

Emission of greenhouse gases during composting of deep litter from pig production – effect of straw content

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SUMMARY

Of the anthropogenic greenhouse gas emission in Denmark animal manure contributes an estimated 40% of methane (CH₄) and 20% of nitrous oxide (N₂O). Livestock production systems undergo changes for the purpose of increasing animal welfare, and such changes often include increasing the amounts of bedding manure. Emission of greenhouse gases from composting pig deep litter was studied during a 4-month period. Effects of increasing the amount of straw used in deep litter (reducing litter density) were included in the study. Methane was produced at a high rate in the centre of the heap at high density during the thermophilic phase of composting, and CH₄ emission was only measured during this phase. In this treatment N₂O was also produced in the centre both initially and after the temperature of the compost had dropped to below 45 °C. Emissions of N₂O were only significant in the low temperature phases. Production of N₂O was probably restricted to the surface layers during the thermophilic phase of composting. Total carbon dioxide (CO₂) emissions were 7.37 and 0.09 kg C/t fresh weight from the heaps with bulk densities of 0.44 and 0.23 kg/l, respectively. Methane emission from the high density compost heap was 191 g C/t and N₂O emission was 58 g N/t. Emissions of CH₄ and N₂O from the low density heap were not detected. The greenhouse effect of gas emission from the high density compost heap was calculated by multiplying the climate force efficiencies and the cumulated gas emission. This calculation showed that CH₄ contributes almost as much to the global warming potential as CO₂, and N₂O contributed twice as much as CO₂.

INTRODUCTION

Animal production contributes significantly to atmospheric nitrous oxide (N₂O) and methane (CH₄). In Denmark anthropogenic emissions of CH₄ are 430 000 t/yr of which 172 000 t are emitted during collection and storage of manure and from manure applied to the soil. The emission of N₂O is 36 000 t/year of which 7000 t are emitted from animal manure (Petersen & Sommer 1999). Globally the emission of CH₄ and N₂O from livestock manure contributes 5–6% to the total emission of CH₄ (Hogan *et al.* 1991; Rotmans *et al.* 1992) and 7% of N₂O (Khalil & Rasmussen 1992).

The efficiency of N₂O in absorbing infrared radiation, which is about 200 times that of carbon dioxide (CO₂), makes it important as a greenhouse

gas (Houghton *et al.* 1992). Furthermore, N₂O contributes to the reduction of ozone in the stratosphere through the photochemical decomposition of N₂O to NO (Cicerone 1987). Methane is also an efficient greenhouse gas. The current climate forcing of CH₄ is 26 times that of CO₂ (Lelieveld & Crutzen 1992) and it has been calculated that CH₄ contributes 9–20% to the total global warming potential (Bouwman 1990; Lashof & Ahuja 1990).

The emission inventories are based on a limited number of data with respect to animal manure. There has been a considerably higher focus on emissions of greenhouse gases from mineral fertilizers. For the purpose of improving the calculation of emissions and developing abatement techniques, there is a need for more knowledge about CH₄ and N₂O emission during the handling of animal manure.

The design of animal production systems is changing to meet the market demand for animals kept under improved conditions of welfare. In pig

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production more pigs will be housed on deep litter instead of slatted floors, and the pigs will have access to outdoor exercise areas in small enclosures. This change will increase the amount of solid manure and could change the level of emissions of greenhouse gases from pig production.

It is known that increasing the amount of straw in the pigs' bedding material will reduce the leaching and volatilization loss of nitrogen (N), because N from urine and faeces is immobilized by microorganisms (Kirchmann & Witter 1989). Changing the amount of straw in the bedding may change the emission of CH₄ and N₂O during the subsequent storage. A high straw content may increase convection of air through the dung heap, and in deep litter with a high air exchange the relative volume of anaerobic sites will be low and the potential for CH₄ and N₂O emission may be less compared to deep litter with little air exchange.

In this study we examined the emission of CO₂, CH₄ and N₂O from two dung heaps with deep litter from pigs at two levels of barley straw content. Furthermore we measured the concentration of CH₄, N₂O and CO₂ inside the two heaps.

MATERIALS AND METHODS

Compost

Gas emission was measured during composting in two heaps of deep litter from fattening pigs. The pigs were housed outdoors on deep litter of barley straw with a tent for protection. The fatteners were brought up from 6 to 24 weeks (17 to 100 kg live weight) in two separate enclosures being strewn with 1.2 and 1.87 kg straw per kg increase in daily live weight. Deep litter collected by the end of a fattening period was mixed by passing the material through a manure spreader on the starting day of the experiment. Immediately after this treatment, each of the deep litter types was stored on separate sealed surfaces (H: 1.3 m, L: 5 m, W: 3 m). The amount and composition of the deep litter used for composting are given in Table 1. The litter was composted from 31 March to 21 August 1998. In both heaps gas composition were measured and compost temperature were determined using pt-100 sensors with data collection on a datalogger (Datataker DT200, Data Electronics LTD, Australia).

Gas composition in the compost

For determination of CH₄, N₂O, CO₂ and oxygen (O₂) concentration inside the compost heaps gas samples were collected from the centre of the heaps by a modification of the technique described by Petersen *et al.* (1998). The two ends of a flexible, but rigid plastic tube with an internal diameter (i.d.) of 10 mm, and containing 4 holes, 2 mm in diameter, per cm

Table 1. Amount and composition of stored deep litter from housing of dairy cows. The volume of the deep litter heaps was 9.75 m³. (In parentheses S.D., n = 3)

	Amount (tons)	Bulk density kg/l	C:N ratio		DM	Ash	Total N	NH ₄	NO ₃	P	K	C
Initial	4.3	0.44	12.76		236 (43)	22.4 (4.8)	7.2 (0.4)	3.0 (0.3)	N.d.	1.9 (0.2)	3.4 (0.1)	91.9 (3.1)
Initial	2.24	0.23	16.27		652 (3)	64.6 (15.2)	8.2 (1.5)	1.1 (0.3)	N.d.	1.5 (0.6)	5.0 (1.9)	133.9 (50.4)

N.d., below detection limit.

length were connected to two 2-m lengths of gas-tight Teflon tubes (i.d. 2 mm). The Teflon tubes were connected to a glass tube fitted with a butyl rubber septum for gas sampling. The perforated plastic tube was buried at the centre of the compost heap, 0.4 m above the bottom. Before gas sampling 60 ml of air was sucked from the tubes, thereafter four samples of 60 ml were removed with syringes and transferred to 5 ml glass bottles fitted with butyl rubber septa. When transferring a sample to the glass bottle an extra needle was inserted through the rubber seal and the bottle was flushed with 45 ml of the gas in the syringe; then the needle penetrating the septum was removed and the 15 ml remaining in the syringe was injected (Petersen *et al.* 1998).

Gas emission measurements

Measurement of N₂O, CH₄ and CO₂ emission commenced immediately after the compost heaps were established. Gas emission was determined using a closed chamber technique (Hutchinson & Mosier 1981; Mosier 1989), which also has been used in previous studies of gaseous emission from composting organic waste (Czepiel *et al.* 1996; Hellman *et al.* 1997).

Two circular PVC frames (D: 8.3 cm, H: 10 cm) were buried to a depth of 5 cm in each of the compost heaps, one frame at the side of the heap at a height of 0.75 m above ground, and one on the top of the heap. During measurements circular PVC chambers with a headspace diameter and height of 8.3 and 10.2 cm, respectively, were mounted onto the frames. A butyl rubber septum was fitted to the chamber and gas samples were collected by penetrating the septum with 60 ml syringes immediately before placing chambers on the cylinders and after 10 and 20 min. The gas samples were transferred to 5 ml glass bottles fitted with butyl rubber septa as described above. Increase in headspace concentrations of N₂O, CH₄ and CO₂ was used for calculating gas fluxes.

Nutrient composition

At the initiation of the experiment three samples each of 2 litres of organic material were taken from the two dung heaps, and stored at -18 °C.

Before analysis the organic material was thawed at 0 °C and each 2 litre sample finely chopped with a cutting machine. Representative subsamples of about 500 g of chopped material were then cut into small pieces, and from this material 100 g was taken for analysis. All manure samples were analysed for dry weight, ash content, total C, Kjeldahl N (N_{total}), TAN (Total Ammoniacal Nitrogen), NO₃⁻, P and K.

Analysis

Nitrous oxide and CH₄ were measured on a Hewlett

Packard (5890, series II) gas chromatograph with an electron capture detector and a flame ionization detector. It was equipped with a 6 ft × 1/8" column with porapak Q 80/100 for N₂O, Ar/CH₄(5%) was used as a carrier at 30 ml/min and temperatures of injection port, oven and detector were 110, 40 and 320 °C, respectively. Methane was isolated with a 6 ft × 1/8" column with porapak N 80/100, it was used as carrier gas at 30 ml/min and temperatures of injection port, oven and detector were 110, 40 and 270 °C. Oxygen and CO₂ was measured on a Varian 3350 gas chromatograph equipped with a thermal conductivity detector. It was equipped with a 1 m × 1/8" column with Molecular Sieve 5A 60/80 for isolating O₂ and a 2 m × 1/8" Haysep R 80/100 for CO₂. The carrier gas was He at a flow rate of 30 ml/min, the temperatures of oven and detector were 40 and 150 °C, respectively.

TAN and NO₃⁻ in the solid manure were extracted in 1 M KCl for 30 min and filtered before analysis on a QuickChem 4200 flow injection analyser (Lachat Instr., Wisconsin, USA). Dry matter (DM) was determined after drying at 105 °C for 24 h, and ash content after heating to 550 °C for 4 h. Total C was determined by dry combustion (Leco model 521-275), K by flame photometry (FLM3, Radiometer, Copenhagen) after dry ashing and solubilization in acid, and P was measured colorimetrically (Spectronic 1001, Bausch & Lomb) after dry ashing and solubilization in acid and a colouring reaction with ammonium molybdate vanadate. Kjeldahl N was analysed using the Kjeldahl method and a Kjellfoss 16200 (Copenhagen, DK).

Calculations

Increases in headspace N₂O, CH₄ and CO₂ concentrations were used for calculating gas emission (F, mg/m² per min) using the linear equation (Mosier 1989):

$$F = \frac{V}{A} \times \frac{\Delta C}{\Delta t}$$

where V (m³) is the jar volume, A (m²) the area of compost covered by the jar, $\Delta C/\Delta t$ the rate of change in gas concentration (mg/m³ per min) in relation to time after the headspace was closed (min).

We tested whether influence of temperature on CH₄ concentration (C, ppm) could be modelled with the Arrhenius equation (Khan *et al.* 1997):

$$C = A \times e^{-E/R \times T}$$

where A is the Arrhenius parameter (CH₄ ppm), E apparent activation energy (J/mol), R the gas constant and T compost temperature 40 cm above the bottom of the heap (°K).

The accumulated gas emission from each compost heap was calculated using the trapezoidal rule (Thomas & Finney 1984). Differences in emission of

gases from the heap were analysed by a general linear model (Proc Glm.) and the linearity was analysed with the NLIN procedure of the SAS statistical package (Statistical Analysis System 1989).

RESULTS AND DISCUSSION

Temperature dynamics in the compost

High temperatures (Fig. 1) characterized the composting of deep litter. The high temperature generates an upward airflow and consequently air mostly enters through the lower section of the heap. High temperature is generated by aerobic metabolism of microorganisms in the heap and is therefore affected by the air flow which, in turn, is strongly related to air-filled space within the heap (Jeris & Regan 1973). The difference in temperature regimes between high and low densities agrees with findings in the study of Fernandes *et al.* (1994) showing that a high bulk density and consequently lower porosity increased process duration. The temperature fluctuations of the low bulk density heap are typical for the composting process. The temperature increases initially with the microbial biomass being dominated by mesophilic zymogenous bacteria and fungal decomposers (Hellmann *et al.* 1997; Herrmann & Shann 1997). Thereafter during the thermophilic phase with temperatures above 60 °C, most pathogens and weeds are killed and thermophilic organisms dominate, i.e. fungal populations decline (Herrmann & Shann 1997). During the temperature decrease (the curing phase) actinomycetes remain and fungi reappear (Hellman *et al.* 1997).

Gas phase concentration in the compost

Initially the increased CO₂ concentrations in the heaps (Fig. 2) probably originated from microbial decomposition of easily degradable substrates such as sugars and proteins. During the initial 40 days of

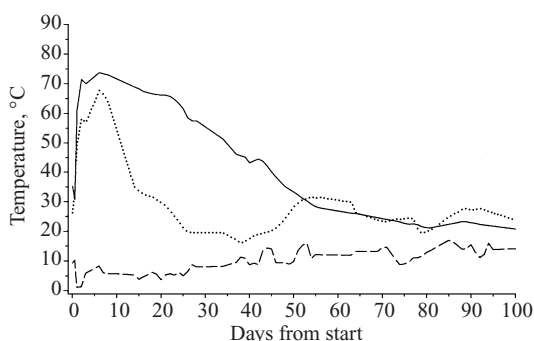


Fig. 1. The temperature at 40 cm height inside two compost heaps during 4 months. The deep litter in the heap had a bulk density of 0.23 kg/l (.....) and 0.44 kg/l (—). Air temperature (---).

composting the CO₂ concentration fluctuated in the high bulk density heap and was inversely related to concentrations of O₂. In this heap convection apparently did not exchange air at a rate sufficient to replenish O₂ used in the aerobic metabolism of organic residues by microorganism. The periodic decrease in CO₂ concentrations initially may be ascribed to a decrease in microbial biomass or microbial activity due to the high temperature of the compost (Hellmann *et al.* 1997). In the lower bulk density heap an initial increase in CO₂ and corresponding decrease in O₂ were measured after 5–10 days, i.e. during the period with increasing temperature. In both heaps CO₂ increased after 80 to 100 days, indicating that cellulose and hemicellulose-decomposing microorganisms had repopulated the heap (Herrmann & Shann 1997). Methane concentrations in the heap were only high under conditions with reduced concentrations of O₂, i.e. in the thermophilic phase of the high bulk density heap (Fig. 3). The number of methanogenic microorganisms in compost has been shown to increase in the thermophilic phase (Hellman *et al.* 1997) and the production of CH₄ in solid pig manure has been shown to increase with increasing temperature under anaerobic conditions (Husted 1994). Concentrations of CH₄ inside the heap may be related to production of CH₄ if the airflow through the heap is constant, the relation was tested using the Arrhenius equation. Figure 4 shows that ln(CH₄) is vaguely linearly related to 1/T for both heaps, indicating that data were not described well with the Arrhenius equation (Fig. 4). The difference in inclination ln(CH₄) to 1/T may be explained by differences in air flow through the two heaps and interactions between flow and temperature.

Apart from a period of between 45–80 days after project start, the concentration of N₂O in both heaps was a little higher than in the environment (Fig. 3). From day 35–80 N₂O concentration was high in the high density heap because the temperature had dropped below 50 °C and oxygen concentrations were between 18 and 21%. In the heterogeneous environment of a composting heap there may be both aerobic zones with nitrification and anaerobic zones with denitrification. From a substrate with a high NH₄ concentration N₂O is probably produced during nitrification (Lipschultz *et al.* 1981). Furthermore, N₂O is an intermediate product of denitrification (Anderson & Levine 1986; Petersen *et al.* 1998) and NO₃⁻ produced in aerobic zones may by diffusion or mass flow move to anaerobic zones where the NO₃⁻ is denitrified to N₂O and N₂.

Gaseous emissions

The spatial variability in emission shown in Fig. 5 agrees with the findings of Husted (1993) and

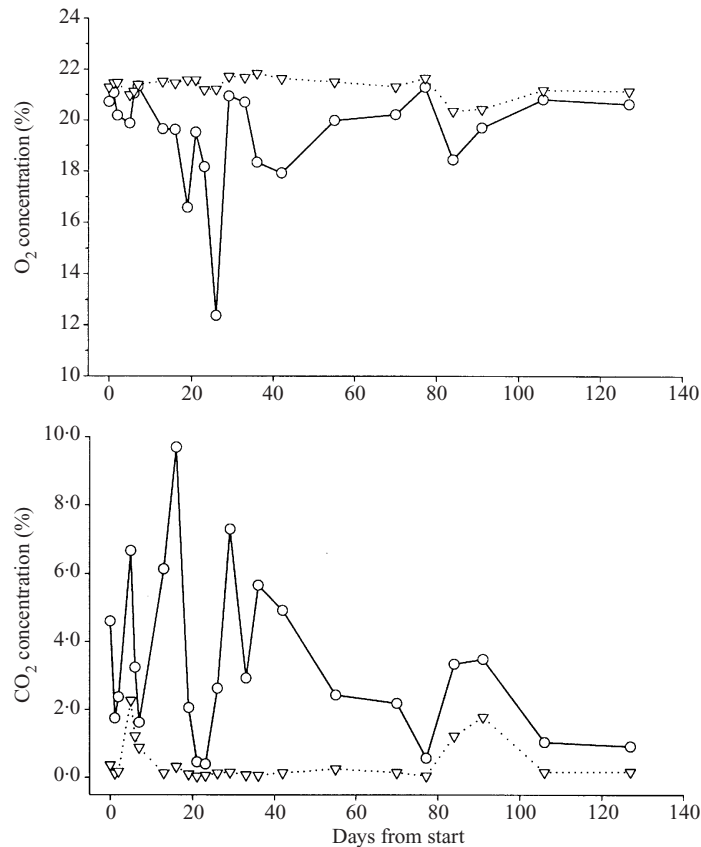


Fig. 2. Carbon dioxide and O₂ concentration in the gas phase at 40 cm height inside the composting deep litter heap at a bulk density of 0.23 kg/l (▽) and 0.44 kg/l (○).

Hellmann *et al.* (1997). This pattern reflects the fact that the high temperature in the compost generates an efflux of air through the top and upper parts of the heap and air intake from the lower parts of the sides (Fernandes *et al.* 1994). Therefore, little or no trace gases are emitted through the bottom half of the heap sides (Hellmann *et al.* 1997). In the following the emission rate is given as the mean of the emission measured with the two chambers mounted on the upper half of the heap.

In the first phase CO₂ emission from the high bulk density heap was high with peak emission rates of 160 g/m² per min. The emission from the low bulk density heap was significantly lower ($P \leq 5\%$) than the emissions from the high bulk density heap. The emission pattern in both heaps was related to the time course of CO₂ concentrations in the heap.

There was no CH₄ emission from the heap at low bulk density, reflecting that CH₄ concentrations were at ambient concentration levels inside this heap throughout the composting period (Figs 3 and 5). Methane emission from the heap at high bulk density clearly reflected the changes in CH₄ concentrations

inside the heap. Emissions were high by Day 1, which has not been observed in previous studies. Thereafter the emission was high from 15 to 30 days and a small increase in the emission was also found after 50–60 days of composting, which is a pattern similar to the time course of CH₄ emissions measured by Hellman *et al.* (1997). The time course and high rate of emission reflect that CH₄ is produced in strictly anaerobic environments and increases with increasing temperature (Hellman *et al.* 1997). Although emissions were related to CH₄ concentrations in the heap, it seems that the emission did not increase significantly until concentrations inside the heap reached *c.* 500 ppm (Fig. 6). Probably CH₄ was oxidized to CO₂ during the transport from the centre to the surface of the heap, and at low concentrations the potential for CH₄ oxidation exceeded the production.

In the low bulk density heap N₂O emissions were low, indicating that NH₄⁺ concentrations inside the heap were constantly low due to a high air convection through the heap and emission of NH₃ (Karlsson & Jeppson 1995; Petersen *et al.* 1998). High N₂O

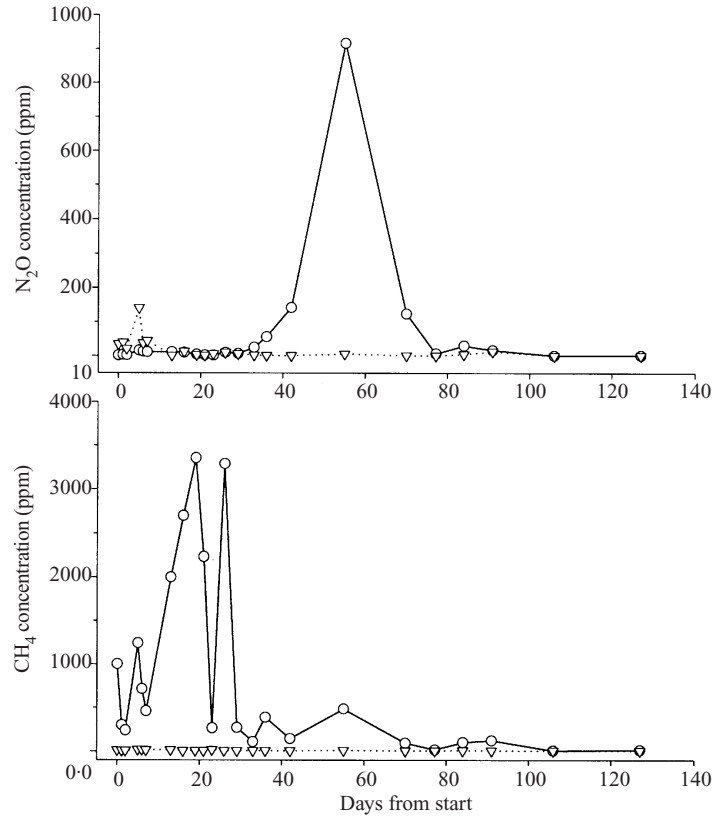


Fig. 3. Nitrous oxide, and CH_4 concentration in the gas phase at 40 cm height inside the composting deep litter heap at a bulk density of 0.23 kg/l (∇) and 0.44 kg/l (\circ).

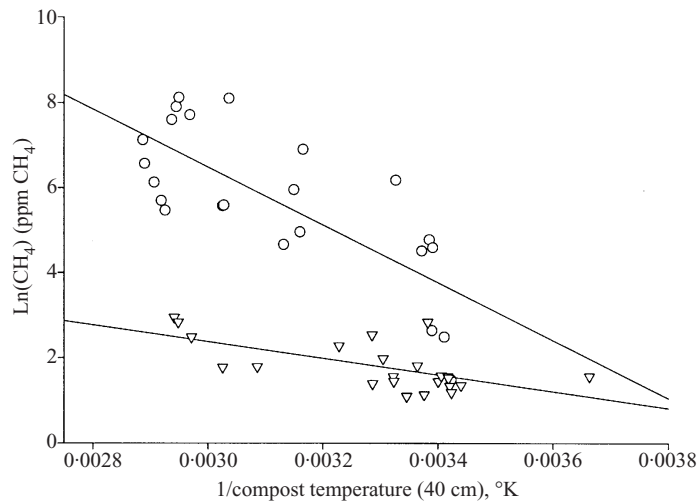


Fig. 4. Arrhenius plot of $\ln(\text{CH}_4)$ versus $1/\text{K}$. In the compost heap at a bulk density of 0.44 kg/l (\circ) the regression equation was $\ln(\text{CH}_4) = -6592 \times 1/T + 26$ ($r^2 = 0.55$) and in the heap at a density of 0.23 kg/l (∇) the relation was $\ln(\text{CH}_4) = -2235 \times 1/T + 9$ ($r^2 = 0.45$).

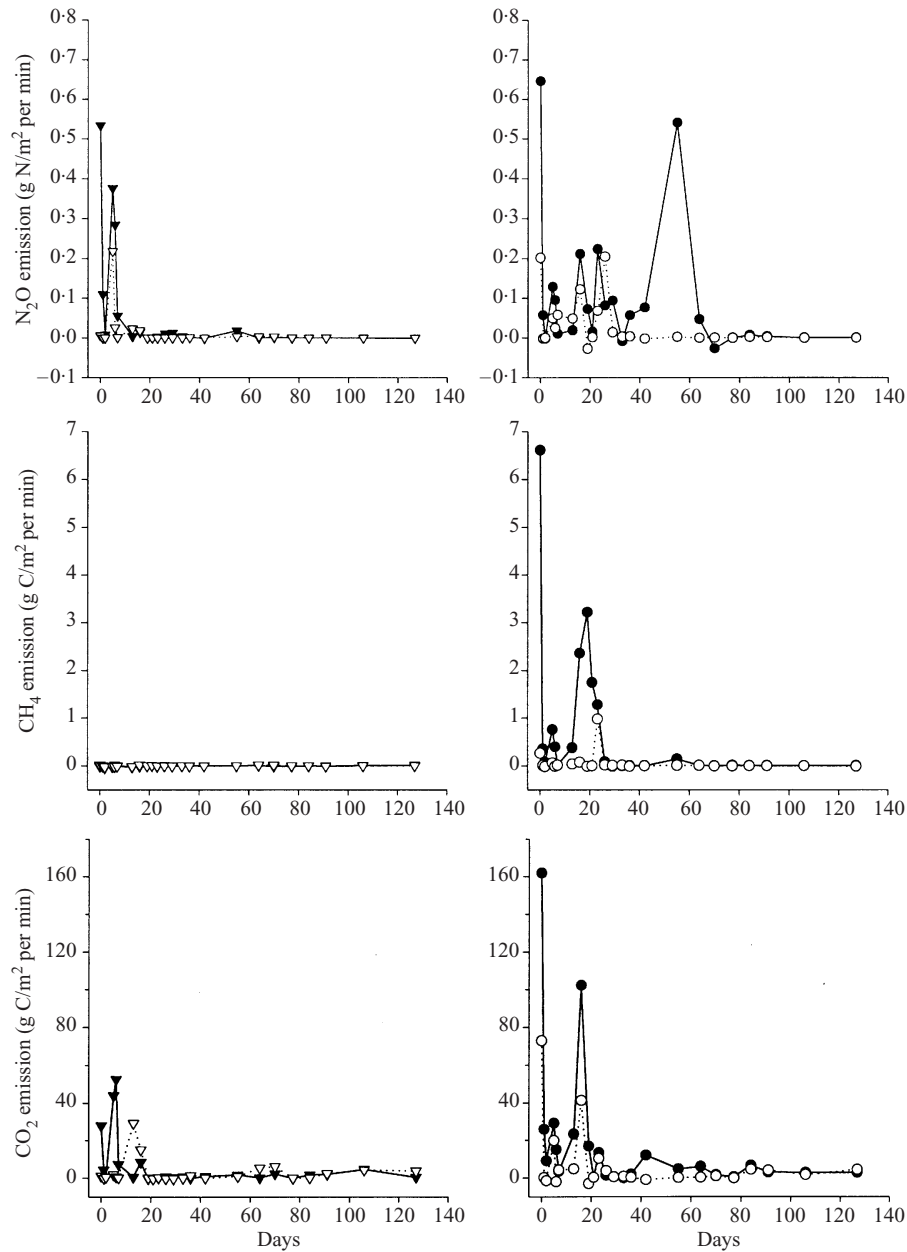


Fig. 5. Emission of CO_2 , CH_4 and N_2O from compost heaps with deep litter from pig production. The emission was determined using two static chambers placed at the top (filled symbols) and the upper half (open symbols) of the side of composting deep litter at a bulk density of 0.23 kg/l (∇) and at 0.44 kg/l (\circ).

emission from the high density heap was determined during day 30–70. A similar trend in the time course of N_2O emission rate has been shown both in studies of compost being turned weekly or several times a week (Czepiel *et al.* 1996; Hellman *et al.* 1997) and in a study of untreated farmyard manure (Petersen *et al.* 1998). The emission pattern of N_2O was not related to

variations in concentrations of N_2O inside the heap suggesting that, with the exception of the phase of high emission from day 35–60, most of the N_2O emitted was not produced at the centre of the heap. This agrees with the findings of Czepiel *et al.* (1996) showing that in a 9-day-old compost high N_2O concentrations were found 0–20 cm from the surface,

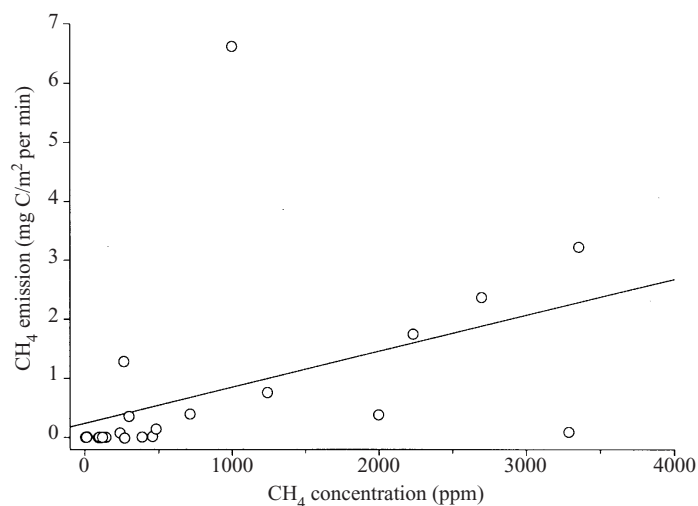


Fig. 6. Methane emission from the top of a compost heap with a density of 0.44 kg/l related to CH_4 concentration at 40 cm height inside the heap, $F(\text{CH}_4) = 0.24(\text{CH}_{4,\text{in heap}}) + 0.24$ ($r^2 = 0.18$). Regression line (—) and measured emission rates (○).

Table 2. Cumulated emission of CO_2 , CH_4 and N_2O from pig deep litter during 4 months of composting

Bulk density kg/l	Carbon dioxide		Methane		Nitrous oxide	
	kg C/t (fresh weight)	% C	g C/t (fresh weight)	% C	g N/t (fresh weight)	% N_{tot}
0.44	7.37	8	191.6	0.2	58.6	0.8
0.23	0.09	0.1	< 0.1	< 0.1	< 0.1	< 0.1

and in a 38-day-old compost high concentrations were found up to 50 cm from the surface, and with observations by Petersen *et al.* (1998) indicating that N_2O emission from a composting pig manure was related to climatic conditions which only affect the surface layers of the compost. The emission rates of this study are similar to the emission rates from untreated pig manure and turned livestock waste (Czepiel *et al.* 1996; Hellmann *et al.* 1997; Petersen *et al.* 1998), and are about one-tenth of the highest emissions from aerated sludge (Czepiel *et al.* 1996).

Cumulated emissions of gases

Total CO_2 emissions were 7.37 and 0.09 kg C/t from the heap with high and low density, respectively (Table 2), the emission was calculated assuming that gases were only emitted from the upper half of the heap. More than 50% was emitted during the initial 15 and 25 days of composting at low and high bulk densities, respectively. The low CO_2 emission from the compost at low bulk density may be related to the short period of composting at high microbial activity. Methane emission from the compost heaps at high density was 191 g C/t which is 3% of the CO_2 emission and N_2O emission was 58 g N/t or about

1% of the CO_2 emission. The emission of CH_4 and N_2O from the heap at low density was not detectable. The N_2O emission from the compost at high bulk density was similar to emissions determined in the study of Sibbesen & Lind (1993). When the climate forcing efficiency of the gases and the cumulated emission rate are multiplied to give effective climate effect of the gas emission relative to CO_2 emission, then the emission of CH_4 contributes almost as much to the global warming potential as CO_2 , and N_2O contributes about twice as much as CO_2 .

CONCLUSION

Emission of greenhouse gases during composting of deep litter from pig production was high if small amounts of straw had been used in the bedding and the litter therefore had a high density. Thus, increasing the porosity of the heap may reduce emission of greenhouse gases during composting. Production of CH_4 and N_2O are separated in space and time. Methane was produced in the heap centre at a high rate during the thermophilic phase of composting and emissions were only measured during this phase. Nitrous oxide was produced initially and after a

decline in the temperature of the compost, and emissions were only significant in these phases at low temperature. Emissions of N_2O probably originated

from the surface layers of the compost heap. Oxidation of CH_4 may reduce emission during periods of low production.

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