Nutrient Cycling in Agroecosystems **60:** 103–113, 2001.

Emissions of NH_3, N_2O and CH_4 from dairy cows housed in a farmyard manure tying stall (housing, manure storage, manure spreading)

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Key words: ammonia, dairy cow, farmyard manure treatment, methane, nitrous oxide, tying stall

Abstract

Emission measurements from dairy cows housed in a tying stall were carried out with the aim of finding factors that influence the amount of emissions and means to reduce emissions. All sectors of animal husbandry were investigated. This enabled calculations of emissions for the whole management system including housing, storage and spreading of manure. Emissions during aerobic composting and anaerobic stacking of farmyard manure were compared. NH_3 and N_2O emissions from tying stalls for dairy cows are low (5.8 g NH_3 LU^{-1} d^{-1}, 619.2 mg N_2O LU^{-1} d^{-1}). Methane emissions from the animal housing are mainly caused by enteric fermentation. During storage and after spreading of farmyard manure substantial differences concerning NH_3, N_2O and CH_4 emissions were observed with composted and anaerobically stacked farmyard manure. The compost emitted more NH_3 than the anaerobically stacked farmyard manure. About one third of the NH_3 emissions from the anaerobically stacked farmyard manure occurred after spreading. Total N losses were at a low level with both storage systems. Greenhouse gas emissions (N_2O and CH_4) were much higher from the anaerobically stacked farmyard manure than from the composted one. As these are ecologically harmful gases, they have to be considered when judging the form of manure treatment.

Introduction

Animal husbandry results in considerable emissions of ammonia (NH_3), methane (CH_4) and nitrous oxide (N_2O). Ammonia emissions cause eutrophication and acidification and thus play an important role in the decline of biodiversity and dying of forests. Critical loads are exceeded in many parts of Europe. Negotiations within the UN-ECE countries aim at controlling ammonia emissions.

CH_4 and N_2O are greenhouse gases and contribute to global warming. Agriculture is the principal source of CH_4 and N_2O at EU level. The Kyoto Protocol requires EU greenhouse gas emissions to be reduced by 8% below 1990 level by the year 2008–2012.

At the “Institut für Land-, Umwelt- und Energietechnik[1]”(ILUET), emission measurements are carried out with the aim of finding factors that influence the amount of emissions and means to reduce emissions from different agricultural sources. Emission measurements to be undertaken have to fulfil the requirements listed in Table 1.

Substrates that emit NH_3, N_2O and CH_4 are inhomogeniously composed. Including only small quantities in the measurements often leads to high variabilities in emissions that do not allow to calculate mean emissions which are representative of the investigated emission source. This phenomenon has often been shown in emission measurements from soils (e.g. Mosier, 1994; Ambus and Christensen, 1995; Velthof et al., 1996) and from animal manure (e.g. Husted, 1993). Emission measurements should therefore include large quantities of the emitting substrates.

As emissions of NH_3, N_2O and CH_4 result from microbiological, chemical, and physical processes, those processes should not be influenced by the measurement technique. This requires emission measurements under field conditions if quantitative emission data are to be gathered.

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[1] Institute of Agricultural, Environmental and Energy Engineering.

Table 1. Aims of emission measurements and requirements on the measurement technique

Aim of emission measurement	Requirement on the measurement technique
• Determination of emission rate [g h^{-1}]	• Measurement of gas concentration [g m^{-3}] and air flow [m^3 h^{-1}]
• Gathering of emission data representative of the source of emission to be investigated	• emission measurements from large quantities of the emitting substrates • Accurate gas concentration analysis
• Little influence on the microbiological activity	• Emission measurements under field conditions
• Determination of net emissions	• Continuous day round measurements • Year round measurements
• Minimising the sum of ecologically noxious emissions	• Simultaneous measurement of NH_3, N_2O and CH_4 • Measurements in all sectors of animal waste management (housing, storage, spreading)

Emissions show diurnal and yearly variations. Therefore emission measurements have to be carried out continuously over several 24-h periods and have to be repeated in course of the year (Mosier, 1989; Schütz and Seiler, 1989).

Emissions of NH_3, N_2O and CH_4 are influenced by a multitude of different factors. Complex interactions exist between different emitting sources (Jarvis and Pain, 1994; Kaiser et al., 1996; Duxbury, 1994). This requires a whole system approach when carrying out emission measurements. The control of the emission of one compound might enhance the emission of another compound or of the same compound but at another stage of management (Pain, 1998).

In Austria most of the cows are housed in straw based or slurry based tying stalls (Konrad, 1994). The tying stall is a common housing system in other European countries as well. So far emission measurements have mainly concentrated on ammonia emissions from loose housing systems for dairy cows (e.g. Isermann, 1994; Monteny and Kant, 1997). There is little knowledge on ammonia emissions from tying stalls. Thus emissions from dairy cows are calculated with emission factors gathered in loose housing systems (BUWAL, 1995). However, due to their different design tying stalls are likely to emit less ammonia than loose housing systems. In order to calculate emission inventories more accurately, emission factors gathered in tying stalls are necessary.

It is also necessary to measure emissions under conditions that are typical of Alpine regions. So far most of the European emission measurements have been carried out in the Netherlands, in Denmark, in the UK or in Northern Germany. Climate as well as management of animal husbandry in those countries differ considerably from conditions in Alpine regions of Austria, Switzerland and Southern Germany. Country specific emission data are therefore necessary.

After leaving the stall, farmyard manure can either be stacked anaerobically or be aerobically composted. So far most experiments have concentrated on ammonia emissions from farmyard manure (e.g. Römer et al., 1994; Dewes, 1996; Kirchmann and Lundvall, 1998). It was shown that composting resulted in higher emissions than anaerobic stacking. However as mentioned before, methane and nitrous oxide emissions must also be considered when evaluating the environmental impact of different methods of manure treatment. Some experiments carried out on the laboratory scale included CH_4 and N_2O in the emission measurements. It was shown that increasing the aeration of the farmyard manure reduced CH_4 and N_2O emissions (Hüther, 1999). Thus it can be assumed that there might exist a conflict between anaerobic stacking that leads to lower ammonia emissions, but higher greenhouse gas emissions and aerobic composting that leads to higher ammonia emissions, but lower greenhouse gas emissions. The effect of both methods of manure treatment has to be quantified in long-term measurements under field conditions.

The method of farmyard manure treatment also influences the change in manure composition, especially in the NH_4–N content. During the composting process NH_4–N is transformed to more stable, organic nitrogen forms that are less subjected to gaseous losses (Hümbelin et al., 1980). Anaerobic stacking does not completely transform NH_4–N. Ammonia emissions during and after farmyard manure spreading are strongly influenced by the NH_4–N content (Menzi et al,. 1997). Thus the emissions after spreading have also to be included in the measurements in order to calculate the net total of emissions from composted and anaerobically stacked farmyard manure.

The aim of our experiments was to assess emissions of NH_3, N_2O and CH_4 from dairy husbandry under Alpine conditions. All sectors of the production process were to be included in the measurements. Measurements were to be carried out under practical conditions.

Materials and methods

Determination of emission rates

If an emission rate is to be determined, the gas concentration and air flow have to be known. Concentrations of NH_3, N_2O and CH_4 were continuously analysed by high resolution FTIR[2] spectroscopy. 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 (Günzler and Böck, 1983; Staab, 1991). 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 spectrometer has to be high. The applied FTIR spectrometer 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 methane and nitrous oxide. The FTIR spectrometer was calibrated with the gas mixing station of the Institute of Biosystems Engineering of the German Federal Agricultural Research Centre.

In closed stalls with a central exhaust fan, the ventilation rate was measured with a fan-based flow meter that covered the whole cross-section of the central exhaust fan. The flow meter was regularly calibrated at the Institute of Agricultural Engineering of the Technical University of Munich. For the determination of the air flow over stored manure and during and after manure spreading ILUET has developed a large open-dynamic-chamber (Figure 1, Amon et al., 1996).

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. 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 1000 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. Manipulations such as, e.g., turning of the compost inside the chamber are possible. Emissions during those manipulations can be registered.

For emission measurements after manure spreading 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}.

Emissions from a tying stall for dairy cows

Emissions of NH_3, N_2O and CH_4 were measured from a centrally ventilated tying stall for 12 dairy cows several times in course of a year. Gas concentrations were alternately measured in the incoming air and in the exhaust air. Measurements were continuously carried out for 24 hours a day during each experiment.

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[2] Fourier transform infrared.

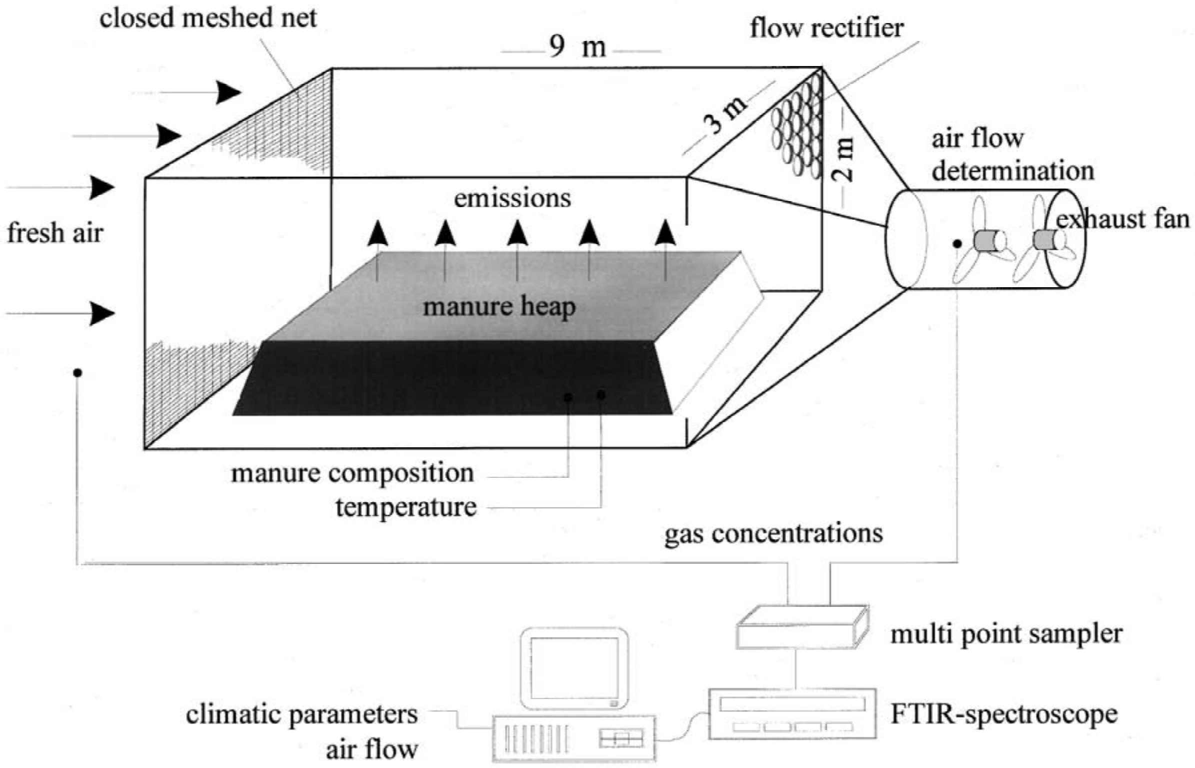

Figure 1. Large open-dynamic chamber developed by ILUET.

Table 2. Overview of the conditions during emissions measurements from a tying stall for dairy cows

Experiment	Date	Climatic conditions				Milk yield	Livestock
		Temp$_{\text{out}}$^{a} [°C]	Temp$_{\text{in}}$^{b} [°C]	rh$_{\text{out}}$ ^{c} [%]	rh$_{\text{in}}$^{d} [%]	[kg cow^{-1} d^{-1}]	units
Slurry I	10-16 to 10-23	8.1	12.6	87.2	58.7	22.4	14.6
Straw I	11-01 to 11-08	5.5	14.6	89.0	61.8	23.0	14.7
Straw II	11-27 to 12-06	−3.0	8.1	90.8			
Slurry II	12-11 to 12-20	−3.1	14.5	97.7		18.5	14.1
Slurry III	01-30 to 02-06	−3.4	9.4	81.4	57.7	16.1	15.5
Straw III	06-16 to 06-26	14.3	19.4	70.1	73.7	16.7	14.1
Slurry IV	06-26 to 07-08	17.5	20.2	61.6	63.5	16.7	13.9
Straw IV	07-24 to 08-01	17.9	20.9	65.8	65.0	16.6	12.6
Slurry V	08-04 to 08-11	19.9	22.1	62.9	66.7	16.8	12.6
Slurry VI	10-17 to 10-31	3.6	13.1	70.9	58.6	20.0	14.6

[a] Temperature outside; [b] Temperature inside; [c] Relative humidity outside; [d] Relative humidity inside.

The tying stall was alternately operated as a slurry based and as a straw based system to enable a comparison between both systems. For the straw based system wooden boards were laid on the dung grids behind the cows and 2 kg of straw per cow and day were littered down. The farmyard manure was mugged out twice a day and brought into the large open-dynamic-chamber to assess emissions from stored farmyard manure as soon as it had left the housing. Emission measurements from fresh manure lasted for 10 days.

Table 3. Farmyard manure composition and mean temperature inside the manure heaps

Experiment	DM[a] [%]	N_t[b] [kg t^{-1}]	NH_4–N[c] [kg t^{-1}]	C/N	pH	Temp. [°C]
• Summer						
Composted FYM[e]	28.3	6.60	1.10	14	7.55	45.0
Stacked FYM	20.4	6.39	1.17	14	7.43	35.3
• Winter						
Composted FYM	22.1	6.69	0.63	16	8.7	34.3
Stacked FYM	21.2	6.31	0.43	15	8.2	22.4

[a]Concentration of dry matter; [b]concentration of total nitrogen; [c]concentration of NH_4–N; [d]farmyard manure.

Table 2 shows date of trial, climatic conditions inside and outside the housing, milk yield per cow and the sum of livestock units inside the housing.

Concurrently with the emission measurements a feeding trial was carried out (Gruber et al., 1998). Thus feed intake and milk yield were known and methane emissions from enteric fermentation could be calculated with the help of regression formulas found by Kirchgessner et al., (1991). Methane emissions caused by enteric fermentation could be distinguished from those caused by the manure.

Emissions during farmyard manure storage

To assess the emissions during farmyard manure storage, two heaps of farmyard manure (each about 7 t) were stored on concrete slabs. Seepage water emissions were collected and analysed for their N content. One heap was composted aerobically, which means it was turned seven times during the storage period. The other heap was stacked anaerobically, with no manipulations performed during the storage period. The large open-dynamic-chamber was build up over the manure heaps to collect the emissions. Each heap was measured continuously for two days, after which the large open-dynamic chamber was moved to the other heap. The storage period lasted for 80 days. The experiment was carried out twice: once under summer conditions and once under winter conditions. Table 3 gives the farmyard manure composition at the beginning of the experiments and the mean temperature inside the manure heap during the storage period.

Emissions after farmyard manure spreading

After the storage period, the measuring chamber was set up on grassland and first the composted and afterwards the anaerobically stacked farmyard manure was spread in the chamber. Emissions during and after spreading were also measured so that the net total of emissions from a particular manure could be determined. The amount of spread manure was equivalent to 20 t ha^{-1}, the mean temperature was 10 °C in the summer experiment and 15 °C in the winter experiment.

Results and discussion

Emissions from a tying stall for dairy cows

Ammonia emissions

Table 4 gives the ammonia emissions measured in a tying stall for dairy cows. Ammonia emissions varied in course of the year and showed a correlation with the temperature inside the housing. This phenomenon is in line with the basic principles of ammonia emission (Denmead et al., 1982). Mean emissions were 5.7 g NH_3 LU^{-1} d^{-1} for the slurry based system and 5.8 g NH_3 LU^{-1} d^{-1} for the straw based system. There was no significant difference in ammonia emissions between both systems. Oldenburg (1989) gives ammonia emissions from a tying stall of 3.79–10.08 g NH_3 LU^{-1} d^{-1}. Emissions from a tying stall situated in

Table 4. Daily ammonia emissions from a tying stall for dairy cows

	NH_3 [g LU^{-1} d^{-1}][a]		
	min	max	mean
Slurry based system	4.0	6.1	5.7 n.s.[b]
Straw based system	3.9	7.4	5.8 n.s.

[a]LU = Livestock Unit; [b]not significant.

the Netherlands were higher (9.0–14.0 g NH_3 LU^{-1} d^{-1}, Groenestein and Montsma, 1991). This might be due to the more intensive management, higher milk yield, and higher protein content of dairy cows' diets in the Netherlands compared with the situation in an Austrian alpine region. Ammonia emissions from loose houses are generally higher than ammonia emissions measured in the tying stall. Isermann, (1994) gives a mean value of 16.6 g NH_3 LU^{-1} d^{-1}. Thus ammonia emissions from tying stalls are overestimated if they are calculated with emission factors from loose houses. Emission inventories should offer separate emission factors for loose houses and tying stalls. However, this would also require knowledge on the percentage of cows housed in tying stalls respectively loose houses in each country. Surveys should be carried out in order to get more accurate data on country specific animal husbandry.

Nitrous oxide emissions

Mean nitrous oxide emissions from the tying stall were 609.6 mg N_2O LU^{-1} d^{-1} (slurry based system) and 619.2 mg N_2O LU^{-1} d^{-1} (straw based system) with no significant differences between both systems (Table 5). Their share in total nitrogen emissions was between 5 and 10%. Sneath et al. (1997) give N_2O emissions from UK livestock buildings of 800 mg N_2O LU^{-1} d^{-1}.

Methane emissions

Methane emissions showed a clear diurnal variation (Figure 2) and were closely correlated with CO_2 emissions (R^2 = 0.807). Maximum emissions were measured in the morning and in the afternoon shortly after the feeding of the cows. Methane as well as CO_2 emissions from dairy cows are mainly caused by enteric fermentation. This explains the close correlation between both gases and the diurnal variation that was also found by other authors (e.g. Kinsmann et al., 1995).

Methane emissions varied in course of the year but did not show a correlation to the season or to climatic parameters. Variations in methane emissions were caused by different milk yield and feed intake. Mean methane emissions (194.4 g CH_4 LU^{-1} d^{-1}) were the same in both systems (Table 6). Calculations of the amount of methane that was caused by enteric fermentation (Kirchgessner et al., 1991) showed that in both systems about 80% of the net methane emission were due to enteric fermentation and about 20% came from the manure. This is in line with the general knowledge that enteric fermentation is a dominant source of agricultural methane emissions.

Table 5. Daily nitrous oxide emissions from a tying stall for dairy cows

	N_2O [mg LU^{-1} d^{-1}][a]		
	min	max	mean
Slurry based system	141.6	1188.0	609.6 n.s.[b]
Straw based system	300.0	1135.2	619.2 n.s.

[a]LU = Livestock Unit; [b]not significant.

Table 6. Daily methane emissions from a tying stall for dairy cows

	CH_4 [g LU^{-1} d^{-1}][a]		
	min	max	mean
Slurry based system	170.4	218.4	194.4 n.s.[b]
Straw based system	184.8	232.2	194.4 n.s.

[a]LU = Livestock Unit; [b]not significant.

Emissions during farmyard manure storage and after spreading

Nitrogen losses

Table 7 shows ammonia emissions from composted and anaerobically stacked farmyard manure. In the summer as well as in the winter experiment the compost emitted more ammonia than the anaerobically stacked farmyard manure. Ammonia emissions from the winter compost were lower than from the summer compost. This was due to heavy snowfall at the beginning of the winter experiment. The snow melted on the warm heap and drained inside the compost. Thus the oxygen supply inside the heap was low and the composting process did not proceed well.

Turning contributed 4% of total ammonia emissions from the compost during the summer experiment. The process of turning plays a minor role in total ammonia emissions during composting.

After spreading of the compost no ammonia emissions were detected. This corresponds well to the results of Menzi et al. (1997) and Kirchmann and Lundvall (1998) who found lower ammonia emissions from strongly decomposed farmyard manure that from fresh farmyard manure. The summer compost did not contain NH_4–N at the end of the storage period and so no ammonia was emitted.

A considerable part of the total ammonia from the stacked farmyard manure was lost after spreading;

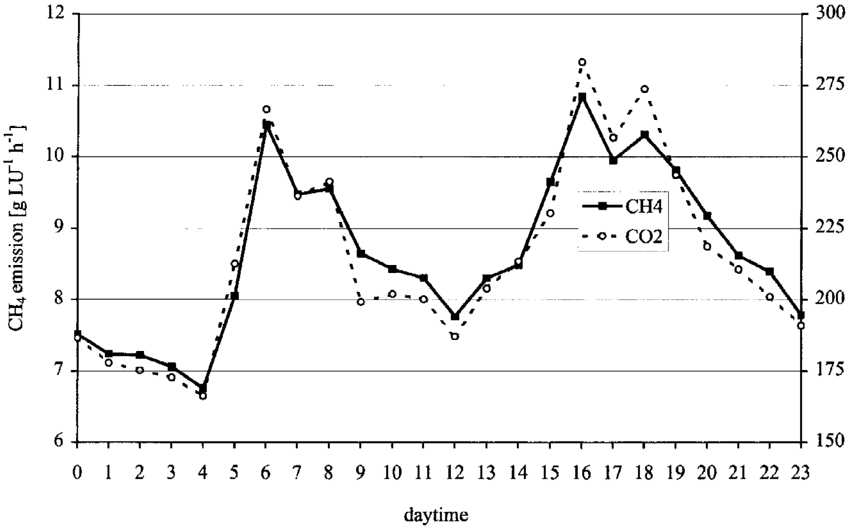

Figure 2. Typical diurnal variation of methane and carbon dioxide emissions from a tying stall for dairy cows.

Table 7. Ammonia emissions from composted and anaerobically stacked farmyard manure

Experiment	NH_3 losses [g (t FM[a])$^{-1}$]			Sum [g (t FM)$^{-1}$]
	Storage	Turning	Spreading	
• Summer				
Composted FYM[b]	643.3	27.2	—	*670.5*
Stacked FYM	162.7	—	85.3	*248.0*
• Winter				
Composted FYM	302.6	—	—	*302.6*
Stacked FYM	46.2	—	197.3	*243.5*

[a] Fresh matter; [b] farmyard manure.

81% of the total emissions occurred after spreading. The winter experiment started in winter and lasted for 80 days. Thus, the stacked farmyard manure from the winter experiment was spread in June, under warm conditions (mean temperature 15 °C). This resulted in higher ammonia emissions. Ammonia emissions after spreading of the stacked manure were 2.8 kg NH_3 ha^{-1} (summer experiment) and 5.74 kg NH_3 ha^{-1}(winter experiment).

Nitrous oxide losses were lower from the composted farmyard manure than from the anaerobically stacked manure (Table 8). They varied between 0.3% and 0.8% of total nitrogen content. Nitrous oxide is formed during aerobic nitrification and anaerobic denitrification with denitrification giving more N_2O that nitrification. Hüther (1999) also found rising N_2O emissions from cattle manure with lower oxygen supply. Her experiments gave N_2O emissions between 0.3% and 1.5% of total nitrogen content. The IPCC guidelines (1997) propose an emission factor for solid storage of 20 g N_2O–N per kg N excreted with a range between 5 and 30 g N_2O–N per kg N excreted. N_2O emissions found in our experiments correspond to a range between 2.7 and 10.2 g N_2O–N per kg N excreted.

N losses via seepage water ranged from 181.9 to 260.1 g N t^{-1} and mainly occurred at the beginning of the storage period. It must be recommended to store farmyard manure on concrete slabs during the first three weeks at least. They must offer the possibility of collecting the seepage water in order to

Table 8. Nitrogen losses from composted and anaerobically stacked farmyard manure

Experiment	N losses [g (t FM[a])$^{-1}$]				% of total N
	NH_3–N	N_2O–N	N in seepage water	Sum	
• Summer					
Composted FYM[b]	552.2	23.9	141.5	717.6 *10.8*	
Stacked FYM	205.7	36.5	260.1	502.3	*7.8*
• Winter					
Composted FYM	249.2	30.0	200.1	479.3	*7.6*
Stacked FYM	201.3	55.6	181.9	438.8	*6.5*

[a] Fresh matter; [b] farmyard manure.

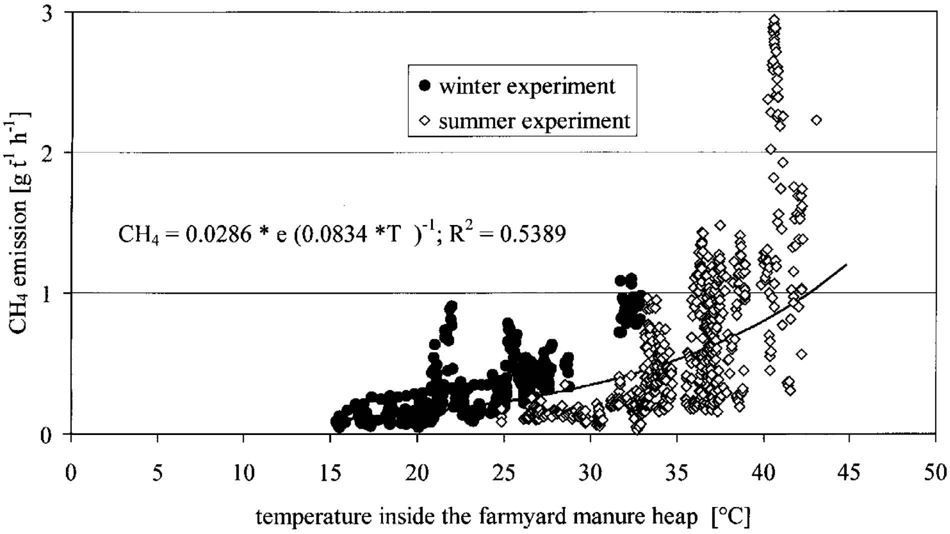

Figure 3. Methane emissions from anaerobically stacked farmyard manure in dependency on the temperature inside the manure heap.

Table 9. Greenhouse gas emissions from composted and anaerobically stacked farmyard manure (80-d storage period)

Experiment	Greenhouse gas emissions [kg CO_2-eq. (t FM[a])$^{-1}$]		
	From N_2O emissions	from CH_4 emissions	Sum
• Summer			
Composted FYM[b]	8.87	4.96	13.83
Stacked FYM	13.65	47.84	61.49
• Winter			
Composted FYM	12.27	24.21	36.48
Stacked FYM	20.64	18.41	39.05

[a] CO_2-equivalents, fresh matter; [b] farmyard manure.

avoid uncontrolled N emissions into the soil and/or groundwater.

Total N losses were at a low level with both methods of manure treatment. Low nitrogen losses during storage of dairy cattle farmyard manure were also found by other authors (e.g. Meyer, 1982; Kirchmann and Lundvall, 1998; Hüther, 1999).

Greenhouse gas emissions

In the summer experiment, the anaerobically stacked farmyard manure emitted about 4.5 times more greenhouse gasses than the aerobically composted farmyard manure (Table 9) with methane emissions contributing about 78% to total greenhouse gas emissions. Methane is formed under warm anaerobic conditions when degradable C is available. Conditions in the anaer-

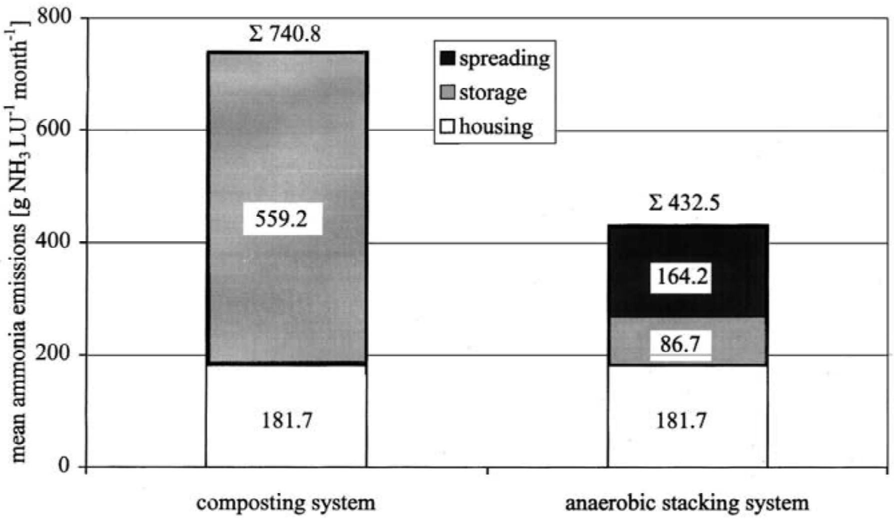

Figure 4. Ammonia emissions from dairy cows housed in a farmyard manure tying stall.

obically stacked farmyard manure favoured methane formation. Temperature inside the manure heap was the main influencing factor on methane emissions from the anaerobically stacked farmyard manure (Figure 3). As the temperature inside the anaerobically stacked winter farmyard manure rose only at the end of the storage period, methane emissions were lower than during the summer experiment. But they would have become much higher if the storage had continued longer. The compost emitted only little methane at the beginning of the storage period whereas methane emissions from the anaerobically stacked farmyard manure were measured during the whole storage period and had not come to their end by the end of the storage period.

Due to the lack of oxygen supply in the winter compost, N_2O and CH_4 emissions were higher than from the summer compost. A sufficient aeration is essential for a good composting process. Insufficient oxygen supply leads to formation of greenhouse gases. If a good composting process is guaranteed, N_2O and CH_4 emissions are low.

Methane emissions from animal waste are estimated by methane conversion factors (MCF, Gibbs and Woodbury, 1993). The IPCC guidelines (1997) propose a MCF for solid storage of 1–2% of the maximum methane production capacity of dairy cattle manure. However, those factors are based on a very limited amount of measurements on a laboratory scale and bear a high range of uncertainty. Methane emissions measured in our experiments ranged between 0.41% (summer compost) and 3.92% (summer anaerobically stacked farmyard manure). As most of the farmyard manure is currently stacked anaerobically, methane emissions from farmyard manure are underestimated. It was shown that composting – which is common especially in organic farming – is an effective means for reducing methane emissions. This mitigation measure could show up in emission inventories by applying different emission factors for composting and anaerobic stacking.

Emissions from the whole management system

Figure 4 shows the net total of ammonia emissions from dairy cows housed in a farmyard manure tying stall. Two scenarios have been investigated: aerobic composting of farmyard manure and anaerobic stacking. Within the anaerobic stacking system, 42% of total NH_3 emissions came from the housing, 20% emitted during farmyard manure storage and 38% after farmyard manure spreading. Within the composting system 75% of net emissions occurred during the composting process. However, even with the composting system, total N losses were still on a low level of about 10% of N excreted.

The composting system resulted in greenhouse gas emissions 25% lower than the anaerobic stacking system (Figure 5). Farmyard manure composting has a considerable potential of reducing greenhouse gas emissions. In both systems, the dominant part of the greenhouse gas emissions came from the housing,

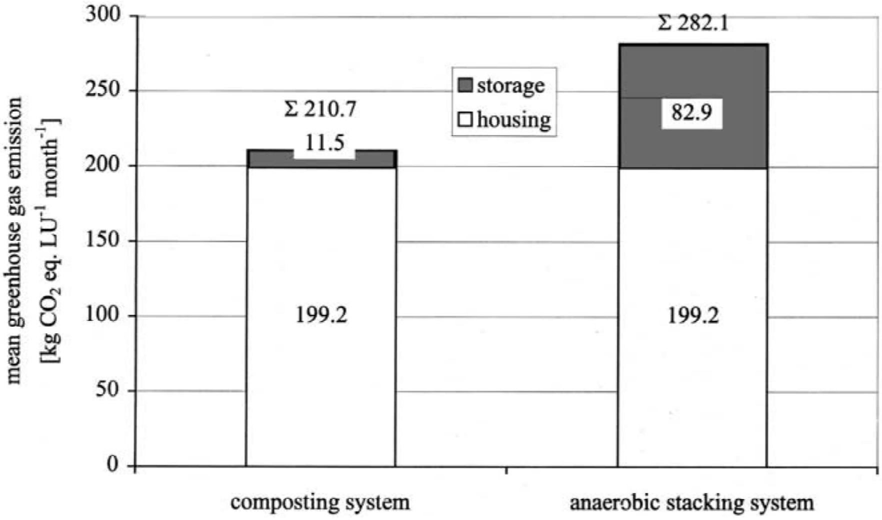

Figure 5. Greenhouse gas emissions from dairy cows housed in a farmyard manure tying stall.

mainly from enteric fermentation. In the anaerobic stacking system the storage contributed 29% to the total emissions.

Conclusions

Ammonia emissions from a tying stall for dairy cows were lower than emissions measured in loose housing systems. For an accurate calculation of emission inventories, it is important to have separate emissions factors for tying stalls and loose houses. Methane emissions in the housing were mainly caused by enteric fermentation. Measures to mitigate methane emissions from animal waste should therefore be applied during animal waste storage.

During storage and after spreading of farmyard manure substantial differences concerning NH_3, N_2O and CH_4 emissions were observed with composted and anaerobically stacked farmyard manure. The compost emitted more NH_3 than the anaerobically stacked farmyard manure. However, those emissions could further be reduced by adding more straw to the farmyard manure which results in a wider C:N ratio. A considerable part of the NH_3 emissions from the anaerobically stacked farmyard manure occurred after spreading. It is important to include the spreading in calculations of the total emissions. Total N losses were at a low level with both storage systems. Greenhouse gas emissions (N_2O and CH_4) were much higher from the anaerobically stacked farmyard manure than from the composted one. As these are ecologically harmful gases, they have to be considered when judging the form of manure treatment. Different emission factors should be applied for calculation of greenhouse gas emission from composted and anaerobically stacked farmyard manure.

It is important to take into consideration all sectors of animal husbandry if mitigation options for ecologically harmful gases are to be found. The distribution of the emissions to the emitting sources differs in dependency on the treatment.

Acknowledgements

This work has been funded by the Austrian Ministry of Agriculture and Forestry.

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