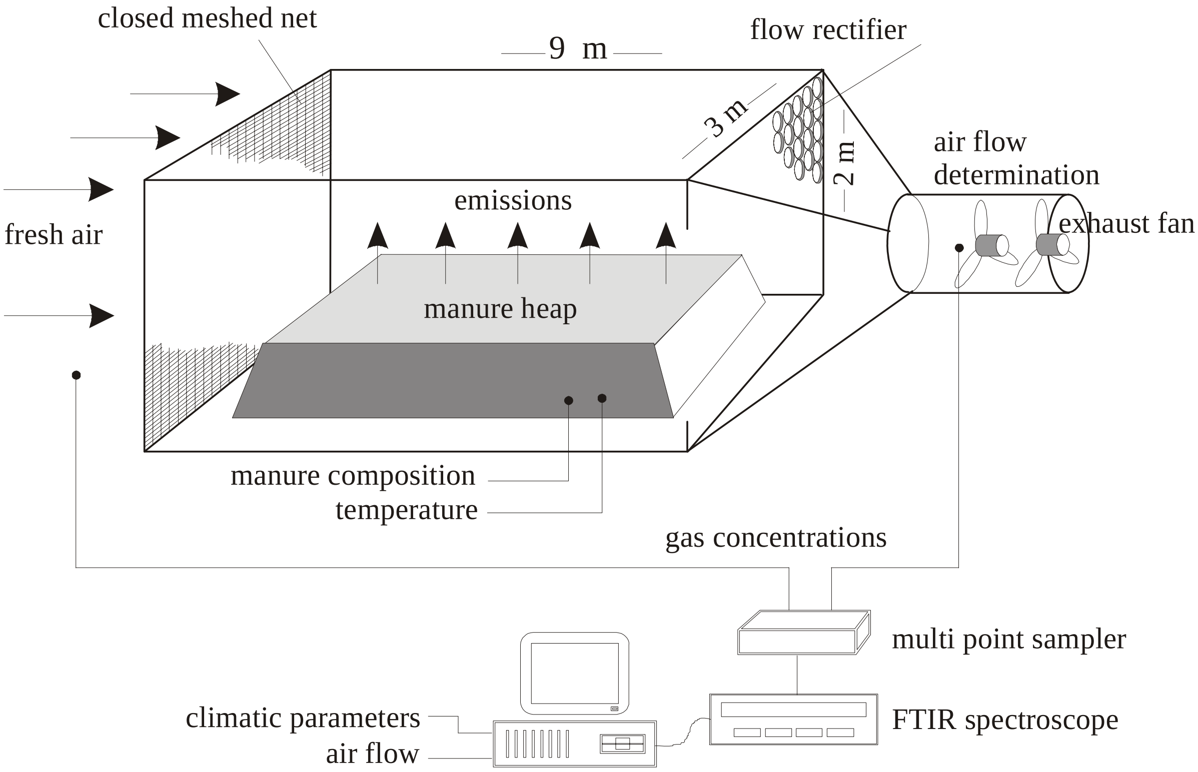

Figure 3. Design of the large open dynamic chamber developed by ILT (after AMON ET AL. 1996)

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.

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. The concentrations of volatile organic carbons (VOC) in the chamber outlet were 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 VOC emissions with odour emissions.

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 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 manually.

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 VOC 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. The molar volume depends on the atmospheric pressure and on the temperature. The temperature in the gas tubes and in the gas cell was constantly kept at 45 °C. The 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. The 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.

Measured parameters. NH_3, N_2O and CH_4 concentrations were measured with FTIR spectrometry and VOC concentrations were measured by a flame ionisation detector (see description above).

The slurry temperature was continuously measured at two heights. Slurry samples were taken biweekly during the whole period of emission measurements. Samples were taken from five different heights of the slurry tank and mixed to one sample that was immediately frozen until the laboratory analysis started. Slurry and farmyard manure samples were analysed for

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

2.2 Experiments

2.2.1 Pig slurry received from a straw flow system

Multikraft Produktions- und HandelsGmbH supplied the additive “Effective Microorganisms (EM)”. The experiments with pig slurry included two treatments:

- Pig slurry received from a straw flow system without EM addition (pig_untr)
- Pig slurry received from a straw flow system with EM addition (pig_EM)

Both slurries were stored in the pilot scale slurry tanks described above. The slurry tanks were not covered during storage period.

Pig slurry was received from a straw flow system in Upper Austria. The animal house has 270 m^2 concrete area and in the rear of the pens a total of 54 m^2 slatted area. 250 fattening pigs are reared in the straw flow system. About 300 g non chopped straw per pig and day are supplied via the straw supply racks in the front of each pen[2]. The pig´s feed consists of 55 % maize, 20 % wheat and 25 % “LIKRA Maiskombi” (a mixture from soya and minerals). The diet composition is not changed during the fattening period. The daily weight gain ranges from 750 to 800 g.

The tank with the treatment „untreated pig slurry“ was filled with 7.70 m^3 of pig slurry. In the tank with “EM amended pig slurry”, 7.65 m^3 pig slurry were stored. On 2004-06-02 16 litres of EM were added to this treatment. Table 1 gives the slurry compositions at the start and at the end of the storage period. Emission measurements started on 2004-06-01 and were originally planned to last for three months. Emissions however had not ceased after three months and it was this decided to continue the experiments until 2004-12-15. The additional measurements were paid from own contributions.

Table 1. Slurry compositions at the start and at the end of the storage period.

		N_t [g (kg FM)$^{-1}$]	NH_4-N [g (kg FM)$^{-1}$]	Dry matter [% FM]	VS [% FM]	pH
pig_untreated	start	2.47	1.23	4.83	3.61	6.51
	end	1.70	1.27	2.46	1.79	7.22
pig_EM	start	2.34	1.40	4.08	3.01	6.51
	end	2.27	1.79	2.67	1.97	7.24

FM = slurry fresh matter

2.2.2 Pig farmyard manure

When more straw is used, farmyard manure is produced in a straw flow system. For an assessment of the environmental impacts of the straw flow system it is vital to quantify emissions from the farmyard manure, as well. Two treatments were investigated:

---

[2] This amount was estimated by the farmer; it is questionable if the estimation is correct as it is doubtable that slurry can be produced with 300 g straw per pig and day; it is more likely that the amount of straw was lower.

- Anaerobic storage of pig farmyard manure received from a straw flow system without EM addition (pig_FYM_untr)
- Anaerobic storage of pig farmyard manure received from a straw flow system with EM addition (pig_FYM_EM).

The farmyard manure was received from a straw flow system in Upper Austria where 540 fattening pigs are reared. The house offers 0.84 m^2 per pig. About 300 g non chopped straw per pig and day are supplied via the straw supply racks in the front of each pen. The pig´s feed consists of 20 % wheat, 10 % peas, 24 % barley, 13 % soya, 30 % maize and 3 % minerals. The diet composition is not changed during the fattening period. The mean daily weight is 790 g with a gain to feed ratio of 1 : 2.7. The farmyard manure is mugged out twice a week.

The farmyard manure was stored in a heap on the concrete area that is situated beside the slurry tanks (see figures 1 and 2). 26 litres of EM were sprayed onto the farmyard manure. No additional manipulations were carried out during the storage period. Farmyard manure with EM addition was stored from 2004-06-02 to 2004-08-16 and then removed from the concrete area.

On 2004-08-16 fresh farmyard manure was delivered from the straw flow system in Upper Austria and anaerobically stored in a heap on the concrete area. This time, no EM was sprayed onto the farmyard manure. Emission measurements from untreated farmyard manure lasted until 2004-12-09. Table 2 gives the farmyard compositions at the start and at the end of the storage periods. Emissions during farmyard manure storage were quantified with the large open dynamic chamber that had a height of 2 m (see figure 3).

Table 2. Farmyard manure compositions at the start and at the end of the storage period.

		N_t [g (kg FM)$^{-1}$]	NH_4-N [g (kg FM)$^{-1}$]	Dry matter [% FM]	VS [% FM]	pH
pig_FYM_EM	start	8.96	4.94	23.08	19.09	8.60
	end	14.64	4.43	29.15	18.95	7.87
pig_FYM_untr	start	11.05	6.11	26.88	21.89	9.31
	end	18.81	5.38	31.43	18.80	8.14

FM = farmyard manure fresh matter

3 Results

This section gives the results of the CO_2, CH_4, NH_3, N_2O and VOC emissions that were measured during the storage of pig slurry and pig farmyard manure with and without the addition of EM. The course of the daily emissions and the cumulated emissions are shown.

3.1 Pig slurry

About 8 m^3 of pig slurry with and without the addition of EM were stored in uncovered pilot scale slurry tanks. The storage period lasted for 200 days. The measurements started in June 2004 and lasted until December 2004.

Figure 4 shows the temperatures in both slurries in course of the storage period. There were only small differences in the slurry temperatures of untreated and EM amended pig slurry. During the warm summer months, the slurry temperatures rose over 20 °C. From Sepember onwards a continuous decline of the slurry temperatures was observed. At the end of the storage period about 7 °C were measured in both slurries.

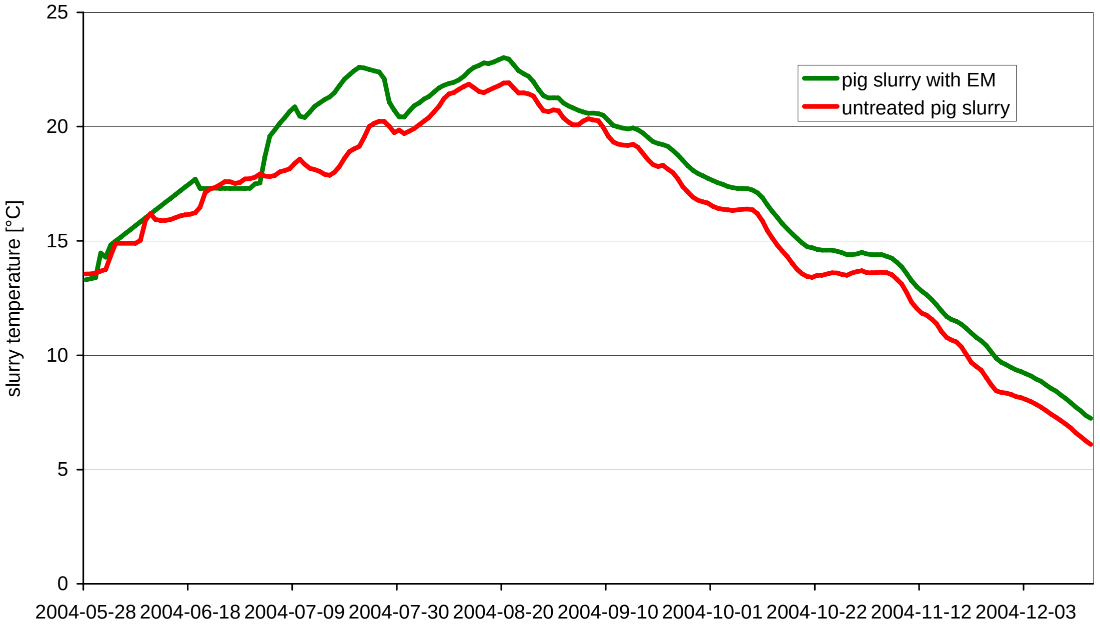

Figure 4. Slurry temperatures from June to December 2004.

3.1.2 Gas concentrations in course of the emission measurements

Figures 5 to 9 show the daily CO_2, CH_4, NH_3, N_2O and VOC emissions that were measured during the storage of pig slurry with and without the addition of EM. The figures give the sum of emissions that were measured from the respective slurry tanks. Emissions are not based on 1 m^3 slurry, but on the total amount of slurry in each tank. As however, the two tanks contained nearly the same amount of slurry, the sum of emissions from both treatments may be compared.

The daily CO_2 emissions did not show a distinct trend in course of the storage period. Differences between both treatments were not clearly visible. In the first half of the storage period, CO_2 emissions were higher than in the second half. Temperatures and thus microbial activity was higher in the first half of the storage period (figure 5).

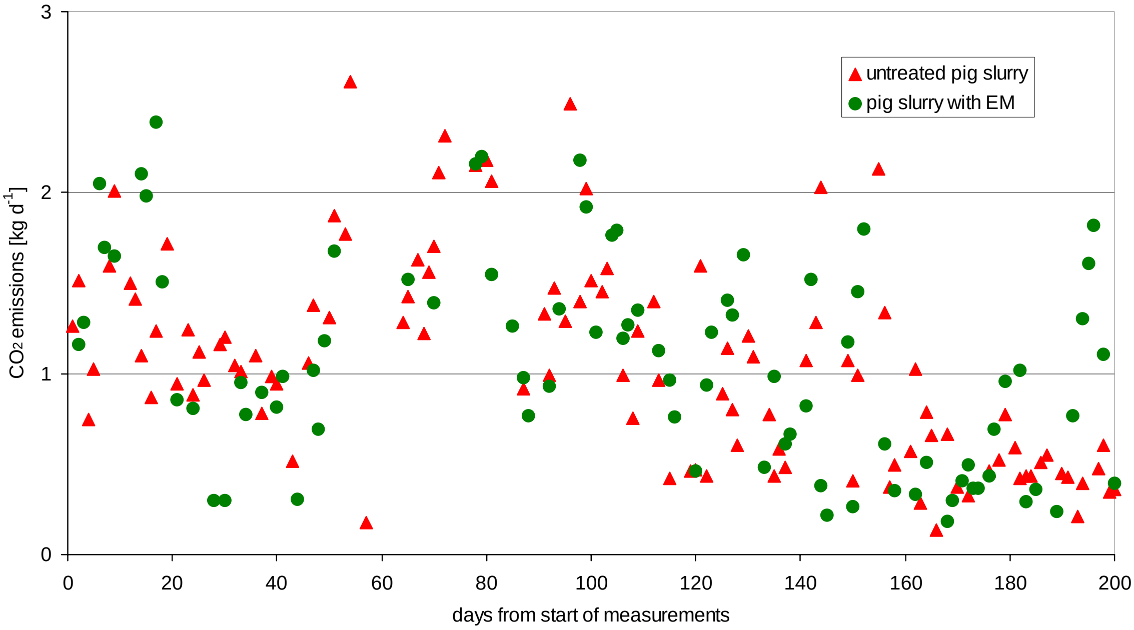

Figure 5. CO_2 emissions from untreated and EM amended pig slurry.

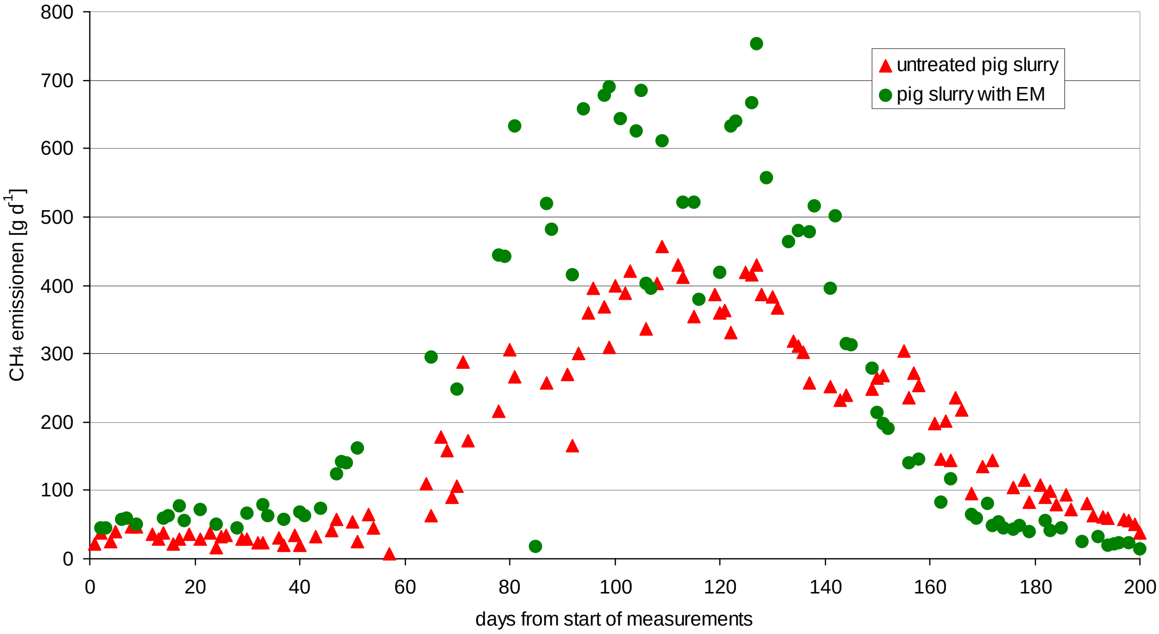

Figure 6. CH_4 emissions from untreated and EM amended pig slurry.

CH_4 emissions were very low at the beginning of the measurements. They increased strongly after the 60th day of storage. This is likely to be due to the increase in ambient air and slurry temperature. In the middle of the storage period, CH_4 emissions stayed on a high level. When the slurry temperature declined in the last third of the storage period, CH_4 emissions decreased again. At the end of the storage period, CH4 has reached a low level, but were still detectable (figure 6).

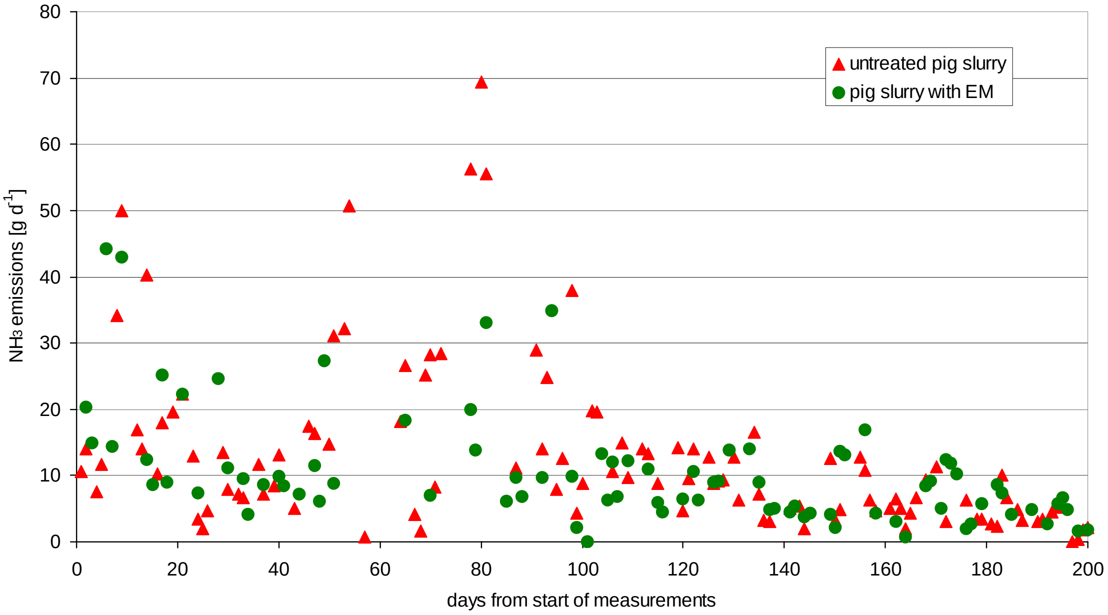

Figure 7. NH_3 emissions from untreated and EM amended pig slurry.

NH_3 emissions showed a considerable variability until the 100th day of storage. Afterwards, NH3 emissions stayed on a lower level than at the beginning of the measurements and showed less variability (figure 7).

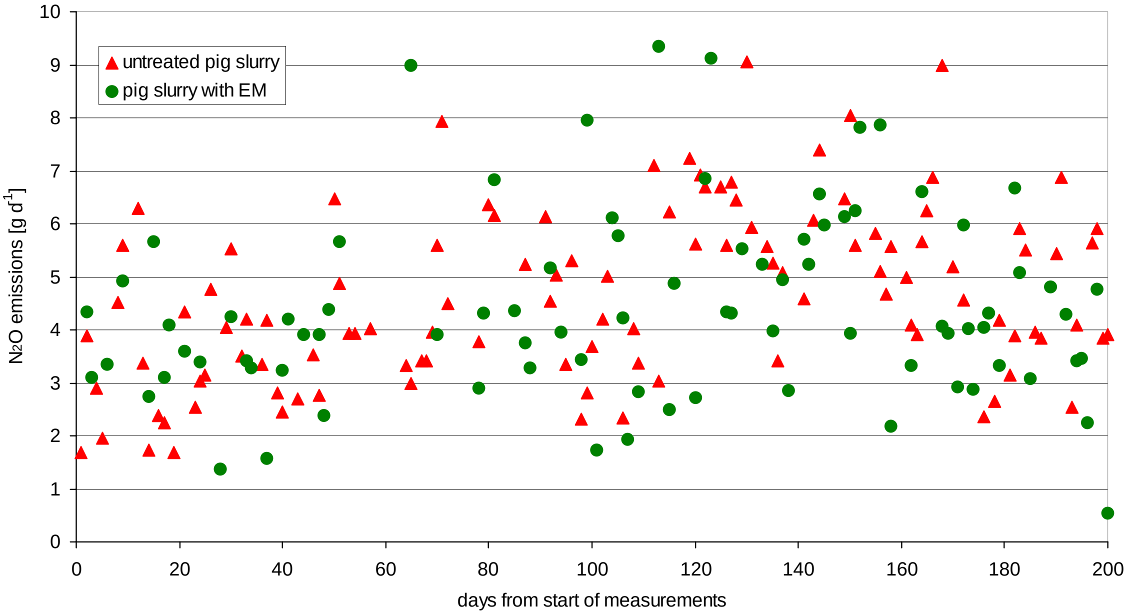

Figure 8. N_2O emissions from untreated and EM amended pig slurry.

N_2O emissions varied throughout the whole storage period between about 2 and 10 g N_2O per day. They did not show a trend in course of the measurement period. N_2O emissions did not decline towards the end of the storage period (figure 8).

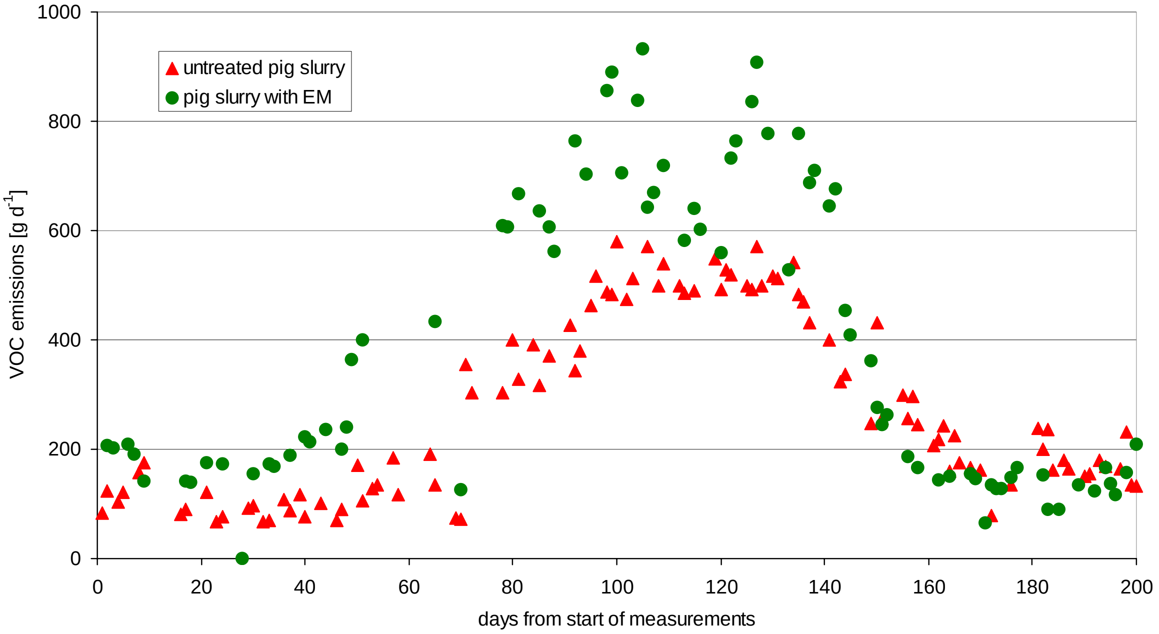

Figure 9. VOC emissions from untreated and EM amended pig slurry.

VOC emissions showed a course that was similar to the course observed with CH_4 emissions: low emissions at the beginning, a maximum in the middle of the storage period and a decline in the last third of the storage period. At the end of the storage period, VOC emissions had reached nearly the same level as in the beginning (figure 9).

3.1.2 Cumulated emissions

About 8,800 gas concentration values per treatment were analysed in course of the measurement period. From these raw data, the daily emissions were calculated. The daily emissions were then added to receive the cumulated emissions. Figures 10 to 14 show the course of the cumulated CO_2, CH_4, NH_3, N_2O and VOC emissions measured during the 200-days storage of pig slurry with and without EM addition.

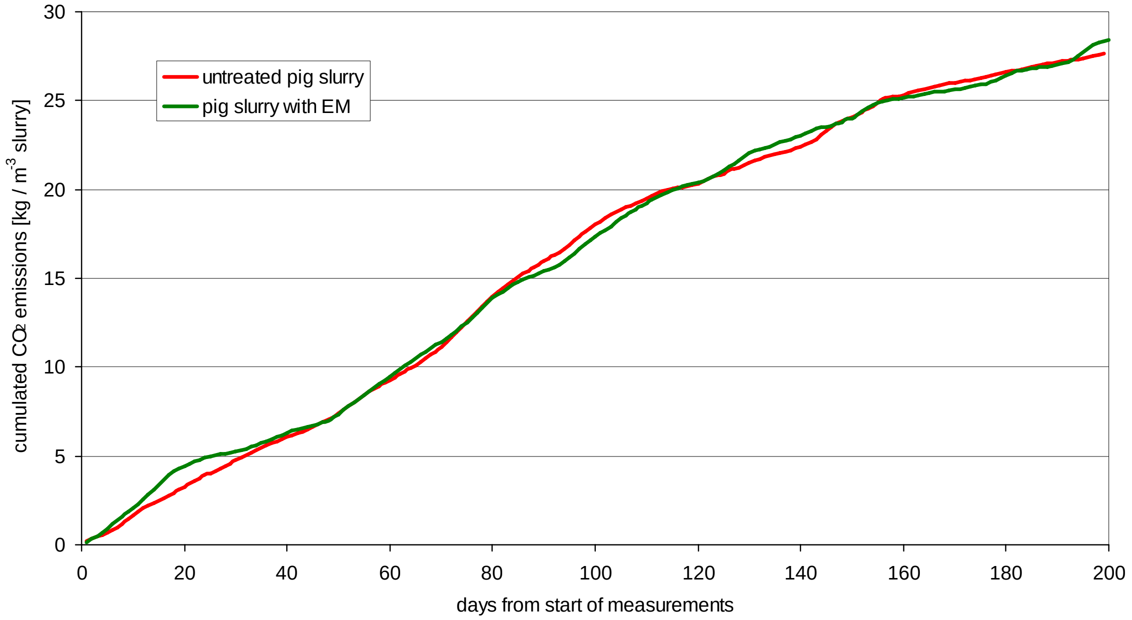

Figure 10. Cumulated CO_2 emissions during the storage of untreated and EM amended pig slurry.

Cumulated CO_2 emissions showed a nearly linear increase from the start of the storage period until the 160th day of storage. Then, CO_2 emissions declined and only a small additional increase was observed. The difference in CO_2 emissions between untreated and EM amended pig slurry were marginal (figure 10).

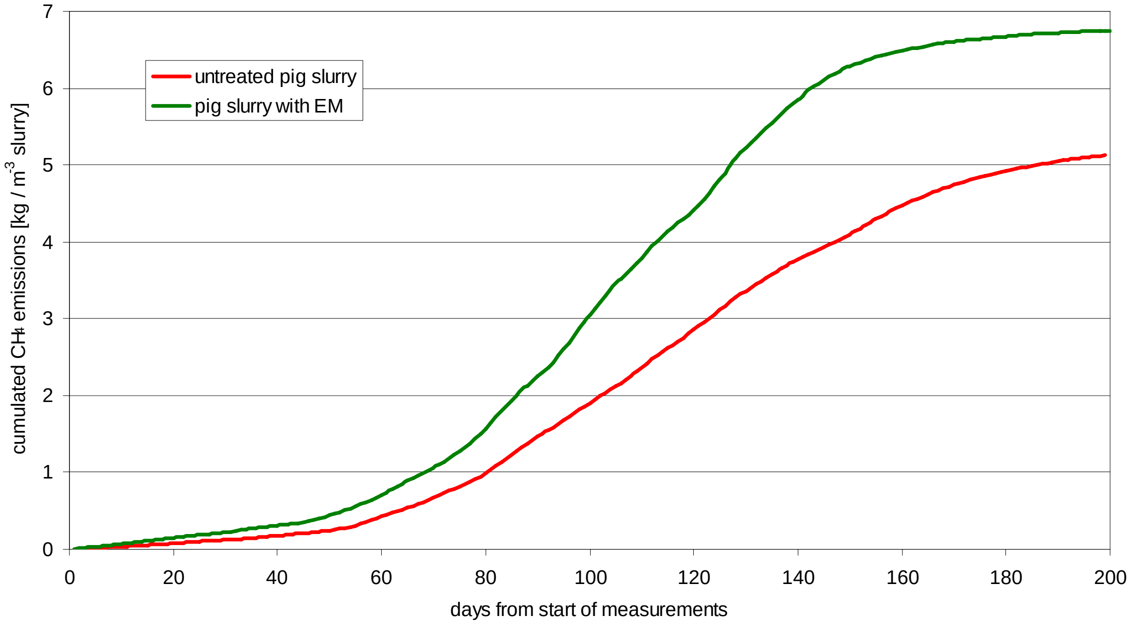

Figure 11. Cumulated CH_4 emissions during the storage of untreated and EM amended pig slurry.

CH_4 emissions were low at the beginning of the storage period. Until the 60th day of storage, they had reached 0.43 kg CH_4 m^{-3} (untreated pig slurry) and 0.71 kg CH_4 m^{-3} (EM amended pig slurry), respectively. After the 60th day of storage, ambient air and slurry temperature rose. CH_4 formation is a temperature sensitive process. So, a considerable increase in CH_4 emissions was observed with both slurries. After the 160th day of storage, when ambient air and slurry temperature declined again, the cumulated CH_4 emissions increased less than during the warmer period before. Untreated pig slurry emitted a total of 5.13 kg CH_4 m^{-3}. When EM was added to pig slurry at the time of storage, the net total CH_4 emissions after a 200-days storage amounted to 6.75 kg CH_4 m^{-3} (figure 11).

From figure 12, the cumulated NH_3 emissions from untreated and EM amended pig slurry can be taken. The increase in cumulated NH_3 emissions was greater in the first two thirds of the storage period, when ambient air and slurry temperature were higher than towards the end of the storage period. Untreated pig slurry emitted a total of 0.322 kg NH_3 m^{-3}. The one-time EM addition at the time of storage reduced net total NH3 emissions to 0.286 kg NH_3 m^{-3}.

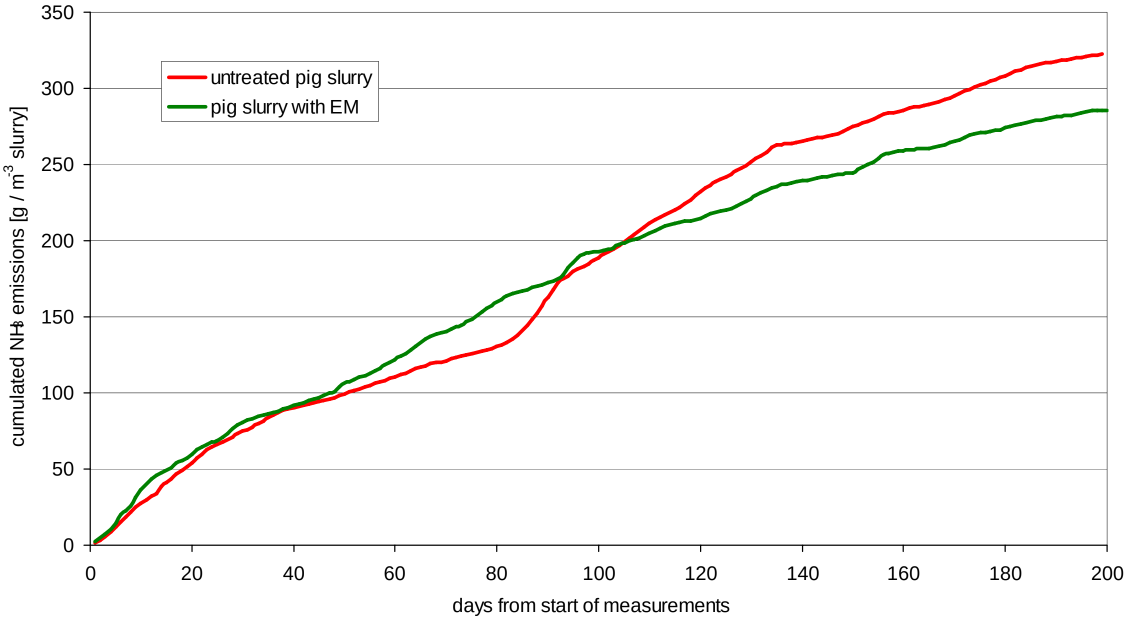

Figure 12. Cumulated NH_3 emissions during the storage of untreated and EM amended pig slurry.

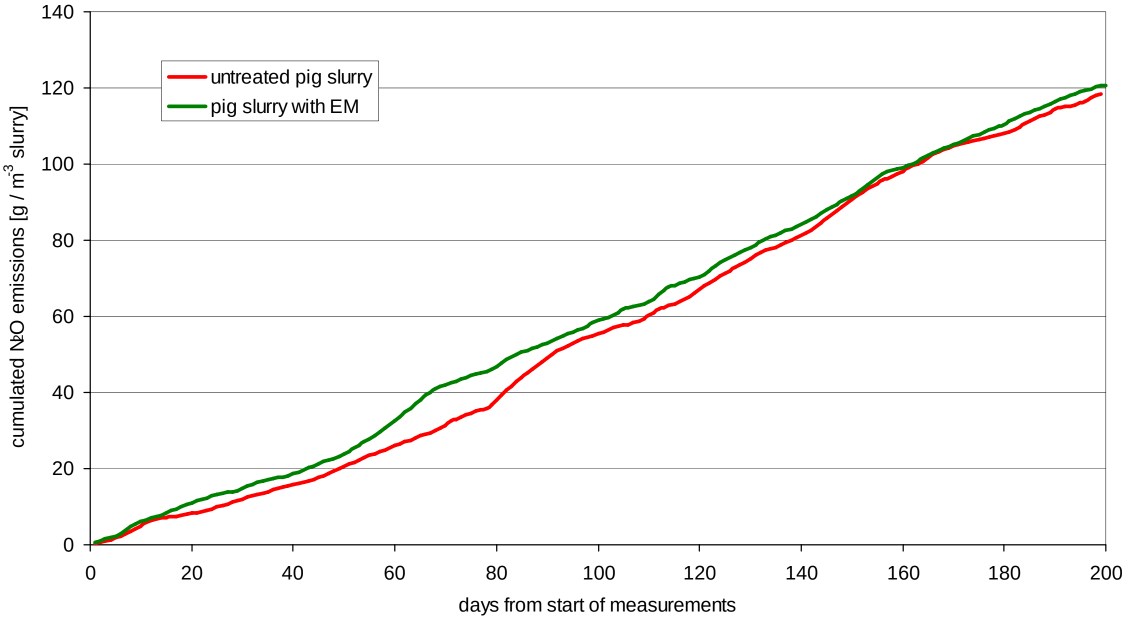

Figure 13. Cumulated N_2O emissions during the storage of untreated and EM amended pig slurry.

Cumulated N_2O emissions showed a linear increase throughout the whole storage period with no decline towards the end. The difference in N_2O emissions between untreated and EM amended pig slurry was very small. Pig slurry with EM addition emitted a total of 121 g N_2O m^{-3} From untreated pig slurry, 118 g N_2O m^{-3} were lost (figure 13).

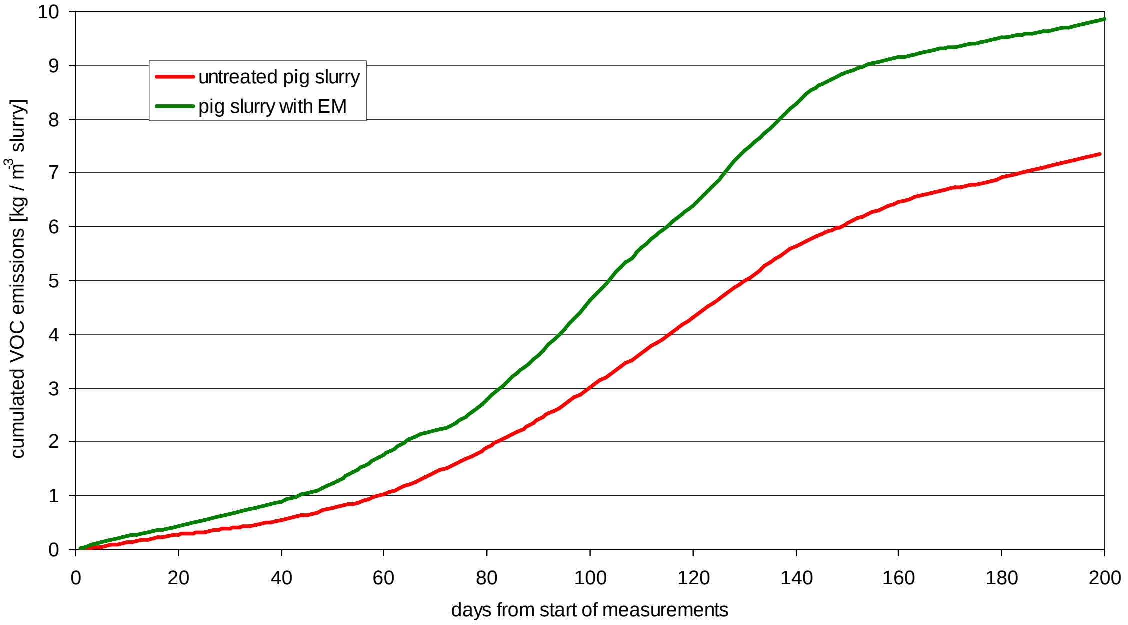

Figure 14. Cumulated VOC emissions during the storage of untreated and EM amended pig slurry.

Cumulated VOC emissions showed a development that was similar to the course of cumulated CH_4 emissions: small emission rates at the beginning of the storage period, high emission rates in the middle of the measurement period and low emissions again towards the end, when ambient air and slurry temperature declined. EM amended pig slurry emitted a total of 9.83 kg CH_4 equivalents per m^3 slurry. From untreated slurry, a VOC emission of 7.34 kg CH_4 equivalents per m^3 slurry was measured (figure 14).

Table 3 summarises net total CO_2, CH_4, NH_3, N_2O and VOC emissions during the storage of pig slurry received from a straw flow system with and without EM addition. Emissions of CH_4 and N_2O were converted to CO_2 equivalent emissions and are expressed as net total greenhouse gas emissions. The global warming potential (GWP) of CH_4 is 21 times the GWP of CO_2. N_2O emissions were multiplied with a GWP of 310 to receive CO_2 equivalents (IPCC 1996).

EM addition resulted in a small increase in CO_2 emissions. As the emitted CO_2 does not origin from fossil sources, it does not contribute to the anthropogenic greenhouse effect. Higher CO_2 emissions indicate a higher microbial activity in the slurry.

CH_4, VOC and greenhouse gas emissions were higher from the EM amended pig slurry than from the untreated pig slurry. N_2O emissions showed hardly any difference between both treatments. NH_3 emissions were reduced by 11 % through the one-time EM addition at the time of storage.

Table 3 Cumulated emissions during the storage of untreated and EM amended pig slurry.

treatment	*cumulated emissions of...*					
	CO_2	CH_4	NH_3	N_2O	VOC	GHG[a]
	[kg m^{-3} FM]	[kg m^{-3} FM]	[kg m^{-3} FM]	[g m^{-3} FM]	[kg m^{-3} FM]	[kg m^{-3} FM]
pig_untreated	27.5	5.13	0.322	118	7.34	144.4
pig_EM	28.4	6.75	0.286	121	9.83	179.2

[a] greenhouse gas emissions

CH_4 emissions given in table 3 are based on a m^3 of slurry fresh matter. When taking the organic dry matter content in the slurry as a basis, the following net total emissions result: 168.2 g CH_4-C (kg VS)$^{-1}$ for EM amended slurry and 106.5 g CH_4-C (kg VS)$^{-1}$ for untreated slurry. Both values are higher than emissions measured in an earlier experiment by AMON ET AL. (2004b). In the earlier experiment, emissions of 97.9 and 99.8 g CH_4-C (kg VS)$^{-1}$, respectively, were measured. The lower emissions were due to a very low dry matter content in the slurry and to a lower slurry temperature. The experiment of AMON ET AL. (2004b) only lasted for 100 days. During this period, a linear increase in CH_4 emissions has been observed. CH_4 emissions had not ceased towards the end of the measurement period and would have further increased, if the measurements had lasted longer. The experiments presented in this report lasted for 200 days. This in another reason, why higher emissions were observed.

The experiments of AMON ET AL. (2004b) showed that EM had the potential to reduce CH_4 emissions during slurry storage when it was added to the pig´s diet and fed to the pigs. No decrease in CH_4 emissions was found, through a one-time EM addition at the time of storage. When EM was sprayed on a daily basis in a straw flow system for fattening pigs, then AMON ET AL. (2004a) measured a considerable decrease in CH_4 emissions from the animal house. From these experiments it may be concluded that a good effect is achieved, if EM is added at an early stage of the manure management continuum and on a regular basis.

The cumulated NH_3 emissions were on a level similar to the level found in an earlier experiment. AMON ET AL. (2004b) measured net total emissions of 337.9 (without EM), 354.3 (with EM) and 266,9 (feeding of EM-FKE) g NH_3 m^{-3} slurry, respectively. The spraying of EM in a straw flow system for fattening pigs resulted in a reduction in NH_3 emissions (AMON ET AL. 2004a).

After the 200-days storage period, the cumulated N_2O emissions amounted to about

120 g N_2O m^{-3} slurry. AMON ET AL. (2004 b) found N_2O emissions of 36 to 41 g N_2O m^3 slurry after a 100-days storage period. In the experiments presented in this report, the cumulated N_2O emissions has reached a level of 55 g N_2O m^{-3} after 100 days of storage. On both experiments, N_2O emissions showed a linear increase throughout the whole storage period. This means, that N_2O is continuously emitted with no major changes in the emission rate in course of the storage period.

As found in the experiments presented in this report, the earlier experiment of AMON ET AL. (2004b) found an increase in VOC emissions when EM was added once at the time of slurry storage. Adding EM-FKE to the pig`s feed resulted in a reduction in VOC emissions during the subsequent slurry storage. The regular spraying of EM in a straw flow system for fattening pigs as well reduced VOC emissions from the pig house (AMON ET AL. 2004a). As with CH_4 emissions, it may be concluded that a good effect is achieved, if EM is added at an early stage of the manure management continuum and on a regular basis

3.2 Pig farmyard manure

Emissions were not only followed from stored pig slurry, but as well during the anaerobic storage of pig farmyard manure received from a straw flow system for fattening pigs. The following section describes CO_2, CH_4, NH_3, N_2O and VOC emissions from pig farmyard manure with and without the addition of EM at the time of storage.

Figure 15 shows the temperature in the farmyard manure with and without EM addition. The farmyard manure with EM addition was stored from May to August 2004. From August to December 2004, emission measurements from untreated farmyard manure were carried out. The farmyard manure heap with EM addition at the time of storage showed a temperature increase to about 40 °C. This temperature maximum lasted for about one week before the temperature declined again. At the end of the storage period, the temperature inside the manure heap was 31 °C.

Without EM addition at the time of storage, a much greater increase in the manure temperature was observed. After one week of storage, the temperature inside the manure heap had reached 54 °C. Only after 40 days of storage, the temperature fell below 50 °C and had reached 41 °C after 80 days. Even when ambient air temperatures were low in November and December, the temperature inside the manure heap did not fall below 30 °C. The high temperature results from microbial activity that takes place inside the manure heap. Farmyard manure temperature is mainly endogenously determined and less dependent from ambient air temperature.

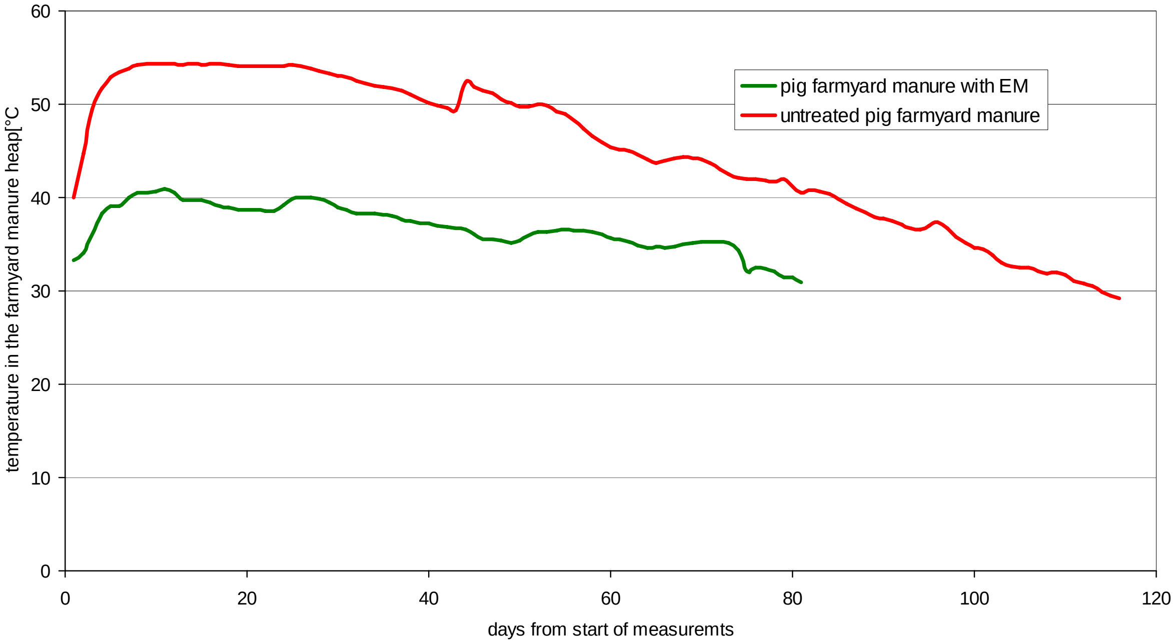

Figure 15. Temperature in the untreated and in the EM amended farmyard manure heaps.

3.2.1. Gas concentrations in course of the emission measurements

Figures 16 to 20 show CO_2, CH_4, NH_3, N_2O and VOC emissions during the anaerobic storage of pig farmyard manure with and without the addition of EM. Emissions were continuously followed two to three times a week for 12 – 18 hours. The figures give daily emissions based on one ton of farmyard manure.

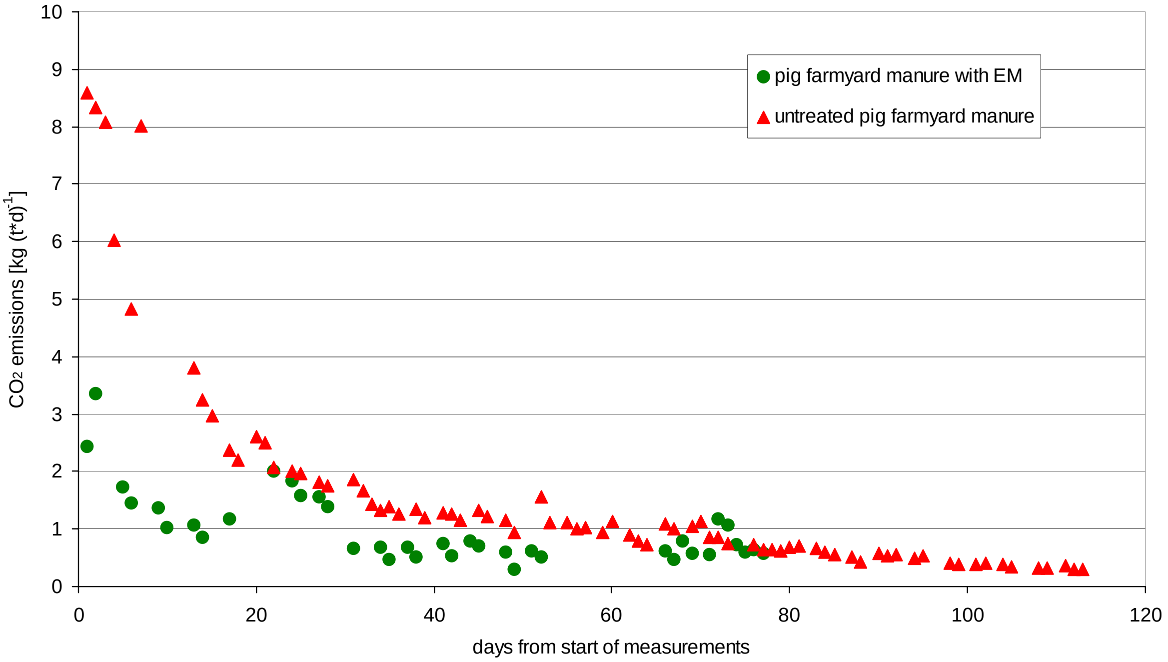

Figure 16. CO_2 emissions from anaerobic storage of untreated and EM amended pig farmyard manure.

In both treatments, the daily CO_2 emissions were high at the beginning of the storage period. Untreated pig farmyard manure showed higher CO_2 emissions than EM amended farmyard manure. A maximum of nearly 9 kg CO_2 per ton of farmyard manure and day was measured. EM amended farmyard manure had a maximum emission of about 3.5 kg CO_2 per ton of farmyard manure and day. After the 20th day of storage, the daily CO_2 emissions decreased with both treatments and stayed on a low level until the end of the experiments (figure 16).

The daily CH_4 emissions reached a maximum between the 20th and 40th day of storage with both treatments. Maximum daily methane emissions ranged around 120 g CH_4 per ton of farmyard manure and day. With untreated farmyard manure, daily CH_4 continuously decreased until the end of the storage period. EM amended farmyard manure had a second, but smaller maximum around the 70th day of storage (figure 17).

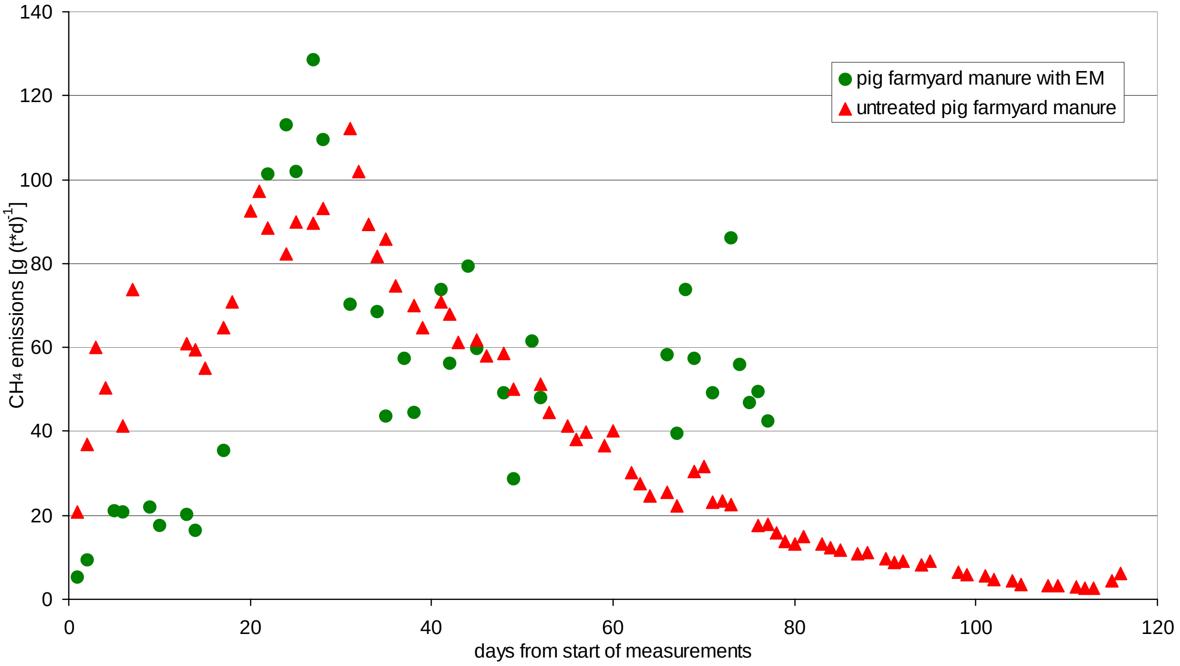

Figure 17. CH_4 emissions from anaerobic storage of untreated and EM amended pig farmyard manure.

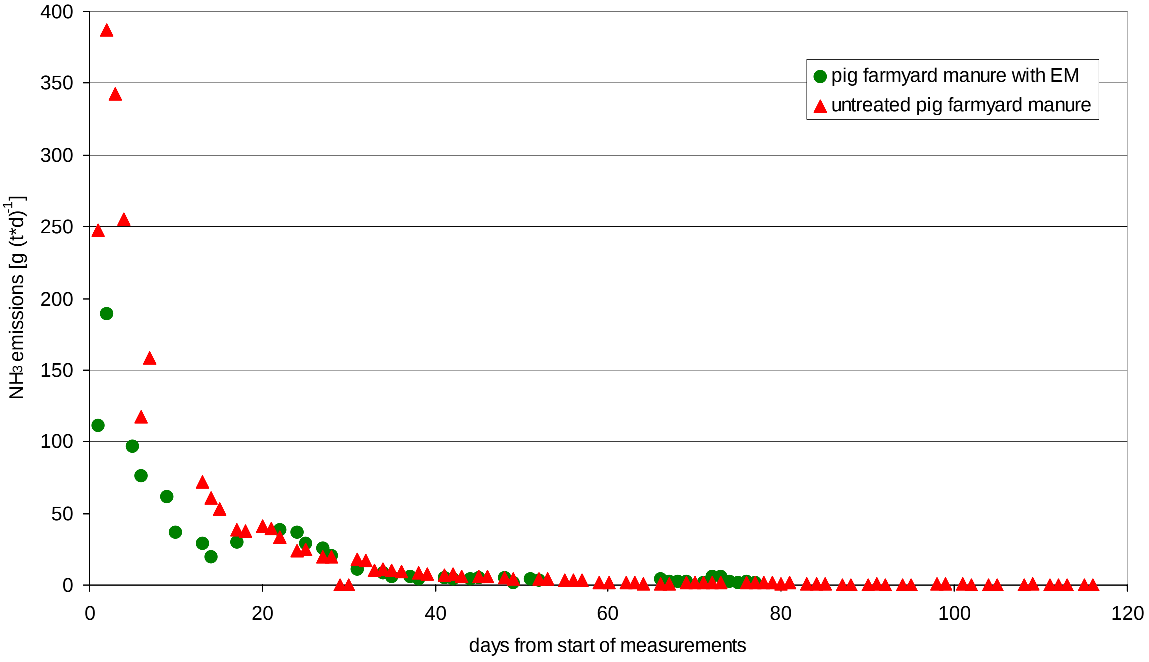

Figure 18. NH_3 emissions from anaerobic storage of untreated and EM amended pig farmyard manure.

The daily NH_3 emissions from untreated and from EM amended farmyard manure were high right after the beginning of the storage period. It then decreased and stayed on a very low level after the 30th day of storage. However, even if the course of the daily NH_3 emissions was similar with both treatments, the maximum daily NH_3 emissions were much higher from untreated farmyard manure than from EM amended farmyard manure (figure 18).

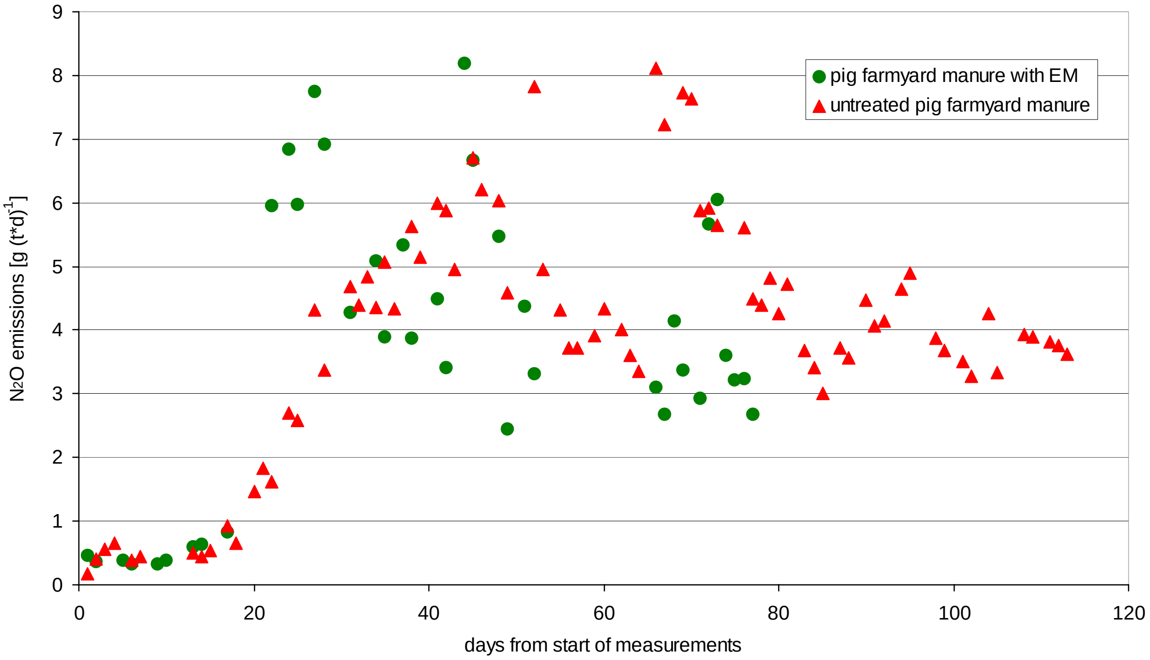

Figure 19. N_2O emissions from anaerobic storage of untreated and EM amended pig farmyard manure.

The daily N_2O emissions were low at the beginning of the storage period with both treatments. They rose only three weeks after the beginning of the storage period. Until the end of the measurements, N_2O emissions varied in a wide range between 3 and 8 g N_2O per ton of farmyard manure and day with no distinct trend. N_2O emissions did not decline towards the end of the storage period (figure 19).

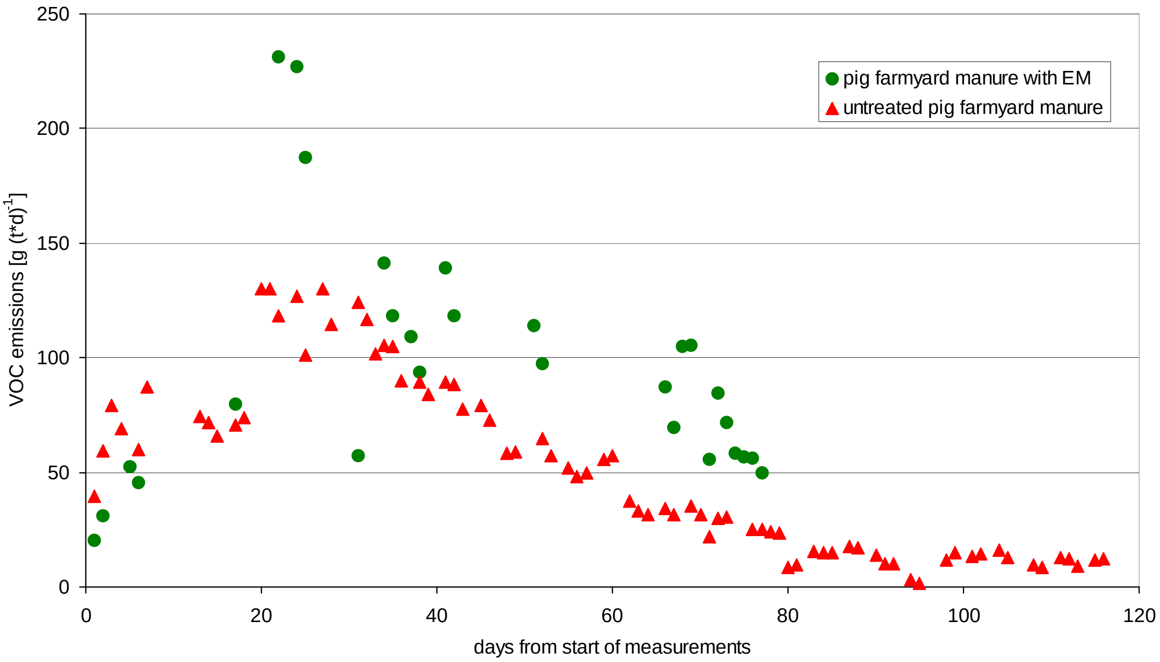

Figure 20. VOC emissions from anaerobic storage of untreated and EM amended pig farmyard manure.

The daily VOC emissions rose immediately after the start of the measurements and reach a maximum on the 30th day of farmyard manure storage. EM amended farmyard manure showed higher daily VOC emissions than untreated farmyard manure. Untreated pig farmyard manure emitted VOC emissions on a low level after the 80th day of storage (figure 20).

3.2.2 Cumulated emissions

Pig farmyard with EM addition was stored from 2004-06-02 to 2004-08-16 and 3,200 emission values were collected. The storage period of untreated pig farmyard manure lasted from 2004-08-16 to 2004-12-09 and comprised 5,800 emission values. From these raw data, the daily emissions per ton of farmyard manure were calculated. The daily emissions were then added to receive cumulated emissions. Figures 21 to 25 show the course of cumulated CO_2, CH_4, NH_3, N_2O and VOC emissions from untreated and EM amended pig farmyard manure that was received from a straw flow system for fattening pigs. Untreated farmyard manure was stored longer than EM amended farmyard manure and the figures depict the full storage period. The comparison of untreated emissions at the end of this chapter however is based on an 80-days storage period for both treatments in order to make net total emissions comparable.

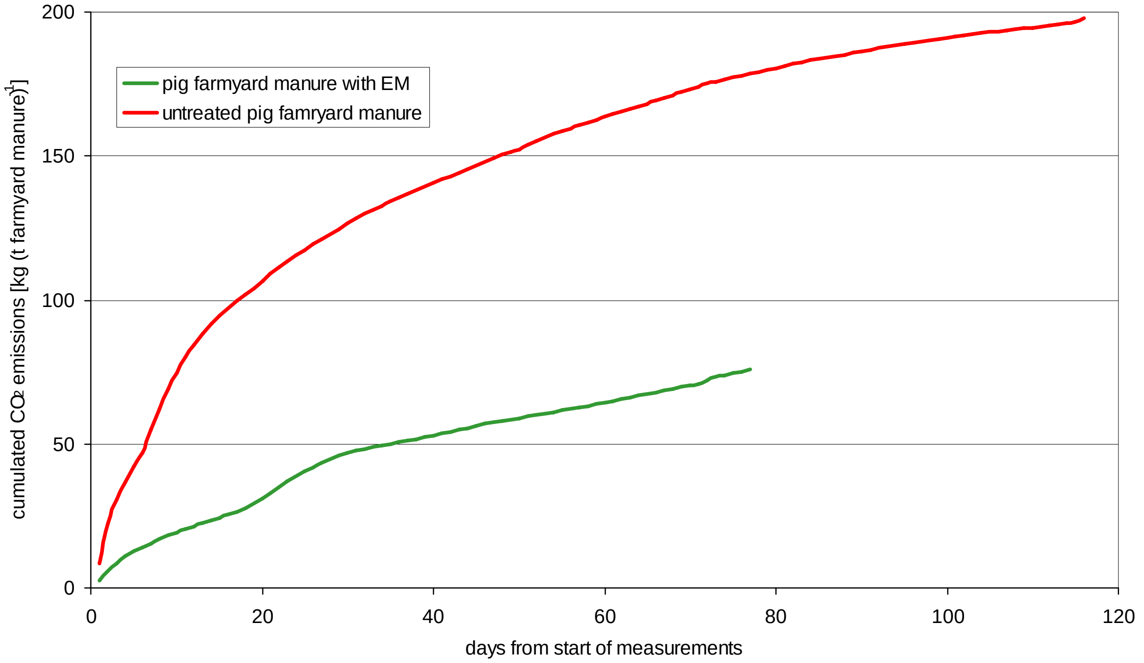

Figure 21. Cumulated CO_2 emissions from anaerobic storage of untreated and EM amended pig farmyard manure.

The cumulated CO_2 emissions from untreated pig farmyard manure showed a strong increase at the beginning of storage. The increase then declined and CO_2 emissions had reached a level of 178.6 kg (t farmyard manure)$^{-1}$. After 115 days, net total emissions of 197.8 kg CO_2 (t farmyard manure)$^{-1}$ had been lost. CO_2 emissions from EM amended pig farmyard manure were lower than from untreated farmyard manure. They amounted to 75.7 kg CO_2 (t farmyard manure)$^{-1}$ after 80 days of storage (figure 21).

Untreated pig farmyard manure showed a strong increase in cumulated CH_4 emissions at the beginning of the storage period. After 80 days, only a small additional increase was measured. Cumulated CH_4 emissions amounted to 4.40 kg CH_4 (t farmyard manure)$^{-1}$ after

80 days and 4.70 kg CH_4 (t farmyard manure)$^{-1}$ after 115 days. From day 20 to day 80, a nearly linear increase in CH_4 emissions was observed from EM amended pig farmyard manure. Total cumulated CH_4 emissions after 80 days of storage were 4.22 kg CH_4 (t farmyard manure)$^{-1}$, which is lower than the cumulated CH_4 emissions that were measured from untreated farmyard manure (figure 22).

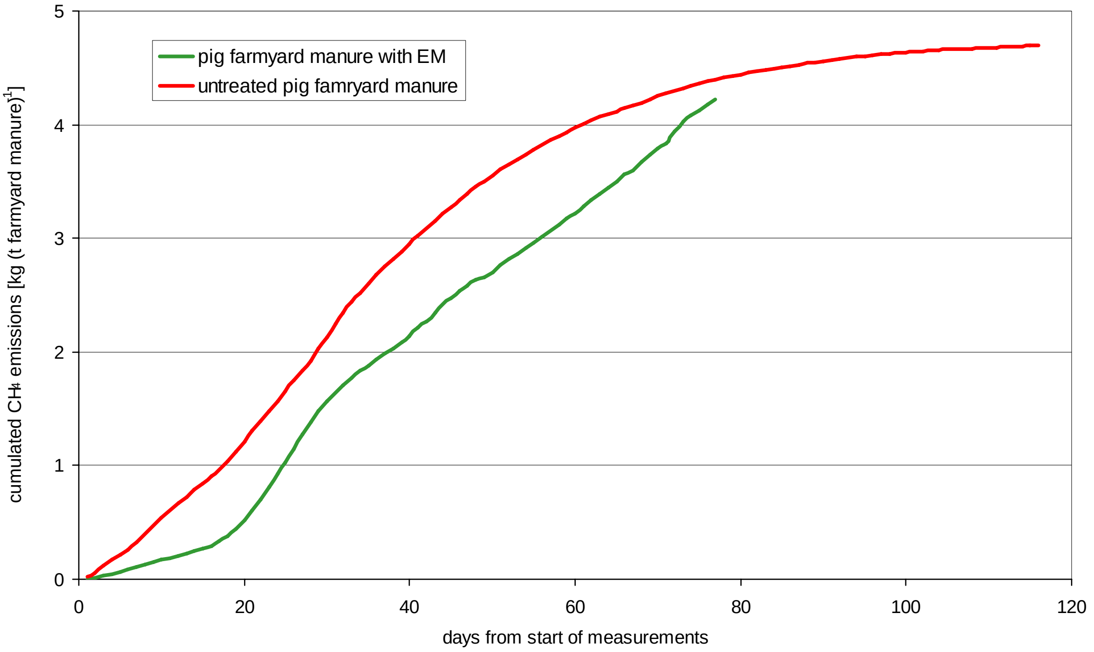

Figure 22. Cumulated CH_4 emissions from anaerobic storage of untreated and EM amended pig farmyard manure.

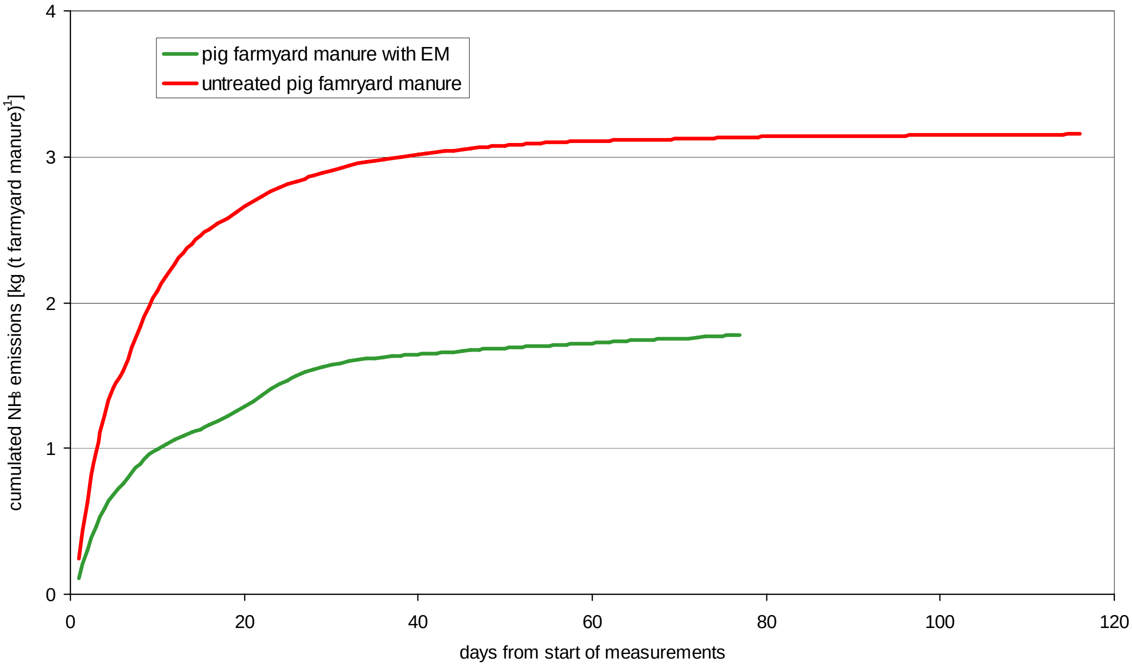

Figure 23. Cumulated NH_3 emissions from anaerobic storage of untreated and EM amended pig farmyard manure.

The cumulated NH_3 emissions from stored pig farmyard manure strongly increased right after the beginning of storage. The increase was especially strong with untreated farmyard manure. After 40 days of storage, only a small additional increase in cumulated NH_3 emissions was observed with both treatments. Untreated pig farmyard manure emitted net total emissions of 3.13 kg NH_3 (t farmyard manure)$^{-1}$ after 80 days and 3.15 kg NH_3 (t farmyard manure)$^{-1}$ after 115 days. The one-time EM addition at the time of storage led to a considerable decrease in cumulated NH3 emissions to 1.78 kg NH_3 (t farmyard manure)$^{-1}$, which is about 43 % lower than net total NH3 emissions from untreated anaerobically stored pig farmyard manure (figure 23).

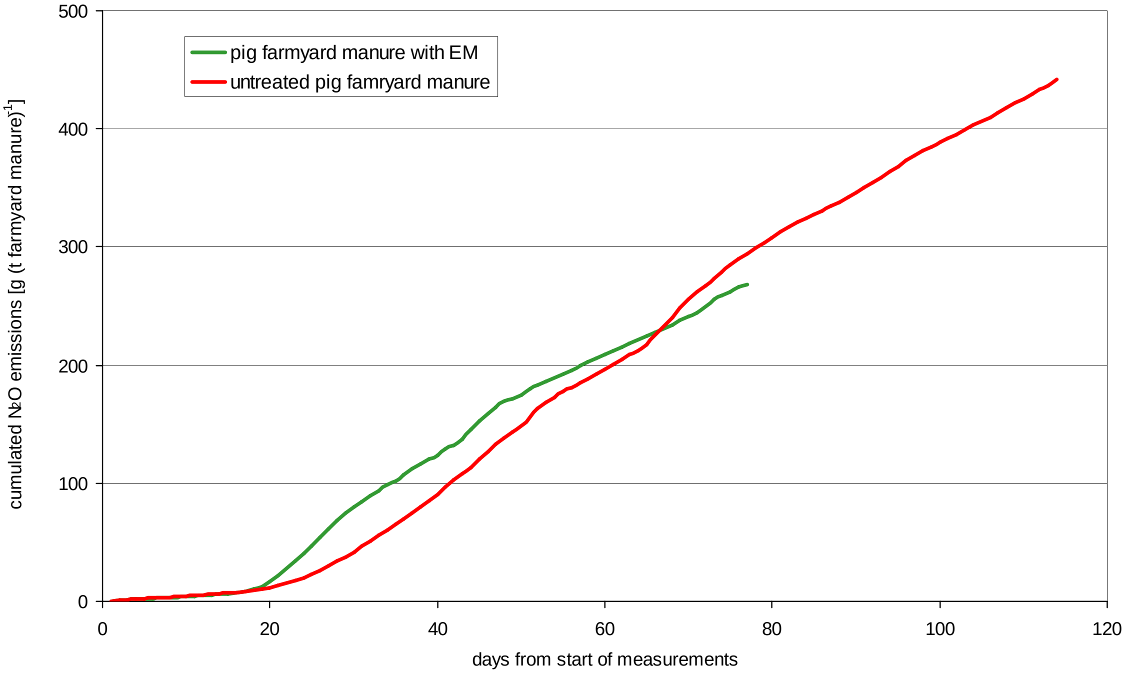

Figure 24. Cumulated N_2O emissions from anaerobic storage of untreated and EM amended pig farmyard manure.

The cumulated N_2O emissions were very low at the beginning of the storage period with both treatments. After 20 days of storage, a nearly linear increase in cumulated N_2O emissions was measured from untreated and EM amended pig farmyard manure. The N_2O emission rate did not decline until the end of the storage period. After 80 days, net total emissions of 295 g N_2O (t farmyard manure)$^{-1}$ had been lost from untreated anaerobically stored pig farmyard manure. After 115 days of storage, N_2O losses amounted to 462 g N_2O (t farmyard manure)$^{-1}$. After 80 days of storage, N_2O emissions from EM amended pig farmyard manure were about 9 % lower than from untreated farmyard manure. They had reached a level of 268 g N_2O (t farmyard manure)$^{-1}$ (figure 24).

The cumulated VOC emissions from untreated pig farmyard manure strongly increased in the first 50 days of storage. Then, the increase in VOC emissions was less strong. After about 80 days of storage, only a small additional increase in the cumulated VOC emissions was measured. VOC emissions from untreated pig farmyard manure had reached a level of 5.53 kg CH_4 equivalents (t farmyard manure)$^{-1}$ after 80 days and a level of 6.01 kg CH_4 equivalents (t farmyard manure)$^{-1}$ after 115 days (figure 25).

EM amended pig farmyard manure showed only small VOC emissions in the first few days of storage. Afterwards, a linear increase in the cumulated VOC emissions was measured. The emission rate had not declined until the end of the 80-days storage period. Pig farmyard manure with EM addition emitted a total of 7.35 kg CH_4 equivalents (t farmyard manure)$^{-1}$ (figure 25).

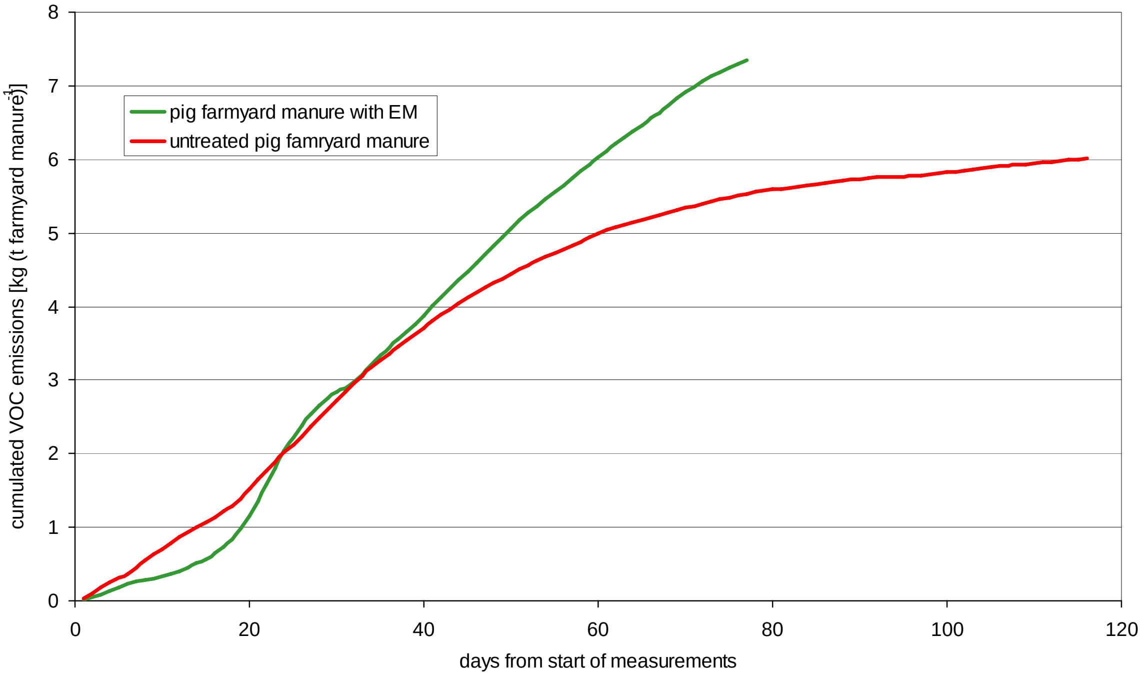

Figure 25. Cumulated VOC emissions from anaerobic storage of untreated and EM amended pig farmyard manure.

Table 4 summarises net total CO_2, NH_3, N_2O and VOC emissions that were measured during an 80-days anaerobic storage of pig farmyard manure with and without EM addition. Emissions of CH_4 and N_2O were converted to CO_2 equivalent emissions and are expressed as net total greenhouse gas emissions. The global warming potential (GWP) of CH_4 is 21 times the GWP of CO_2. N_2O emissions were multiplied with a GWP of 310 to receive CO_2 equivalents (IPCC 1996).

Table 4 Cumulated emissions during the storage of untreated and EM amended pig farmyard manure.

treatment	*cumulated emissions of...*					
	CO_2 [kg t-1 FM]	CH_4 [kg t^{-1} FM]	NH_3 [kg t^{-1} FM]	N_2O [g t^{-1} FM]	VOC [kg t^{-1} FM]	GHG[a] [kg t^{-1} FM]
pig_FYM_untr	178.6	4.40	3.13	295	5.53	183.7
pig_FYM_EM	75.7	4.22	1.78	268	7.35	171.7

[a] greenhouse gas emissions

The temperature inside the manure heap was considerably higher in untreated pig farmyard manure than in EM amended farmyard manure (see figure 15). CO_2 emissions were higher from untreated farmyard manure. The reason probably lies in the microbial activity being more aerobic in the untreated farmyard manure, whereas metabolic processes in the EM amended farmyard were mainly anaerobic.

CH_4 and N_2O emissions were lower from EM amended farmyard manure than from untreated farmyard manure. This led to lower net total greenhouse gas emissions. These amounted to 171.7 kg CO_2 equivalents (t farmyard manure)$^{-1}$ and 183.7 kg CO_2 equivalents (t farmyard manure)$^{-1}$, respectively.

The net total NH_3 losses were about 43 % lower than from untreated farmyard manure. As with pig slurry, the one-time EM addition at the time of storage led to a reduction in NH_3 emissions.

VOC emissions were higher from EM amended than from untreated farmyard manure. VOC emissions may give a hint on the potential for odorous emissions, but it has not yet been possible to establish a correlation between VOC and odour emissions. VOC emissions do not contain information on the quality of odorous emissions.

4 Conclusions

This research report works on CO_2, NH_3, N_2O and VOC emissions from storage of pig slurry and pig farmyard manure received from a straw flow system for fattening pigs. The influence of a one-time EM addition at the time of storage on the amount of emissions was investigated. From June to December 2004 continuous emission measurements were carried out from pilot scale slurry tanks and from 8-t-farmyard manure heaps. The following results were found:

- The one-time EM addition at the time of *pig slurry* storage increased CO_2 emissions by 3 %, CH_4 emissions by 32 %, VOC emissions by 34% and net total greenhouse gas emissions by 24%.
- N_2O emissions were not influenced by the EM addition.
- NH_3 emissions were considerably reduced by 11 % through the addition of EM.
- Together with results from earlier experiments on emissions from slurry stores (AMON ET AL. 2004b) and from a straw flow system for fattening pigs (AMON ET AL. 2004a), it may be concluded, that EM should be added at an early stage of the manure management continuum and on a regular basis to evolve its positive effects.
- Untreated and EM amended pig farmyard manure were anaerobically stored. The temperature inside the untreated pig farmyard manure was higher than in the EM amended farmyard manure. CO_2 emissions were higher from untreated pig farmyard manure. The reason probably lies in the microbial activity being more aerobic in the untreated farmyard manure, whereas metabolic processes in the EM amended farmyard were mainly anaerobic.
- The one-time EM addition at the time of pig farmyard manure storage reduced CH_4 emissions by 4 %, NH_3 emissions by 43 %, N_2O emissions by 9 % and greenhouse gas emissions by 7 %. VOC emissions were 33 % higher than with untreated pig farmyard manure.

References

AMON, B., FRÖHLICH, M., KRYVORUCHKO, V., AMON, T. (2004a). Einfluss von „Effektiven Mikro-Organismen (EM)“ auf Ammoniak-, Lachgas- und Methanemissionen und auf das Geruchsemissionspotential aus einem Schrägbodenstall für Mastschweine. Endbericht im Auftrag der Multikraft Produktions- und HandelsGmbH, Dezember 2004.

Amon, B., Kryvoruchko, V., Amon, T., Moitzi, G. (2004b). Wirkung des Zusatzstoffes „Effektive Mikroorganismen (EM)“ auf den Umfang von Ammoniak-, Methan- und Lachgasemissionen und auf das Geruchsemissionspotential während der Lagerung von Rinder- und Schweineflüssigmist. Endbericht, Februar 2004. Im Auftrag von Multikraft GmbH, A-4631 Haiding / Wels.

AMON, B., MOITZI, G., SCHIMPL, M., KRYVORUCHKO, V., WAGNER-ALT, C. (2002). Methane, Nitrous Oxide and Ammonia Emissions from Management of Liquid Manures, Final Report 2002. On behalf of „Federal Ministry of Agriculture, Forestry, Environmental and Water Management“ and „Federal Ministry of Education, Science and Culture“.

AMON B., AMON T., BOXBERGER J., PÖLLINGER A. AND ZAUSSINGER A. (1996). Entwicklung einer Meßeinrichtung zur Erfassung umweltrelevanter Gasemissionen. Die Bodenkultur 47 (7), 247 –253.

IPCC (1996). Climate Change 1995: The Science of Climate Change. In: Intergovernmental Panel on Climate Change; J.T. Houghton, L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg, and K. Maskell, (Ed.), Cambridge University Press, Cambridge, U.K.

Zaludik, K. (1997). Untersuchungen zum Schrägbodensystem für Mastschweine. Diplomarbeit an der Universität für Bodenkultur, Wien.