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Comparison of greenhouse gas emissions from solid pig manure during storage versus during composting with respect to different dry matter contents

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Abstract

The green house gas emissions from pig manure during storage were compared with those during composting. The manure was prepared artificially by mixing liquid pig manure with different amounts of straw giving dry matter contents of 14 %, 18 % and 22 %. The incubations were carried out for 97 days at 25 °C in 100 L scale. GC equipped with an FID, ECD and WLD detected the concentrations of methane, nitrous oxide, oxygen and carbon dioxide. Ammonia emissions were measured by titration. The global warming potential, calculated in CO_2 equivalents per kg dry matter of excreta were obtained by use of the specific global warming potential (100 year time horizon) for nitrous oxide and methane. The indirect global warming potential of ammonia was calculated by additional use of the specific emission factor of 0.01, which means that 1 % of emitted ammonia is converted to nitrous oxide. The most important gas for global warming was found to be nitrous oxide. This gas contributed to 71 to 85 % to total CO_2 equivalents. At low dry matter contents methane becomes more important and contributes to maximum 28 % of total CO_2 equivalents. The global warming potential of ammonia amounted only up to 14 %. For relatively low dry matter contents of 14 and 18 % the composting process reduced CO_2 equivalents to 28 to 55 % of the values from storage. With high straw amendment (22 % dry matter content) the storage emitted only 65 % of the CO_2 equivalents from composting. The amendment of high amounts of wheat straw to manure with low dry matter content reduced the relatively high emissions from storage process much better than composting of manure with low dry matter content.

Keywords: pig manure, methane, nitrous oxide, ammonia, greenhouse gas, composting, storage

Zusammenfassung

Vergleich der Treibhausgasemissionen aus Schweinefestmist während der Lagerung und Kompostierung unter Berücksichtigung verschiedener Trockenrückstandsgehalte

Die Klimagasemissionen von Schweinemist während der Lagerung wurden mit denen der Kompostierung verglichen. Der Festmist wurde künstlich hergestellt, indem Schweinegülle mit unterschiedlichen Mengen an Stroh vermischt wurde. Dabei wurden Trockenrückstandsgehalte von 14, 18 und 22 % eingestellt. Die Inkubation wurde über 97 Tage bei 25 °C im 100 L Maßstab durchgeführt. Die Konzentrationen an Methan, Lachgas, Sauerstoff, und Kohlendioxid wurden mit einem GC gemessen, der mit FID, ECD und WLD ausgestattet war. Die Ammoniakemissionen wurden durch Titration bestimmt. Das globale Erwärmungspotenzial, ausgedrückt in CO_2-Äquivalenten pro kg Trockenrückstand aus der Gülle wurde mit Hilfe der spezifischen globalen Erwärmungspotenziale (Zeithorizont: 100 Jahre) für Lachgas und Methan erhalten. Das indirekte globale Erwärmungspotenzial für Ammoniak wurde durch zusätzliche Berücksichtigung des spezifischen Emissionsfaktors von 0,01 erhalten, welcher bedeutet, dass 1 % des emittierten Ammoniaks in Lachgas umgewandelt werden. Als bedeutendstes Treibhausgas stellte sich Lachgas heraus. Dieses Gas machte 71 bis 85 % der gesamten CO_2-Äquivalente aus. Bei niedrigeren Trockenrückstandsgehalten nahm die Bedeutung von Methan zu und machte dann maximal 28 % der gesamten CO_2-Äquivalente aus. Bei relativ niedrigen Trockenrückstandsgehalten von 14 bzw. 18 % reduzierte der Kompostierungsprozess die emittierten CO_2-Äquivalente auf 28 bis 55 % der bei der Lagerung erhaltenen Werte. Bei hohen Strohzugaben (Trockenrückstandsgehalt: 22 %) betrugen die Emissionen bei der Lagerung nur 65 % von denen der Kompostierung. Die Zugabe von Stroh zu einstreuarmen Mist reduzierte die hohen Emissionen bei der Lagerung stärker als die Kompostierung des einstreuarmen Mistes.

Schlüsselworte: Schweinefestmist, Methan, Lachgas, Ammoniak, Treibhausgase, Kompostierung, Lagerung

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1 Introduction

Anthropogenic activities like agriculture contribute to the increase of greenhouse gas concentration in the atmosphere, resulting in a higher global warming potential (Ahlgrimm, 1995). Apart from emitting the greenhouse gases methane (CH_4) and nitrous oxide (N_2O), agriculture is furthermore known as the most important source for ammonia (NH_3) emission in Europe (Sommer and Hutchings, 2001).

The greenhouse effect of these gases can be determined by specific global warming potential. It is an index for estimating the comparison (in kg kg^{-1}) between the relative global warming contribution due to an atmospheric emission of a particular greenhouse gas, and the emission of carbon dioxide (CO_2) for a certain time horizon. In contrast to CH_4 and N_2O, NH_3 has only an indirect global warming potential, which can be estimated by the use of the emission factor that is 0.01 (IPCC 2000). This means that 1 % of NH_3 is converted to the direct greenhouse gas N_2O after its release into the air. However, NH_3 causes a lot of other negative effects like soil acidification and physiological perturbation of plants (Goulding et al. 1998; Pearson and Stewart, 1993).

Germany signed the UN ECE Gothenburg Protocol, which results in an obligation to reduce NH_3 emissions from the year of 1990 to 2010 by 28 %. Furthermore, Germany has committed herself to reducing the emissions of CO_2 by 25 % between 1990 and 2005, and the so-called Kyoto gases by 21 % between 1990 and 2008/2012. Hence, it is expected that the quantification of greenhouse gas contribution from agriculture has to be done more accurately (BMVEL and UBA, 2002). Important sources of emissions include the storage and the composting of solid manure (Berges and Crutzen, 1996, Clemens and Ahlgrimm, 2001).

In Germany in 1999, about 30 % of the cattle and 20 % of the pigs were kept on solid manure systems (BMVEL and UBA, 2002). In spite of some investigations concerning CH_4, N_2O or NH_3, the simultaneous emissions of these gases during the storage or the composting of the solid manure has been scarcely investigated. The following processes generate the gases: NH_3 is formed by the metabolization of urea and emitted at increasing temperature and pH-value above 7. By nitrification, NH_3 is metabolized under aerobic conditions to nitrate (NO_3^-). Under conditions of low oxygen pressure NO_3^- can be reduced to N_2 (Groenestein et al., 1993; Schmidt et al., 1999; Hao et al., 2001). From both nitrification and denitrification processes, N_2O can be emitted. CH_4 is formed by a group of strictly anaerobic archaebacteria. The conditions, which enable the formation of the greenhouse gases, are found in the different spheres of manure heaps. The emission of greenhouse gases is affected to a high degree by the addition of straw. High straw amendments allow a better aeration of the manure, which reduce the emissions of CH_4 and N_2O (Hüther, 1999). Low straw amendments result in higher CH_4 emissions. Before being spreaded on the field, the manure is stored nearby the house or on the field. To produce compost, in some farms (ecological agriculture) the manure is turned frequently or aeration trains are installed in order to obtain a higher exchange of respiration gases. The greenhouse gas emissions from these procedures have been examined by some studies (Martin and Dewes, 1992; Hellmann, 1995; Hao et al., 2001). However, due to the relatively high costs and operating expense of those treatments, most farmers store the manure without additional treatment.

On non-mixed manure type of treatment, there are only very few studies existing. Sommer (2001) investigated the emissions from unaerated storage of cattle deep litter. Sometimes before, Amon (1998) had examined the comparison between turned and unturned cattle manure from a tied house. To our knowledge, there has been no comparison published between the storage and the composting of pig manure with forced aeration. Pig manure contains much more total Kjeldahl nitrogen (TKN) than it is from cattle and is expected to emit more nitrogenous gases. Also the sum of NH_3-N and NH_4^+-N, which is given as total ammoniacal nitrogen (TAN), is higher.

The intention of this publication is to compare the greenhouse gas emission from storage of pig manure with those from composting, with respect to the different dry matter (DM) contents.

2 Material and Methods

The manure samples were prepared artificially by mixing liquid pig manure from a fattening pig farm with straw in order to obtain different DM contents (Table 1). This procedure provides a relatively homogenous material. The TKN content of these samples might be higher than that from practically obtained manure because the total urea is part of the liquid manure. The mixtures were then incubated in isolated reactors, which simulate the storage and the composting of the manure. The reactors, with a volume of 100 L, were equipped with forced aeration and connected to an aeration system. In reactors simulating manure storage, the air streamed over the manure at a rate of 120 L h^{-1}, and in those simulating manure composting, the air streamed from the bottom to the top at a rate of 2.7 m^3 h^{-1} per m^3 of initial manure volume. The height of the manure columns was between 37 cm (14 % DM) and 56 to 64 cm (18 and 22 % DM). The incubation period was 97 days at an ambient temperature of 25 °C. The leachate was allowed to run through a grid into the space below the manure. The emissions from manure and leachate were measured in one in order to obtain a complete quantification of green house gas emissions. As well as the temperature, the gas samples were also taken at least 5 times in

Table 1
Properties of liquid pig manure and wheat straw used for preparation of solid manure samples

Material	DM (%)	TKN (% of DM)	TAN (% of DM)	C (% of DM)	org. DM (% of DM)	C/N-ratio (-)
Liquid manure	9.1	8.4	6.4	40.0	75.8	4.8
Straw	88.0	0.56	0.05	45.3	96.3	80.9

Table 2
Properties of the artificially prepared pig manure samples for different treatment. c: composting, s: storage

DM (%)	Mass (kg)	Bulk density ($t\ m^{-3}$)	org. DM (%)	TKN (% of DM)	TAN (% of DM)	C (% of DM)
14.0	45.7 c	0.65 c	11.8	5.8	3.9	41.8
	42.4 s	0.60 s	11.8	5.8	3.9	41.8
18.0	50.4 c	0.48 c	15.7	4.4	2.9	42.7
	49.7 s	0.43 s	15.7	4.4	2.9	42.7
22.0	27.3 c	0.23 c	19.7	3.5	2.2	43.3
	26.8 s	0.24 s	19.7	3.5	2.2	43.3

seven days. In each of the stored manure, a Perspex tube (outer diameter: 25 mm, inner diameter: 20 mm, length: 800 mm) was inserted vertically in the center of the manure. Holes (5 mm in diameter) at 100 mm height above ground allowed the passage of the compost air inside a chamber of the tube which was connected by metal pipe for sample taking. The material of the composted samples was mixed outside the reactor every 7 days (at the first 56 days) and every 14 days (after 63 days). The manure was analyzed both at the beginning and at the end of composting and storage. Additionally samples were taken when mixing the composted manure samples. The properties of the artificially prepared manure samples are shown in Table 2.

The concentrations of CH_4, N_2O, CO_2 and oxygen from inlet air and waste air were determined by a gas chromatographic system (Shimadzu GC 14B) as described by Hüther et al. (1995). In brief, the system was equipped with two different columns (Porapak QS, 80/100: 1.5 and 3.0 m; molsieve 5Å, 60/80: 4.5 m; 80 °C) and three detectors (FID: 320 °C, ECD: 320 °C, TCD: 100 °C). The carrier and the make-up gases for the system were helium and nitrogen respectively. The samples were injected by using a headspace sampler (Dani, HSS 86.50; aux. press. 0.18 bar, carr. press. 2.80 bar). The emissions were calculated as the product of concentration (waste air subtracted by inlet air) and aeration rate. The NH_3 content of the waste air was detected by using washing bottles filled with boric acid (2 %) followed by a pH-titration with 0.1 N sulfuric acid.

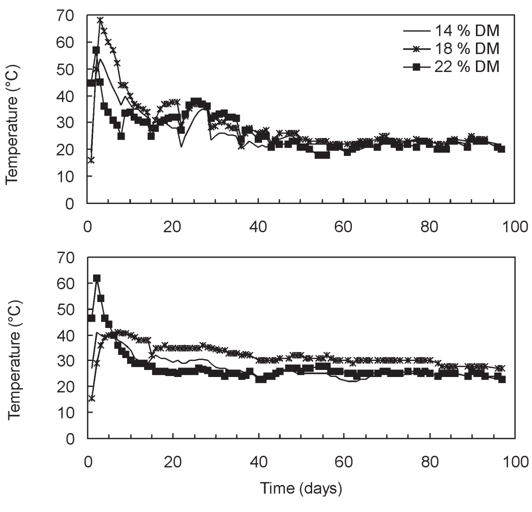

Fig. 1
Temperature course of composted (top) and stored (bottom) solid pig manure with different DM content for 97 days at 25 °C

3 Results

3.1 Characterization of the rotting process

All of the composted samples reached maximum temperatures (> 50 °C, thermophilic phase) for one or two days during the first seven days of composting. There was no correlation between maximum temperature and DM contents observed during the experiment. The time after which temperature decreases permanently to 42 °C or lower (mesophilic phase) was between four and ten days. After mixing the manure in weekly or biweekly intervals, the temperature went down for about 5 K for a short time and arose again (Figure 1). During storage, the maximum temperature at 22 % DM reached 60 °C and was much higher than it was at lower DM contents (40 and 41 °C, respectively). The time after which temperature decreased permanently below 42 °C (mesophilic phase) showed no correlation with the DM content. It was in the same range as for the manure from composting (Figure 1).

Table 3
Carbon balance during composting and storage of solid pig manure for 97 days at 25 °C in percent of initial amount

Carbon recovered	Composting			Storage		
	14 % DM	18 % DM	22 % DM	14 % DM	18 % DM	22 % DM
In manure	19.0	24.5	28.9	43.8	43.1	34.0
In leachate	0.7	0.7	0.0	1.1	0.2	0.3
By sample-taking	5.4	3.5	6.6	-	-	-
As CO_2-C	47.3	68.5	71.0	60.3	59.1	55.3
As CH_4-C	0.8	0.7	0.0	4.4	1.0	0.1
Recovery	73.2	97.9	106.5	109.6	103.4	89.7

Table 4
Nitrogen balance during composting and storage of solid pig manure in percent of initial amount

Nitrogen recovered	Composting			Storage		
	14 % DM	18 % DM	22 % DM	14 % DM	18 % DM	22 % DM
In manure	13.3	24.5	31.9	40.2	47.2	55.0
In leachate	18.0	4.7	0.7	37.5	11.9	1.5
By sample-taking	2.8	1.7	6.1	-	-	-
As NH_3-N	7.9	19.7	29.5	9.4	6.2	18.8
As N_2O-N	1.6	1.6	1.9	5.3	3.4	2.3
N_2-loss (calculated)	56.4	47.8	29.9	7.6	31.3	21.9

Beneath the temperature, gaseous emissions are indicators for the course of the rotting process. As seen from the CO_2 emissions, as an indicator for the microbial activity, the oxidation of organic compounds during composting reached the highest level at the beginning, and was decreasing rapidly until it reached a relatively steady value after about 49 days for all DM contents (Figure 2).

At the lowest DM content of 14 %, the anoxic metabolization (which is indicated by CH_4 production) started after 20 days. At this time, CO_2 concentration in waste air had already passed the maximum and reached relatively low values. At 22 % DM, CH_4 emission was negligibly low (Table 3).

The carbon balance during the composting was as follows:

- Between 47 and 71 % of the carbon was respired to CO_2.
- Between 19 and 29 % of the carbon remained in the manure.
- Less than 1 % of the carbon were found in the leachate.
- Less than 1 % of the carbon were emitted as CH_4.

At storage the course of CO_2 emissions was comparable with that of composting with the exceptions that the decrease to constant values at low level was earlier (during 30 days) and that CH_4 formation started more slowly but halted longer than at composting.

The carbon balance for storage was as follows:

- Between 55 and 60 % of the carbon was respired to CO_2.
- Between 34 and 44 % of the carbon remained in the manure.
- Up to 1 % of the carbon were found in the leachate.
- Between 0.1 and 4 % of the carbon were emitted as CH_4.

The initial total nitrogen content of artificially prepared solid manure occurred to ca. 65 % as total ammonia nitrogen, which is the dominating compound for mineral nitrogen. During the composting or storage a part of the mineral nitrogen was rebound into organic compounds or denitrified. Consequently, e.g. after 84 days, the percentage of TAN was reduced to values between 18 and 33 % of initial concentration (Figure 3).

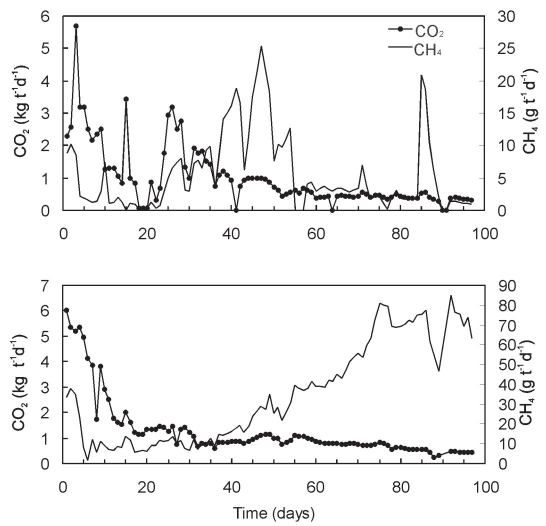

Fig. 2
Typical course of C emissions during composting (top) and storage (bottom) of solid pig manure for 97 days at 25 °C (14 % DM)

The time course of nitrite (NO_2^-), NO_3^- and N_2O concentrations as indicators for nitrification and denitrification processes differed with the DM content. When using a DM content of 14 %, enhanced NO_3^- concentrations were observed at about 20 days, which indicates nitrification. The following decrease of NO_3^- concentration and increase of N_2O emissions indicated incomplete denitrification (Figure 3, Figure 4). This assumption was confirmed by high CH_4 emissions during that time, which clearly indicated anoxic zones in the manure. For this DM content it has to be considered, that N_2O might have been also generated from the leachate.

Using DM contents of 22 %, the NO_3^- concentrations increased continuously after day 40. This can be explained by a complete aeration of the manure, which prevented anoxic denitrification and methane formation. N_2O emissions occurred relatively early (data not shown) and with decreasing N_2O emissions, the NO_3-concentration increased. This fact is in contrast to the manure with lower DM content and can be explained by a better aeration in this manure resulting in a higher oxygen concentration. At these conditions, N_2O was formed obviously during nitrification, and denitrification was completed without N_2O formation. The calculated loss of nitrogen during denitrification of all storage experiments was between 30 and 56 % (Table 4). For storage, the course for NH_3 and N_2O emissions was relatively similar to those from composting. NH_3 emissions during storage decreased more slowly and the N_2O emissions appeared later than at composting (Figure 4). The calculated loss of nitrogen during denitrification was much lower than from composting and yielded only between 8 and 31 %. These values are confirmed to the values from Petersen et al. (1998).

For storage experiments the time course of oxygen concentration 10 cm above ground of the manure was determined. In contrast to the other samples, the DM content of 22 % allowed complete aeration during the whole duration (Figure 5).

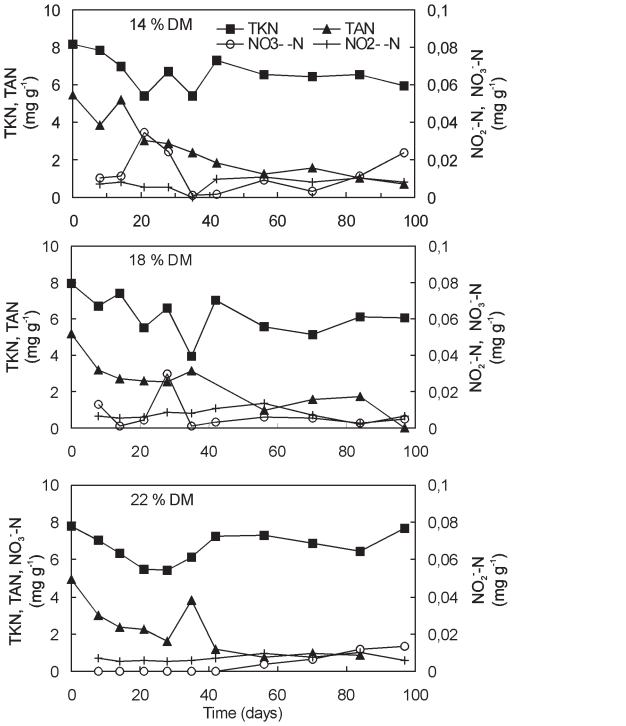

Fig. 3
Course of N-distribution during composting of solid pig manure with different DM contents

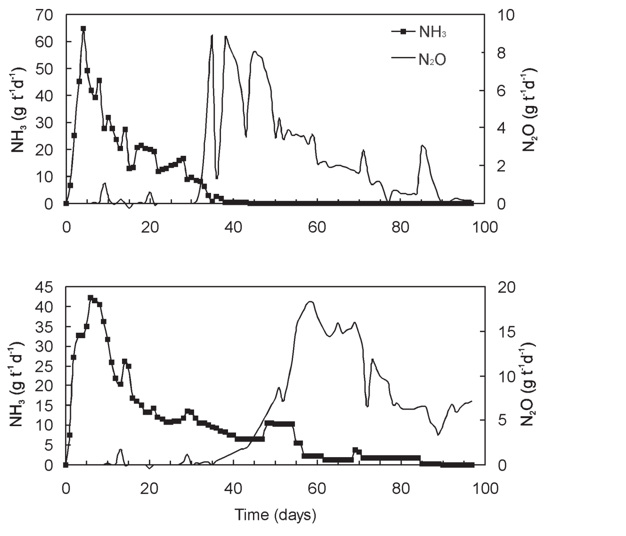

Fig. 4
Typical course of N emissions during composting (top) and storage (bottom) of solid pig manure (14 % DM)

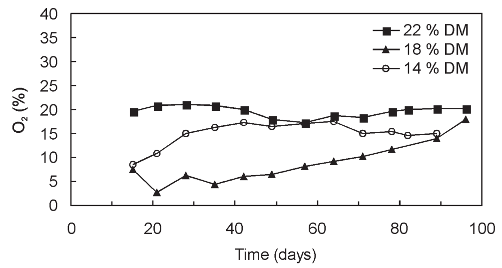

Fig. 5
Oxygen concentration in the 10 cm height above ground in solid pig manure with different DM contents during storage at 25 °C

Table 5
C/N ratio of differently treated solid pig manure at the beginning and end of incubation period

Treatment	DM (%)	C/N initial (-)	C/N final (-)
Composting	14.0	7.2	10.3
Composting	18.0	9.7	9.7
Composting	22.0	12.4	11.7
Storage	14.0	7.2	8.4
Storage	18.0	9.7	8.9
Storage	22.0	12.4	7.7

Table 6
Emissions of CH_4, N_2O, and NH_3 during storage or composting of solid pig manure

	DM (%)	CH_4-C (% of manure-C)	N_2O-N (% of manure-N)	NH_3-N	CH_4 (g kg^{-1} manure-DM)	N_2O	NH_3
Compost	14.0	1.5	1.7	8.2	7.7	2.4	9.2
Compost	18.0	1.6	1.8	21.2	8.3	2.5	23.3
Compost	22.0	0.1	2.1	32.9	0.6	3.0	36.8
Storage	14.0	7.6	5.5	9.8	40.1	8.0	10.9
Storage	18.0	2.5	3.6	6.7	13.0	5.2	7.4
Storage	22.0	0.4	1.3	21.0	2.2	1.8	11.2

The C/N ratio increased at low DM contents (Table 5). This behavior is explained by the high initial NH_4^+-N content with low content of organic matter, which can fix nitrogen during microbial processes into organic compounds and reduce by this ammonia nitrogen loss.

3.2 Emissions of greenhouse gases

The emissions of greenhouse gases were calculated in percentage of initial excremental nitrogen or excremental carbon content, which allows an "element flow" determination (Table 6). For the carbon containing CH_4 a strong decrease of emissions when using higher straw amendment was found at composting and storage. Using DM contents of 14 or 18 %, the CH_4-C emissions for both processes reached values between one and eight percent of initial carbon content. With DM contents of 22 %, practically no methane emissions were obtained. For each DM content, the emissions from the storage were higher than that from the composting.

From the nitrogen containing emissions, NH_3-N is emitted to a much higher percentage than N_2O-N. For storage, there was no clear effect of straw amendment on ammonia emissions obtained. For DM content of 14 %, the NH_3-N emissions from both composting and storage were nearly equal whereas they were up to three times higher with composting at DM contents of 18 or 22 %. The nitrogen loss by NH_3 emissions is the highest when using composting process with high DM contents and is the lowest when using storage process or composting of manure with low DM contents.

The maximum emission of N_2O was 5.5 % N_2O-N. By that much, it was lower than the NH_3-N emission. During the composting process, only a slight increase related to DM content was observed. At the storage, emissions decreased strongly with higher DM content. The highest emissions were reached when using low DM contents (14 %) in the storage process. The percentage of the N_2O emitted from storage was two to three folds higher than it was from composting. When using high straw amendment (22 % DM) the N_2O emission from the storage was slightly lower than that from the composting, but it only reached about one to two percent.

3.3 Effect of emissions on global warming

The calculated CO_2 equivalents (IPCC 2001) are shown in Table 7. In order to allow a direct comparison between the different processes and DM contents, the values were calculated in mass unit of gas per mass unit of DM originating from liquid pig manure. From the investigated gases, the (indirect) greenhouse gas effect of NH_3 is found negligibly low. However, it has to be mentioned again that NH_3 has a lot of other negative effects on the environment, which are not quantified by the global warming potential. The main originator for global warming during manure storage or composting is N_2O. For storage, the N_2O emission per DM of liquid manure increases with the decreasing of the DM content. Additionally, the contribution of CH_4 becomes more important. This can be make clear by the CO_2 equivalent ratio between N_2O and CH_4 which decreases with lower DM content at storage from 10 (22 % DM) to 3 (14 % DM). At the composting it decreases from 59 to 6. The total emissions from the storage are, at the lowest DM content, 3.6 folds higher than those from the composting. At highest DM content they are 0.6 times lower than those from composting.

Table 7
Calculated CO_2 emission equivalents of CH_4, N_2O, and NH_3 during storage or composting of solid pig manure using GWP (time horizon: 100 years; N_2O: 296, CH_4: 23, NH_3: 3.83) according to IPCC (2001). The GWP for NH_3 was calculated by additional use of the emission factor (0.01) for the conversion of emitted NH_3 into N_2O (IPCC 2000)

Treatment	DM (%)	CO_2 equivalents (g kg^{-1} DM*)			
		CH_4	N_2O	NH_3	total
Compost	14.0	117	713	35	925
Compost	18.0	195	759	90	1045
Compost	22.0	15	888	141	1044
Storage	14.0	921	2366	42	3329
Storage	18.0	304	1555	29	1888
Storage	22.0	51	535	90	676

*DM related to pig manure without straw

Table 8
Properties, aeration rate and gaseous emissions from pig manure compared with cattle manure (Hüther 1999) for 63 days of composting. TKN, TAN and C are given in % of DM. The emissions were calculated on its total (excreta and straw)

Animal species	DM (%)	TKN (%)	TAN (%)	C (%)	Aeration rate ($m^3\ m^{-3}\ h^{-1}$)	N_2O-N (% of N)	CH_4-C (% of C)	CO_2 equivalents (g kg^{-1} DM)
Pig	22.0	3.5	2.2	43.3	2.7	1.71	0.04	283
Cattle	21.6	2.1	0.8	40.3	1.2	0.16	1.3	176

4 Discussion

The effect of straw amendment on CO_2 emission equivalents is relatively high at storage where an increase of DM content from 14 to 22 % resulted in 5 fold lower CO_2 emission equivalents. With composting the difference of emissions with different DM contents is negligible. Obviously mixing of the composted material leads to a more complete aeration of the manure, which lowers CH_4 formation. Furthermore, the denitrification of NO_3^- in composted manure is assumed to take place more completely so that the N_2O emissions are lower than they are in the non-mixed manure. One possible explanation could be the concentration of organic compounds, which is higher in composted manure and is used by the heterotrophic denitrificants as electron donator. In a comparison between composting and storage of cattle manure in practical scale (7.5 t) in wintertime, Amon (1998) found that CO_2 emission equivalents were slightly lower with the composting than with the storage (136 g CO_2 equivalent kg^{-1} DM for storage and 117 g kg^{-1} for composting). The DM content of composted samples was 22 % and that of stored samples 21 %. The lower emissions during composting are in contrast to the result of this study where the storage emitted less CO_2 equivalents at 22 % DM. It has to be considered that both gas exchange rates and hence aerobic conditions were increased. A furthermore possible reason for the different values is different emission pattern with different animal species. For instance, in the experiments from Amon the percentage methane emissions were much higher than those obtained in this study.

For evaluating the influence of the animal species, the results from the presented study using a DM content of 22 % are compared with studies using a similar design with cattle manure (Hüther, 1999). The manure used by Hüther contained nearly the same DM content, but a much lower nitrogen content. In the experiment of Hüther some leachate occurred, which was removed in weekly intervals. The air also streamed upwards, but had a lower aeration rate of 1.2 $m^3\ m^{-3}\ h^{-1}$.

The comparison of these laboratory studies confirms that pig manure emits more nitrous oxide (18 fold) and less methane (30 fold) than cattle manure, calculated on mass unit gas per mass unit DM content. The influence of the different aeration rates is not regarded as to be decisive for the big difference of N_2O emission during this study. In the studies of Hüther (1999), it was found out that the differences in N_2O emissions using different aeration rates from 0.6 to 3.6 $m^3\ m^{-3}\ h^{-1}$ were lower than factor 5. The high N_2O emissions of pig manure can be explained mainly by the higher TKN and TAN content in pig manure, which can lead to an extensive nitrification and denitrification, which is not inhibited in solid manure by high NH_3 concentrations (Hüther, 1999).

When evaluating ecological effects of food production two types of ecological damages have to be differentiated. On the one hand the impact of greenhouse gas emissions on atmosphere (calculated as CO_2 equivalents) is of relevance, and on the other the impact of ammonia on terrestrial and aquatical ecosystems has to be taken into account. For instance, in this study it is shown that from manure with low CO_2 emission equivalents (storage at 22 % DM) high amounts of ammonia can be emitted (Table 6, Table 7). For further ecological evaluation, a mathematical description has to be developed, which includes both types of ecological damages.

From this study the following recommendations can be concluded in order to reduce greenhouse gas emissions during storage of pig manure: Even though it is relatively expensive due to high operation expenses, the composting process results at DM contents of 18 % and below in lower CO_2 emission equivalents than the storage. The specific emissions from fuel combustion for turning the compost have to be taken into account additionally but are considered to be relatively low. For instance Hao (2001) found emissions for fuel for active turning of less than 2 % of CO_2 emission equivalents from CH_4 and N_2O. However the amendment of straw to DM contents of 22 % and following storage reduces the emissions much more than the composting. Only when high amendment of straw is not possible, the more operation expensively composting of manure is necessary to reduce greenhouse gas emissions.

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