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Project Summary

Review of Emission Factors and Methodologies to Estimate Ammonia Emissions from Animal Waste Handling

Michiel R. J. Doorn, David F. Natschke, and Pieter C. Meeuwissen

The report summarizes and discusses recent available U.S. and European information on ammonia (NH_3) emissions from swine farms and assesses its applicability for general use in the U.S., particularly in North Carolina. The emission rates for the barns calculated by various methods show good agreement and suggest that the barns are a more significant source than previously thought. A general emission factor for barns of 3.7 ± 1.0 kg NH_3/year/finisher pig (or 59 ± 10 g NH_3/kg live weight/year) is recommended, based on the results of multiple field tests. For lagoons, it was found that there is good similarity between the field test results and the number calculated by a mass balance method. The suggested annual NH_3 emission factor for swine farm lagoons in North Carolina is 2.4 kg/year/pig. The emission factor for lagoons, based on field tests at only one lagoon, is considered to be less accurate than that for barns. Emission rates from sprayfields were estimated using a total mass balance approach, while subtracting the barn and lagoon emissions.

This Project Summary was developed by the National Risk Management Research Laboratory's Air Pollution Prevention and Control Division, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

In the U.S., the atmospheric deposition of ammonia (NH_3) and other nitrogen compounds has received renewed attention as a major route of entry into watersheds, especially the lower river basins and coastal estuaries of the eastern U.S. Atmospheric NH_3 also contributes to the formation of fine particulate matter by reacting with acid gases from combustion sources. The most significant source of NH_3 emissions (about 80%) in the U.S. is livestock waste. An increasing tendency toward industrialization of farming practices in the U.S. over the last two decades has resulted in increased farm size and confinement of animals. For example, in 1991, the average swine population in North Carolina was about 4.5 million, and the number had increased to about 10 million by 1997. To better understand NH_3 emissions from large swine farms, the State of North Carolina coordinated a significant test effort during the late 1990s. Initially, this program focused on the waste storage lagoons because they were believed to be the major source of NH_3. Later, the focus shifted toward emissions from barns. Field tests and field test results are summarized in the report, as well as a comprehensive mass balance approach and supporting information from the European and U.S. scientific literature.

Dutch and Danish NH_3 emission methodologies follow a mass balance approach based on the average yearly nitrogen excretion per animal type and the different emission or volatilization factors from specific emission sources; i.e., barn, storage/treatment, and land application. This approach takes into account the entire waste management pathway.

There are general limitations to a nitrogen mass balance approach. Inaccuracies in the determination of the nitrogen content of manure or litter can lead to inaccuracies in estimates of NH_3 losses. Another limitation of the mass balance method is that it is not equipped to address the loop that is induced by the use of NH_3-laden lagoon water to flush and fill the pit under barns, as occurs in North Carolina pull-plug barns. However, the approach may be appropriate for a flush-type farm. The method may also be useful as an emission estimation tool in discussions regarding the closing of lagoons and alternative waste treatment methods.

Field Tests In North Carolina

Comprehensive field tests were conducted in the mid to late 1990s at a swine operation in Eastern North Carolina (Farm 10). The test program at Farm 10 was coordinated by the North Carolina Department of Environment and Natural Resources (NCDENR) and included research teams from or funded by NCDENR, the U.S. Department of Agriculture (USDA), U.S. EPA's Air Pollution Prevention and Control Division (APPCD), North Carolina State University, and the University of North Carolina at Chapel Hill. Farm 10 is an integrated farrow-to-finish farm with nine finishing barns and four farrowing barns. The waste management system is "flush-type" with a pit under each side of the barn running the length of the barn. Each pit (per half barn) is flushed every week (assumed) for several hours with water from the lagoon. After flushing, no water remains in the pits. This type of waste removal system is uncommon, because most farms now have a pull-plug system. At the time of the tests, the total swine population at Farm 10 consisted of 7,480 finishers, 1,212 sows and boars, and 1,410 piglets; average weights were 135 lb (61.4 kg), 400 lb (181.8 kg), and 25 lb (11.4 kg), respectively. The Farm 10 total live weight was 1,529,850 lb (695,386 kg), and the average animal weight was 151 lb (69 kg).

Barns

A coarse NH_3 average emission factor of 9.9 g/pig/day was reported for several swine barns at Farm 10 in North Carolina. On an annual basis, these emissions are presented as 3.69 kg/pig/year with an individual seasonal range of 2.74 – 4.75 kg/pig/year. Note that the values presented for Farm 10 are described as an "upper bound," since data were collected only during the daytime.

Follow-up field tests were conducted at four separate feeder-to-finish farms in southern North Carolina in 2000. Each farm consisted of 10 tunnel-ventilated barns with a pull-plug waste removal system. Three barns at each farm were tested, representing young, middle, and older age groups within the production cycle. Preliminary conclusions indicate that there is no statistically significant variation in the emission factor as a function of age or weight. The most likely explanation for this is that the recycled lagoon water used to flush the pit below the barn floor provides a baseline emission source that contributes a significant portion of the barn emissions. Also, it is noted that there is a significant diurnal cycle. Based on these field tests, a preliminary emission factor of 4.31 kg/pig/year is suggested for emissions in the summer from pull-plug, feeder-to-finish operations.

Lagoons

The lagoon at Farm 10 was sampled by several research groups over a period of a year using different techniques. One group used a flux chamber method to measure NH_3 emissions from the lagoon surface. The NH_3 was converted to nitric oxide which, in turn, was measured using a chemiluminescence technique. A micrometeorology method was used by another group. This technique uses a vertical array of wind speed and temperature sensors operated with the air sampling occurring in parallel. During testing, this vertical array is floated to the middle of the lagoon. Ammonia concentrations were obtained by drawing unfiltered air through gas-washing bottles containing sulfuric acid at a known rate for 4 hours. The resulting ammonium (NH_4^+) concentrations were analyzed using colorimetry. Test results are summarized in Table 1.

Spraying Operations

Effluent from the lagoon is sprayed on surrounding crop fields. Unfortunately, no NH_3 emissions from spraying operations were measured for Farm 10; however, one Georgia field study was found that pertains to NH_3 emissions from sprayfields. A micrometerology method was used to determine NH_3 emissions from a sprayed oats field of 12 hectares in Georgia. To this field, 45 kg total N per hectare was applied, of which 4.7 and 20.3 kg volatilized during application and post-application, respectively. This translates into a volatilization factor of 56%. Ammonia volatilization from land application of pig slurry in France was estimated to be between 37 and 63% of ammoniacal nitrogen. Another source reported an even greater range for NH_3 losses from land application of pig waste, 11 to 78% ammoniacal nitrogen.

Discussion

To date, the most complete U.S. data set of NH_3 emissions based on field measurements from a full-scale swine farm is that of North Carolina Farm 10. The Farm 10 emission estimates can be compared with estimates based on the mass balance method. Because finishing pigs are the most significant sub-source category, and only emissions from finishing pig barns were collected at Farm 10, the finisher pig population was used as a base for the comparisons. No field tests were conducted at the farm's sprayfields, but an attempt was made to estimate these emissions based on volatilization percentages from the literature.

Table 2 summarizes NH_3 emission rates from barns, lagoon, and sprayfield for Farm 10, as well as rates calculated by a mass balance. The emission rates for the barns in Table 2 show good agreement and suggest that the barns are a more significant source than previously thought. The emission rate for barns from the mass balance approach is somewhat lower than those of the field tests, but this may be due to the low volatilization percentage that was used in the mass balance computation (15%). It is believed that there is enough evidence to recommend an emission factor for average finisher pigs of 3.7 ± 1.0 kg NH_3/year/pig (59 ± 10 g NH_3/kg live weight/year). This value is supported by the 4.3 kg NH_3/year/finisher pig reported for the summer.

There is surprising similarity between the field test results for the lagoon (average 49 kg/day) with the number calculated by the mass balance method, which was 52 kg/day. Consequently, the suggested annual emission factor for NH_3 emissions from a swine farm lagoon in North Carolina becomes 26 g/kg live weight/year. This lagoon emission factor does not take vacancy and mortality into account, nor does it address differences in lagoon characteristics (e.g., pH) or climatological factors (e.g., temperature, rain, and wind). Additional study of lagoons aimed at enhancing understanding of nitrogen pathways (e.g., to sludge or to N_2) will assist in further developing a comprehensive mass balance.

By applying the simple mass balance method, sprayfield emissions at Farm 10 were estimated at 19 kg/day (6,950 kg per year). This reflects emissions only

Table 1. Results from Ammonia Emission Field Tests at Lagoons at Two NC Swine Farms					
Field Test Method	Farm No.	Study Period	NH_3 per Lagoon (kg/day)	NH_3 per Animal (kg/ani./yr)	NH_3 per Standard Live Weight (kg/kg/yr)
Flux Chamber	10	Aug. 1997	156.2	5.64	0.0821
	10	Dec. 1997	32.8	1.19	0.0172
	10	Feb. 1997	11.9	0.43	0.0062
	10	May 1998	66.3	2.40	0.0349
	10	**Average**	**66.8**	**2.42**	**0.0351**
Micro-meteorology	10	Spring 1997 to Winter 1998	28.1	0.75	0.0133
	10	Spring 1997	26.0	0.94	0.0137
	10	Summer 1997	50.5	1.82	0.0265
	10	Winter 1998	20.5	0.74	0.0107
	10	**Average**	**31.3**	**1.06**	**0.0161**

Table 2. Summary of Farm 10 Emissions Data			
Source	Activity	Emissions kg/day	Method
Barns/lagoon/sprayfield	Finishers only	143	Mass balance
Barns	All pigs	64	Mass balance
Barns	Finishers only	43	Mass balance
Barns	Finishers only	76	OP-FTIR[a] field test
Barns	Finishers only	56	Field test
Barns	Finishers	33-69	Literature, Europe
Barns	Generic pigs	64	Literature, Canada
Lagoon	All pigs	52	Mass balance
Lagoon	All pigs	67	Flux chamber field test
Lagoon	All pigs	31	Micrometeorology field test
Lagoon	All pigs	49	Average of 2 field tests
Lagoon	Finishers only	33	Average of 2 field tests
Sprayfields	Finishers only	19	Mass balance
[a]Open-path Fourier Transform Infrared			

from finishers (61.4 kg). As indicated earlier, this number constitutes a rough guess. The calculations in this section suggest that sprayfield operations are a small but significant fraction of total farm emissions. But, since spraying is limited to certain seasons and certain hours of the day, it is likely that these spray operations are quite significant during the actual events.

Conclusion

The total of emissions for finishing pigs from barns (76 kg/day), lagoon (33 kg/day), and assumed spray application (19 kg/day) is 128 kg/day (or 102 g NH_3/kg live weight/year). The 128 kg/day number compares well to the number established by the simple total mass balance (143 kg/day). Therefore, it can be concluded that a mass balance approach can be useful in estimating NH_3 emissions from swine farms, especially those that do not employ pull-plug waste flushing technology.

The average weight of the swine at Farm 10 is 69 kg. If we assume that this swine population reflects a self-sustaining population (i.e., is similar to the average swine population in North Carolina), we can arrive at an emission factor of 7 kg NH_3/animal/year (using the 102 g NH_3/kg live weight/year number). This emission factor is a generic emission factor based mainly on field data for two farms in North Carolina for barns and one farm for lagoons. The sprayfield component was calculated using a simple mass balance approach based on nitrogen feed intake. This emission factor is comparable to other generic emission factors from the literature (see Table 3). The three European emission factors in Table 3 are all somewhat lower than the North Carolina emission factor. The difference may be a result of numerous factors, including (but not limited to) different animal waste handling practices (use of lagoons and flushing with lagoon water as opposed to pits) and lower average ambient temperatures. If we take the 1997 emission factor (5 kg/animal/year) as a lower boundary, we may possibly suggest a range for the North Carolina emission factor of ± 2 kg/animal/year.

Table 3. Comparison of Ammonia Emission Factors for Swine	
Source	NH_3 Emission Factor (kg/animal/yr
1992 Report	5
1997 Report	5
1998 EMEP/CORINAIR	6
1994 Report	9[b]
This Report[a]	7 ± 2

[a]Number now believed to be biased high, apparently due to earlier interpretation error
[b]Based on limited field tests and theoretical sprayfield emissions estimation

M. Doorn and D. Natschke are with ARCADIS Geraghty & Miller, Durham, NC, and P. Meeuwissen is with ARCADIS, Arnhem, The Netherlands.
Susan A. Thorneloe *is the EPA Project Officer (see below).*
The complete report, entitled "Review of Emission Factors and Methodologies to Estimate Ammonia Emissions from Animal Waste Handling," will be available at http://www.epa.gov/ORD/NRMRL/Pubs or as Order No. PB2002-105708; Cost: $29.50, subject to change, from:
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The EPA Project Officer can be contacted at:
Air Pollution Prevention and Control Division
National Risk Management Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711-0001

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