Vandré, Robert; Wulf, Sebastian; Häußermann, Uwe and Horlacher, Dieter

N_2O emissions from solid manure storage – Calculation of a national emission factor

Based on a study of the literature it was assessed whether national emission factors for N_2O emissions from the storage of solid manure could be reliably defined for application in Germany. In Germany solid manure from cattle and pig production usually is stored without further treatment for up to 6 months in open heaps. According to results given in the literature, O_2 availability in solid manure heaps is the most important influential factor governing N_2O emissions. A reliable modelling of the N_2O emissions from solid manure based on substrate quality and management is, however, not possible. From measurements selected as representative of German substrate and storage heap conditions an emission factor for solid manure heaps (solid storage) of 0.013 kg N_2O-N (kg N)$^{-1}$ was calculated.

Keywords
Nitrous oxide, solid manure, emission factor

Abstract
Landtechnik 68(1), 2013, pp. 38–42, 1 figure, 2 tables, 29 references

With the signing of the Kyoto Protocol and the Framework Convention on Climate Change (UNFCCC), Germany undertook to regularly report on the emissions of climate relevant gases. Along with numerous other business sectors, German agriculture contributes to national greenhouse gas pollution. Apart from emissions from arable land and enteric fermentation, one of the most important sources of climate relevant gases in agriculture is the management of farmyard manure.

For the compilation of the greenhouse gas inventory, guidelines with default emission factors for greenhouse gases from farmyard manure are given (IPCC Guidelines). These emission factors are to be applied as long as no justified national emission factors are available. The IPCC 1996 and 2000 Guidelines to be applied currently [1; 2] give a uniform factor for emissions from solid manure systems of 0.02 kg N_2O-N (kg N)$^{-1}$. More recent IPCC Guidelines from 2006 [3] differentiate between solid manure storage with 0.005 kg N_2O-N (kg N)$^{-1}$ and animal housing on deep litter with 0.01 kg N_2O-N (kg N)$^{-1}$.

The discrepancy between the officially validated values in the 1996 and 2000 IPCC Guidelines and those of 2006 provided a good reason for evaluating the available literature on N_2O emissions from the storage of solid pig and cattle manure and the applicability of the results for agricultural practice in Germany. The aim is to derive an emission factor for solid manure storage.

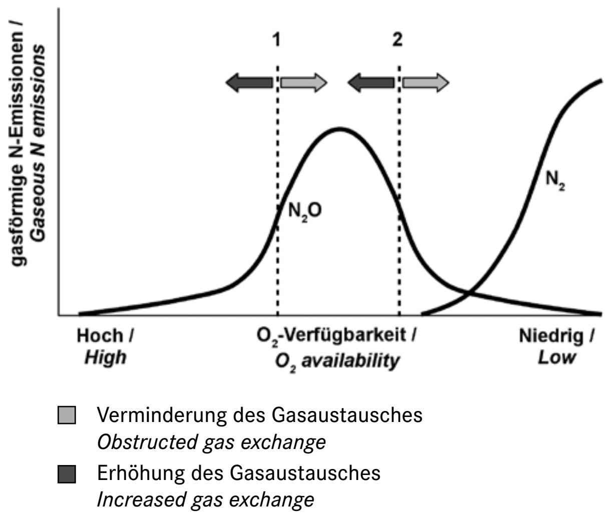
Gas exchange and oxygen availability

Increased N_2O emissions can occur in the presence of average or small-scale alterations in O_2 availability [4] whereas strictly anaerobic conditions, occuring for instance in liquid manure storage without floating cover, inhibits N_2O production because no nitrification, and therefore also no denitrification, takes place. Under strictly aerobic conditions also no N_2O production occurs because complete nitrification takes place (no nitrifier-denitrification; [4; 5]). Denitrification as obligate anaerobic conversion does not occur either.

The inhibition of N_2O production by very low as well as very good O_2 availability can lead to an opposite effect, depending on manure conditions (**Figure 1**): In a loosely-structured solid manure heap (case 1) N_2O emissions are increased through obstructing gas exchange, e.g. by compaction or covering (light arrows). Encouraging gas exchange, e.g. through increasing straw content or through ventilation (dark arrows), reduces N_2O production. In a compact solid manure heap of high density with high moisture content and low gas exchange (case 2) the opposite effects are achieved. This explains apparently contradictory literature information.

A positive relationship of gas exchange and N_2O emissions is observed repeatedly. Aerobic composting of manure with good O_2 availability through increased gas exchange, for instance by frequent mixing of the the manure heap, can encourage N_2O

Fig. 1



Model concept depicting the relationship between O_2 availability and N_2O emissions (according to [4])

production through N mineralisation and self-heating [6; 7]. Conversely, increased compaction in the heap, increased moisture content, or precipitation, as well as covering the manure heap, can reduce gas exchange, self-heating and the temperature in the heap [8]. On the other hand, other studies report a negative relationship between gas exchange and N_2O release. High straw and dry matter contents, which are associated with increased gas exchange, caused reduced N_2O emissions [9; 10; 11; 12]. In [13] an increase in N_2O emissions when obstructing gas exchange through compacting or covering of deep litter heaps was observed. In general, high N_2O emissions tend to occurre from solid manure with an increased density in the manure heap [5]. A clear relationship between emissions and substrate type is also recognisable here. On average, cattle deep litter shows reduced emissions compared with cattle solid manure from other housing systems. Because deep litter contains more straw than other types of solid manure, the substrate has a reduced density and therefore, presumably, higher gas exchange rates. High straw content with the associated wide C/N ratios might also cause microbial N immobilisation suppressing N_2O production [12].

Length of storage and temperature

Often maximum emissions are observed during the starting phase following the building of a heap [11; 14; 15; 16]. As a rule, emissions increase in this phase parallel to self-heating of the heap. Often, however, an increased N_2O release is observed only after the starting phase [6; 13; 17; 18; 19]. The delayed release is explained by the fact that nitrification and denitrification are not thermophilic processes and therefore could be restricted through the initial self-heating process [20].

Repeated measurements at different times of the year show higher N_2O emissions in the warmer seasons [8; 21; 22; 23]. A diurnal pattern of emissions concurrently with temperature was observed by [24]. On the whole, however, a close link between temperature and N_2O release is not clear as in solid manure heaps zones with very different conditions concerning temperature can occur at the same time [15].

Neither is there a rule to the duration of emissions. With exception of [19], emissions are still identifiable - but often very low – by the end of the measurement period. If manure heap substrate is mixed within the measuring period high emissions can occur, even towards the end of the measuring periods [6]. Because, contrary to the conditions in nearly all the measurements documented in the literature, heaps of solid manure usually have new manure continually added, it can be assumed that in practice there will be a continuance of N_2O production during the complete time of storage.

Solid manure storage in Germany

In Germany, livestock farming with farmyard manure must provide stationary and paved storage capacities for a period of 180 days [25]. Additionally, intermediate storage areas for solid manure on farmland may be used.

According to the KTBL working group "Amounts of solid manure produced“, he manure storage period until application on the fields mostly is around 6 months. Because the heap of manure is continually added to, the storage period averages 3 months. The most important application time for solid manure is spring and late summer/autumn. As a rule, neither active compaction of the manure heap nor mixing of the solid manure to encourage aerobic activity is done.

Literature research

For calculating emission factors primary literature was used in which measurements of N_2O emissions from manure store heaps under practical conditions are documented. Not included were measurements of emissions from small-scale experimental setups (floor area 1 m^2 or smaller, amount smaller than 1 m^3) or experiments where the information on measurement conditions was not sufficiently detailed.

Calculation of emission factors

The results and measurement conditions of N_2O emissions were compiled in tables and standardised as kg N_2O-N per kg total-N. The results most representative of the conditions in Germany were selected and assessed using the following criteria:

In Germany solid manure is usually not compacted or composted, therefore only results from untreated stored solid manure were considered (**Table 1**).

In Germany DM contents of solid manure from cattle and pigs typically range from 20 to 25 % and N contents from 4.8 to 9.7 g/kg FM (N contents take into account storage losses [26]). Substrates with values near this range were considered: DM from 18.5 % [22] to 25.8 % [8]; N from 4.3 g/kg FM [6] to 12 g/ kg FM.

Table 1

Literature information on N_2O emissions from solid manure and boundary conditions of measurements. Untreated manure heaps only

	Tierart *Animal type*	**Festmist-Typ** *Manure type*	**TM/*DM*** [%]	**N** [g/kg FM]	**Lagerdauer** *Duration* [d]	**Randbedingungen** *Climate information*	**Emissionsfaktor** *Emission factor* [kg N_2O-N/kg N]
Ahlgrimm et al. 2000 [17]	Schwein/*Pig*	Tretmist/*Straw courts*			100		0,01158
Ahn et al. 2011 [6]	Rind/*Cattle*	-	24	4,3	80	−5 bis 10 °C	0,00588
Amon 1998 [18]	Rind/*Cattle*	Anbindestall, Festmist *Tie stall, solid manure*	20	6,4	80	Juni–September *June–September*	0,008
			21	6,3	82	März–Juni *March–June*	0,013
Brown et al. 2002 [24]	Rind/*Cattle*	-	16	5,7	ca. 90	⌀ 18,5 °C	(0,42 g N m^{-2} d^{-1})
Chadwick 2005 [8]	Rind/*Cattle*	Tiefstreu/*Deep litter*	20,2	5,3	96	Mai–August *May–August*, 12 bis 22 °C	0,023
			25,8	5,2	90	Dezember–März *December– March*, 0 bis 10 °C	0,001
			19,9	3,3	109	Juni– September *June–September*; 16 bis 26 °C	0,013
Espagnol et al. 2006 [28]	Schwein/*Pig*	Tiefstreu/*Deep litter*	36,1	12,0	90	Okt.–Dez./*Oct.–Dec.*; −2,5 bis 23 °C	0,032
Hao et al. 2001 [7]	Rind/*Cattle*	Feedlot-Festmist *Feedlot solid manure*	29,5	17,7	90	5 bis 25 °C	0,00621
Hao et al. 2011 [29]	Rind/*Cattle*	Feedlot-Festmist *Feedlot solid manure*	49,5	18,3	99	Sommer–Herbst *Summer–Autumn*, ⌀ 11,3 °C	0,00029
			44,9	20,3	99	Sommer–Herbst *Summer–Autumn*, ⌀ 11,3 °C	0,00057
Mathot et al. 2012 [22]	Rind/*Cattle*	Anbindestall, Festmist *Tie stall, solid manure*	16,4/20,5	5,6/6,8	ca. 120	Winter–Frühjahr *Winter–Spring*	0,00104
Osada et al. 2001 [14]	Rind/*Cattle*	Tiefstreu/*Deep litter*	41	5,6	57	Juli–August *July–August*	0,0022
Petersen et al. 1998 [4]	Schwein/*Pig*	-	24,6	11,5	ca. 60–100	Frühjahr–Sommer *Spring–Summer*, ⌀ 16,9 °C	0,001–0,005
Sneath et al. 2006 [27]	Rind/*Cattle*	Laufstall, Festmist *Loose housing, solid manure*	26,7	8,44			0,00511
Sommer 2001 [13]	Rind/*Cattle*	Tiefstreu/*Deep litter*	36	8,7	132	Oktober–März *October–March*	0,0012
Sommer und Dahl 1999 [19]	Rind/*Cattle*	Tiefstreu/*Deep litter*	42	8,4	197	Oktober–Januar *October–January*, Windeinfluss *influenced by wind*	0,000046
Sommer und Møller 2000 [11]	Schwein/*Pig*	Tiefstreu/*Deep litter*	24	7,2	143	April–August *April–August*	0,0081
Thorman et al. 2007 [16]	Schwein/*Pig*	Tiefstreu/*Deep litter*	25	7,8	ca. 360	ab Ende März *from the end of March*	0,02630
	Rind/*Cattle*	Tiefstreu/*Deep litter*	19,8	5,2	ca. 360	ab Mitte April *from mid of April*	0,04320
Wolter et al. 2004 [15]	Schwein/*Pig*	Tiefstreu/*Deep litter*	36	12,5	113	Oktober–Februar *October–February*	0,019

One study with manure from a common sloping floor (strawflow) system is considered as well although no substrate characteristics are given [17]. The average of these selected values was used as proposal for the emission factor.

Results and discussion

On the whole, 17 publications containing practically-relevant measurements of N_2O emissions from solid manure could be reviewed (**Table 1**). In three of these the experimental parameters or the results given were too imprecise for the calculation of emission factors or ambiguous, as no information on the amount of manure was given or the measurement period was too short [24], N_2O results were only given as a range [4], or data in text and the illustrations were incompatible [19]. Further studies did not include treatments that could be applied to German conditions (feedlot manure with wood shavings and composting [7], composting inside a barn [27]).

Based on the validity of substrate characteristics for German conditions seven studies remained with a total of ten independent N_2O emission measurements from untreated solid farmyard manure (**Table 2**).

For most of the selected measurements, the storage conditions also differed from those that would be regarded as typical for Germany. With some measurements a reduction in N_2O production through increased straw content could be expected. On the other hand, measurements during the colder times of the year and therefore reduced N_2O emissions are underrepresented. However, as there is no information that enables a more accurate evaluation of the measurements, all values were regarded as equally relevant and no further discrimination of the data was done.

Table 2

The measurements used for calculating the average emission factor

	Tierart *Animal type*	Emissionsfaktor *Emission factor* [kg N_2O-N (kg N)$^{-1}$]
Ahlgrimm et al. 2000 [17]	Schwein/Pig	0,01158
Ahn et al. 2011 [6]	Rind/Cattle	0,00588
Amon 1998 [18]	Rind/Cattle	0,00518
	Rind/Cattle	0,00802
Chadwick 2005 [8]	Rind/Cattle	0,023
	Rind/Cattle	0,001
Mathot et al. 2012 [22]	Rind/Cattle	0,00104
Sommer und Møller 2000 [11]	Schwein/Pig	0,0081
Thorman et al. 2007 [16]	Schwein/Pig	0,0263
	Rind/Cattle	0,0432

Conclusions

The arithmetic mean of the ten measurements selected as representative equals 0.013 kg N_2O-N (kg N)$^{-1}$. This value is recommended as national emission factor for N_2O emissions from the storage of solid manure. The accuracy of the emission factor and thus the inventory calculation can only be increased if more measurements over the total storage period and under practical conditions, in the best case on practical farms, are carried out and documented along with details of the measurement conditions. Also the conditions of animal housing under which the solid manure is produced needs to be documented. Important is the amount of bedding applied as well as the description of the manure storage site and the meteorological conditions during measurement.

References

[1] Intergovernmental Panel on Climate Change (IPCC) (1996): Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Reference Manual (Volume 3). http://www.ipcc-nggip.iges.or.jp/public/gl/invs6c.html. Zugriff am 13.03.2012

[2] Intergovernmental Panel on Climate Change (IPCC) (2000): Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. http://www.ipcc-nggip.iges.or.jp/public/gp/english/4_Agriculture.pdf; Zugriff am 10.05.2012

[3] Intergovernmental Panel on Climate Change (IPCC) (2006): 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4 Agriculture, Forestry and Other Land Use. http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html. Zugriff am 29.08.2011

[4] Petersen, S. O. (2011): Methane and nitrous oxide emissions from livestock manure: The scientific basis. In: Emissionen der Tierhaltung. Treibhausgase, Umweltbewertung, Stand der Technik. KTBL-Schrift 491, Darmstadt, S. 122–133

[5] Webb, J.; Sommer, S.G.; Kupper, T.; Groenestein, K.; Hutchings, N.J.; Eurich-Menden, B.; Rodhe, L.; Misselbrook, T.H.; Barbara Amon, B. (2011): Emissions of Ammonia, Nitrous Oxide and Methane During the Management of Solid Manures. Agroecology and Strategies for Climate Change, Sustainable Agriculture Reviews 8, pp. 67–107

[6] Ahn, H. K.; Mulbry, W.; White, J. W.; Kondrad, S. L. (2011): Pile mixing increases greenhouse gas emissions during composting of dairy manure. Bioresource Technology 102, S. 2904–2909

[7] Hao, X.; Chang, C.; Larney, F.J.; Travis, G.R. (2001): Greenhouse Gas Emissions during Cattle Feedlot Manure Composting. J. Environ. Qual. 30, pp. 376–386

[8] Chadwick, D. R. (2005): Emissions of ammonia, nitrous oxide and methane from cattle manure heaps: effect of compaction and covering. Atmospheric Environment 39, pp. 787–799

[9] Ahlgrimm, H.-J.; Hüther, L.; Schuchardt L. (1998): Ausmaß der Emissionen von N_2O und CH_4 bei der Behandlung und Lagerung tierischer Exkremente. In: Abschlussbericht zum Projekt A1a.5 des BMBF-Klimateilschwerpunktes „Spurenstoffkreisläufe", Braunschweig, FAL

[10] Külling, D. R.; Menzi, H.; Kröber, T. F.; Neftel, A.; Sutter, F.; Lischer, P.; Kreutzer, M. (2001): Emissions of ammonia, nitrous oxide and methane from different types of dairy manure during storage as affected by dietary protein content. Journal of Agricultural Science 137, pp. 235–250

[11] Sommer S. G.; Møller H. B. (2000): Emission of greenhouse gases during composting of deep litter from pig production – effect of straw content. Journal of Agricultural Science 134, pp. 327-335

[12] Yamulki, S. (2006): Effect of straw addition on nitrous oxide and methane emissions from stored farmyard manures. Agriculture, Ecosystems and Environment 112, pp. 140–145

[13] Sommer, S. G. (2001): Effect of composting on nutrient loss and nitrogen availability of cattle deep litter. European Journal of Agronomy 14, pp. 123-133

[14] Osada, T.; Sommer, S.G.; Dahl, P.; Rom, H. B. (2001): Gaseous emission and changes in nutrient composition during deep litter composting. Acta Agriculturae Scandinavica, Section B - Soil & Plant Science 51(3), pp. 137-142

[15] Wolter, M.; Prayitno, S.; Schuchardt, F. (2004): Greenhouse gas emission during storage of pig manure on a pilot scale. Bioresource Technology 95, pp. 235–244

[16] Thorman, R. E.; Chadwick D. R.; Harrison R.; Boyles L. O.; Matthews, R. (2007): The effect on N_2O emissions of storage conditions and rapid incorporation of pig and cattle farmyard manure into tillage land. Biosystems Engineering 97, pp. 501-511
[17] Ahlgrimm, H.-J.; Breford, J.; Asendorf, W. (2000): Methane and nitrous oxide emissons from different forms of pig fattening. In: AgEng Warwick 2000: full papers, agricultural engineering into the third millennium, 02.–07.07.2000, Warwick, ESAE
[18] Amon, B. (1998): NH_3-, N_2O- und CH_4-Emissionen aus der Festmistverfahrenskette Milchviehanbindehaltung Stall - Lager - Ausbringung. Dissertation am Institut für Land-, Umwelt und Energietechnik, Universität für Bodenkultur Wien. VDI-MEG, Forschungsbericht Agrartechnik 331
[19] Sommer, S. G.; Dahl, P. (1999): Nutrient and Carbon Balance during the Composting of Deep Litter. J. agric. Engng Res. 74, pp. 145-153
[20] Chadwick, D.; Sommer, S.; Thorman, R.; Fangueiro, D.; Cardenas, L.; Amon, B.; Misselbrook, T. (2011): Manure management: Implications for greenhouse gas emissions. Animal Feed Science and Technology 166–167, pp. 514–531
[21] Department for Environment, Food and Rural Affairs (Defra) (ohne Jahresangabe): The Effect of FYM Storage Conditions and Land Application Practices on N_2O Emissions. Research Project Final Report, Defra Project code CC0246, 2000–2004, http://randd.defra.gov.uk/Document.aspx?Document=CC0246_7027_FRP.doc, Zugriff am 18.1.2013
[22] Mathot, M.; Decruyenaere, V.; Stilmant, D.; Lambert, R. (2012): Effect of cattle diet and manure storage conditions on carbon dioxide, methane and nitrous oxide emissions from tie-stall barns and stored solid manure. Agriculture, Ecosystems and Environment 148, pp. 134–144
[23] Petersen, S. O.; Lind, A. M.; Sommer, S. G. (1998): Nitrogen and organic matter losses during storage of cattle and pig manure. Journal of Agricultural Science 130, pp. 69-79
[24] Brown, H. A.; Wagner-Riddle, C.; Thurtell, G. W. (2002): Nitrous oxide flux from a solid dairy manure pile measured using a micrometeorological mass balance method. Nutrient Cycling in Agroecosystems 62, pp. 53–60
[25] Düngeverordnung – DüV (2007): Verordnung über die Anwendung von Düngemitteln, Bodenhilfsstoffen, Kultursubstraten und Pflanzenhilfsmitteln nach den Grundsätzen der guten fachlichen Praxis beim Düngen
[26] Kuratorium für Technik und Bauwesen in der Landwirtschaft (KTBL) (Hrsg.) (2010): Betriebsplanung Landwirtschaft 2010/11. KTBL, Darmstadt
[27] Sneath, R. W.; Beline, F.; Hilhorst, M. A.; Peu, P. (2006): Monitoring GHG from manure store on organic and conventional dairy farms. Agriculture, Ecosystems and Environment 112, pp. 122–128.
[28] Espagnol, S.; Hassouna, M.; Robin, P.; Levasseur P.; Paillat J.-M. (2006): Emissions gazeuses de NH_3, N_2O, CH_4 lors du stockage de fumier de porc provenant d'une litière accumulée: effets du retournement. Journées Recherche Porcine 38, pp. 41–48
[29] Hao, X.; Benke, M.; Larney, F. J.; McAllister, T. A. (2011): Greenhouse gas emissions when composting manure from cattle fed wheat dried distillers' grains with solubles. Nutr Cycl Agroecosyst 89, pp. 105–114

Authors

Dr. Robert Vandré, **Dr. Sebastian Wulf**, **Uwe Häußermann** and **Dr. Dieter Horlacher** are scientists at the Association for Technology and Structures in Agriculture (KTBL), Bartningstr. 49, D-64289 Darmstadt, e-mail: r.vandre@ktbl.de