Stakeholders Feedlot Air Emission Data Collection Project
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INTRODUCTION

Quantifying air emissions from animal agriculture is a complex process. The complexity arises from the multitude and variety of individual sources responsible for emissions, the extreme variability of these emissions, and the variety of gaseous components being emitted. Emission sources include barns, manure storages, silage piles, dead animal compost structures, land application of manure and a variety of other smaller emissions sources. Facility design and management, for example, can have a major impact on all types of emissions. In fact, each of these sources will have a different emission profile with significant fluctuations throughout the day and throughout the year.

The Minnesota Pollution Control Agency (MPCA) currently regulates feedlot air emissions/odor through the state hydrogen sulfide (H_2S) ambient air standard. This standard is a 30-minute average of 30 ppb found more than twice in five days, or a 30-minute average of 50 ppb found more than twice per year. The MPCA currently addresses ammonia (NH_3) emissions from livestock production facilities during the environmental review portion of the feedlot permitting process. The MPCA is obligated to consider NH_3 emissions from livestock production facilities during the environmental review and permitting process as a result of the proposed Minnesota Department of Health (MDH) chronic and acute inhalation health risk values for NH_3. The MPCA began testing for the presence of ammonia emissions from feedlot facilities during 1998 (Sullivan *et al*., 1999).

In light of the concern and regulatory requirements facing livestock producers and the MPCA, the evaluation of air emissions from livestock production facilities is a critical exercise. Currently, the experimental data available that MPCA uses to make decisions is incomplete. An interim guidance to assist MPCA feedlot permitting staff, management, and producers is being developed until adequate evaluation and regulatory tools can be created and implemented.

A Minnesota Stakeholder Work Group has recently initiated an air emission data collection project that includes swine, dairy, beef and poultry facilities. This report describes the results obtained from five different swine farms that were monitored for odor, H_2S, and NH_3 during 1999.

METHODS

<u>Site selection</u>

A total of five farms were selected based on type of housing, production system, and storage of manure. Detailed information on each farm is given in Table 1. A number of related factors were considered during the site selection process. These included size of the facility (animal units), property line setback distance, and accessibility. All facilities were included in this study after consent of the producer.

Table 1. Details of sites selected

Site	No. of animals	Average body weight (kg)	Ventilation type	Manure storage		Area of emitting barns (m^2)
				Type	Area (m^2)	
Nursery	1,800	15 - 20	Mechanical	Earthen basin	1,024	580
Farrow-to-finish	3,000	200	Mechanical/ Natural	Earthen basins	South - 510 North - 1,000	Gestation - 180 Nursery - 400 Finishing - 220
Wean-to-finish	2,240	45 - 60	Natural	Deep pit	470	470
Finishing	2,000	50 - 60	Natural	Deep pit	770	770
Finishing	180	45 - 60	Natural (hoop)	Deep straw bed	145	190

<u>Air sampling and analysis</u>

Each site was monitored for odor, H_2S and NH_3 source emissions. A set of equipment was used to collect air samples from the odor source including a vacuum box, an air pump, Teflon tubing and 10 L Tedlar bags (SKC Inc., Eighty Four, PA). The vacuum box (Vac-U-Chamber, SKC-West, Inc., Fullerton, CA) and air pump (Aircheck, Model 224-PCXR3 (or 4), SKC Inc., Eight Four, PA) were used to draw the odorous air into a sampling bag. The sample is taken at 3 L/min for about 3 minutes. The tubing used in the sampling apparatus was 1/4" Teflon FEP tubing (Cole-Parmer Instrument Company, Vernon Hills, IL).

A wind tunnel was used to measure odor emissions from the surface of the liquid manure storage basins. Schmidt *et al*. (1999) gives a detailed description of this wind tunnel. The air sample is collected at the outlet of the wind tunnel by the sampling apparatus described above. The sampled surface area covered by the wind tunnel is 0.232 m^2. A hot wire anemometer (Air Velocity Meter, Model 441S, Kurtz Instruments, Carmel, CA) measures air speed at the outlet of the tunnel.

Air samples from the various emission sources were collected twice during the 30-day period from each of the five sites. Hydrogen sulfide and ammonia were measured from the sample bag within one minute after the sample was taken. Carbon dioxide was also measured for samples taken from naturally ventilated buildings in order to assess their ventilation rate. Ventilation rates in these barns were estimated using a carbon dioxide balance method (Albright, 1990, Phillips *et al*., 1998). Ventilation rates in mechanically ventilated barns were quantified by noting the number of exhaust fans running during the air sampling period and estimating the airflow rate of each fan using fan manufacturer's data.

A Jerome Hydrogen Sulfide Analyzer (Model 631-X. Arizona Instrument, Phoenix, AZ) was used to measure H_2S concentration. This instrument measure dissolved sulfur compounds in air.

The measuring range is 0.001 to 50 ppm. The accuracy is: ± 0.003 ppm at 0.050 ppm H_2S; ± 0.03 ppm at 0.5 ppm H_2S; ±0.3 ppm at 5 ppm H_2S; ±2 ppm at 25 ppm H_2S.

Colorimetric tubes (Gastec Corporation, Ayase-City, Japan) were used to measure NH_3 and CO_2 concentrations. The measuring range for NH_3 is from 0 to 30 ppm with an accuracy of ±25%. CO_2 range is from 300 to 5,000 ppm with an accuracy of about ±30 ppm.

An olfactometer and a panel of eight trained panelists were used to measure the odor threshold. The olfactometer is a venturi-type dynamic dilution olfactometer (AC'SCENT® International Olfactometer, St. Croix Sensory, Inc., Stillwater, MN). It can provide 12 different dilutions ratios of charcoal-filtered fresh air with the sample air ranging from 2^3 to 2^{13} (10 to 8,000) nominally. The procedure is in accordance with ASTM Standard E679-91 and proposed European Standard ODC 543.271.2.629.52 (Air Quality Determination of Odor Concentration by Dynamic Olfactometry). Odor plume measurements were made at three different sites with at least seven individuals who are trained to determine odor intensity in the ambient air. This procedure is described in detail by Jacobson *et al*. (1998).

Emission rates were calculated as the product of the measured odor or gas concentration multiplied by the ventilation rate of the barn or wind tunnel, and divided by the area of the source. This method of calculating emissions results in reported values for all sources of OU-m^3/m^2-s (for odor) and $\mu g/m^2$-s (for gases).

RESULTS AND DISCUSSION

All data was collected between July and October 1999. Air temperature varied from 5 to 33 ^oC, with the exception of a few days in October when minimum temperatures were around 0 ^oC. Relative humidity varied from 15 to 100%, with an average of about 70%. Wind speed varied from 0.2 to about 10 m/s, with an average value of 2.6 m/s.

All data is subjected to large variability. Ranges are given when possible in order to show the variations among measurements. Emission rates (odor and gaseous emissions) from naturally ventilated barns are usually subjected to more variation than other types of barns. This is probably related to sampling methods or ventilation rates estimates, but there may be other important sources of variation such as ventilation rates, type of management, type of feed, etc. In fact, large variations have always been observed in most air quality studies (*e.g*. Hartung *et al*., 1998, Groot Koerkamp *et al*., 1998, Hobbs *et al*., 1999, etc.).

Odor

Results from odor measurements taken at the five different sites are summarized in Table 2. Odor emission rates are reported as the geometric mean of the measured values.

The gestation/finishing barn and the south basin at the farrow-to-finished site gave the highest odor emissions, 34.2 and 82.2 OU-m^3/m^2-s respectively. The gestation/finishing barn had higher emission rates than any other type of barns within this study. These numbers are within the range given by Jacobson *et al*. (1999) for different swine barns, but about 5 times higher than the mean emission rates given by Zhu *et al*. (1999) for either a finishing or gestation barn.

Table 2. Odor emission rates

Site	Source	Odor emission ($OU\text{-}m^3/m^2\text{-}s$)	
		Geometric mean	Range
Nursery (mechanical ventilation)	Barn	19.25	18.0 - 20.6
	Basin - with straw cover	16.6	12.7 - 21.7
	Basin - top of liquid	79.0	N/A
Farrow-to-finish (mechanical ventilation)	Barn - gestation/finishing	34.2	15.1 - 65.3
	Barn - nursery	9.7	7.1 - 13.3
	South basin (nursery)	82.2	N/A
	North basin (gestation-finishing)	20.3	N/A
Wean-to-finish (curtain-sided)	Barns	10.7	1.6 - 29.4
Finishing (curtain-sided)	Barns	11.7	2.1 - 33.9
Finishing (hoop barn)	Barns	8.1	6.8 - 9.6

The wean-to-finish and finishing barns (including the hoop barns) emitted significantly fewer odors (about 10 $OU\text{-}m^3/m^2\text{-}s$) than the gestation/finishing barn at the farrow-to-finish site. This difference is probably related to the type of management, arrangement and design of buildings, diet differences, water sources, and type of manure collection and storage used in the different farms.

Odor emission rates from the hoop barn with straw bedding were lower (8.1 $OU\text{-}m^3/m^2\text{-}s$) than rates for the deep-pitted wean-to-finish and finishing barns (10.7 and 11.7 $OU\text{-}m^3/m^2\text{-}s$, respectively). Odor from a straw-based system is of a different nature than odor from a deep-pitted system, but the difference in offensiveness is not indicated by the detection threshold measurement.

Mean odor emission from the nursery barn (nursery site) was about two times higher than emission from the nursery barn at the farrow-to-finish site. It was also two times higher than emissions from the wean-to-finish and finishing sites. The emission rate given for the nursery barn (nursery site) in Table 2 is equivalent to the mean emission measured by Zhu *et al*. (1999) in a nursery.

Odor emission rates from manure storage units (about 80 $OU\text{-}m^3/m^2\text{-}s$ for the basins with nursery manure and about 20 $OU\text{-}m^3/m^2\text{-}s$ for the basin with gestation-finishing manure) were higher than those reported by Jacobson *et al*. (1999) for similar facilities.

Odor plume measurements were taken at the naturally ventilated finishing and at the wean-to-finish sites (Figures 1 and 2).

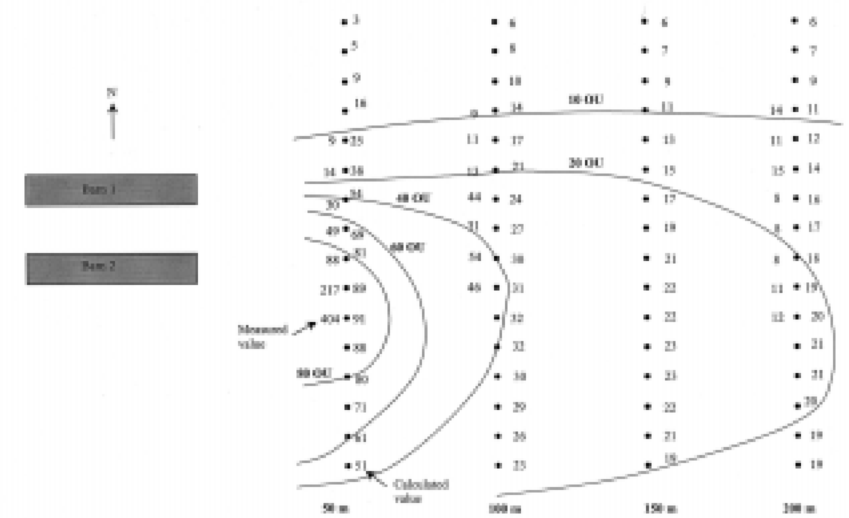

Figure 1. Odor plume measurements downwind of a naturally ventilated deep-pitted swine finishing site (7/29/99)

It is shown in Figure 1 that odor decreased from 80 OU at 50 m downwind from the barns to 20 OU at 200 m from the barns. Odor intensity measurements at a distance of about 5 m from the barns ranged from very faint odor (less than 20 OU) to faint and distinct odor (about 130 OU). Atmospheric conditions at the day measurements were taken were reasonably stable. Wind was blowing from the west with a speed of less than 1 m/s, air temperature of about 30 °C and relative humidity of 85%.

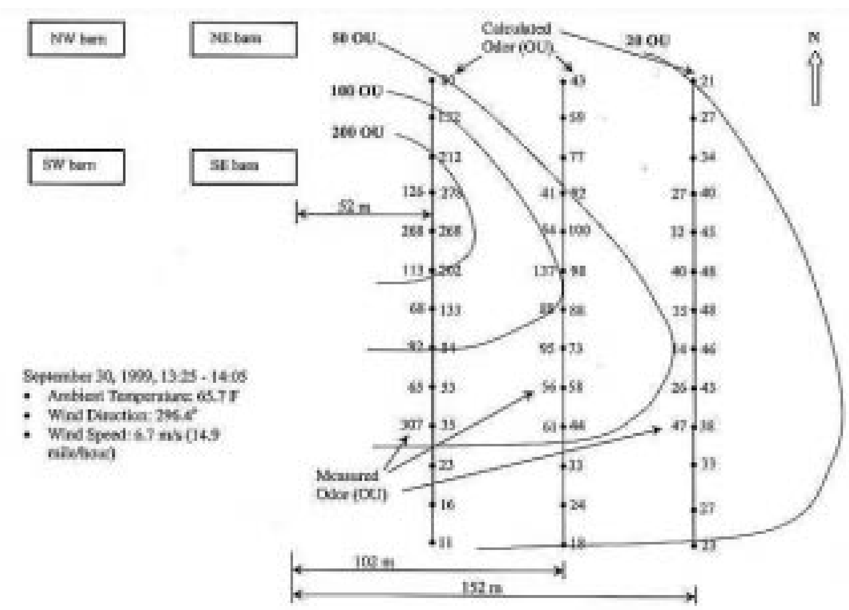

Figure 2. Odor plume measurements downwind of a naturally ventilated wean-to-finish swine site (9/30/99)

Odor plume measurements taken at the wean-to-finish site (Figure 2) on September 30, 1999 indicated that levels decreased from 200 OU to 20 OU in about 100 m. Odor levels at about 50 m downwind from the barns were higher than at the finishing site (Figure 1), but measurements were not taken in the same day and weather conditions were significantly different. Odor levels at 150 or 200 m from the barns were similar in both sites (about 20 OU).

Hydrogen sulfide

Results from H_2S source measurements taken at the five different swine sites are summarized in Table 3. Emission rates are reported as the arithmetic mean of the measured values.

Table 3. H_2S emission rates

Site	Source	H_2S emission (μg H_2S/m^2-s)	
		Mean	Range
Nursery (mechanical ventilation)	Barn	11.6	8.6 - 14.6
	Basin - with straw cover	3.0	1.5 - 4.5
	Basin - top of liquid	100.0	N/A
Farrow-to-finish (mechanical ventilation)	Barn - gestation/finishing	24.0	10.7 - 54.5
	Barn - nursery	5.6	4.8 - 6.3
	South basin (nursery)	92.3	N/A
	North basin (gestation-finishing)	16.5	N/A
Wean-to-finish (curtain-sided)	Barns	6.4	0.5 - 14.1
Finishing (curtain-sided)	Barns	6.8	0.2 - 17.2
Finishing (hoop barn)	Barns	0.7	0.25 - 1.1

As with odor emission from buildings, the highest H_2S emissions were observed at the farrow-to-finish and nursery sites (about 12 and 18 μg H_2S/m^2-s). H_2S emission rates for the wean-to-finish and finishing barns are comparable to emission rates given by Zhu *et al*. (1999), Jacobson *et al*. (1999) and Ni *et al*. (1999) for similar facilities. The low value obtained for the hoop barn (0.7 μg H_2S/m^2-s) is probably due to aerobic activity that takes place at the surface of deep bedding systems, thus minimizing H_2S emissions.

H_2S emission rates from basins storing nursery manure were the highest among all measurements taken (between 90 and 100 μg H_2S/m^2-s). They are also higher than values reported by Jacobson *et al*. (1999) for similar facilities, but well within the range reported by the same researchers in a previous study (Jacobson *et al*., 1997). The basin storing gestation-finishing manure at the farrow-to-finish facility was emitting significantly less H_2S than the other basins (16.5 μg H_2S/m^2-s). A 97% reduction in H_2S emission (from a 100 μg H_2S/m^2-s at the top of the liquid to 3 μg H_2S/m^2-s at the top of the straw cover) was achieved by covering the manure with straw.

Ammonia

Results from NH_3 source measurements taken at the five different swine sites are summarized in Table 4. Emission rates are reported as the arithmetic mean of the measured values.

Table 4. NH_3 emission rates

Site	Source	NH_3 emission ($\mu g\ NH_3/m^2$-s)	
		Mean	Range
Nursery (mechanical ventilation)	Barn	23.9	14.7 - 33.1
	Basin - with straw cover	0	N/A[a]
	Basin - top of liquid	19.3	N/A[a]
Farrow-to-finish (mechanical ventilation)	Barn - gestation/finishing	40.9	15.1 - 65.3
	Barn - nursery	10.2	7.1 - 13.3
	South basin (nursery)	84.6	N/A[a]
	North basin (gestation-finishing)	20.3	N/A[a]
Wean-to-finish (curtain-sided)	Barns	76.0	9.6 - 187.4
Finishing (curtain-sided)	Barns	60.1	16.8 - 141.9
Finishing (hoop barn)	Barns	69.0	24.1 - 113.9

a - only one measurement was taken.

The wean-to-finish and finishing (both curtain-sided and hoop barns) sites had the largest emission rates (60 to 76 and $\mu g\ NH_3/m^2$-s). A maximum emission rate of 187 $\mu g\ NH_3/m^2$-s was measured at the wean-to-finish site. This value is similar to maximum NH_3 emission rates measured by Zhu *et al*. (1999) from a curtain-sided naturally ventilated finishing barn. The relatively high emission rates obtained from the hoop barn as compared to emissions from the farrow-to-finish and nursery sites are probably due to the composting process that occurs within the straw bedding system.

The nursery barn at the nursery site was emitting twice as much ammonia (23.9 $\mu g\ NH_3/m^2$-s) than the nursery at the farrow-to-finish site (10.2 $\mu g\ NH_3/m^2$-s). Zhu *et al*. (1999) reported much higher emission rates from a nursery barn (up to 140 $\mu g\ NH_3/m^2$-s) than in the present study.

Emission from the gestation/finishing barn (40.9 $\mu g\ NH_3/m^2$-s) at the farrow-to-finish site was higher than the values reported by Zhu *et al*. (1999) for a gestation barn (less than 10 $\mu g\ NH_3/m^2$-s).

Comparison with other published data is difficult because most emission rates have been reported in terms of animal units or kg of animal live weight.

Although only one measurement was taken from the manure storage basins, it is shown that the straw cover can reduce significantly NH_3 emissions (from 19.3 $\mu g\ NH_3/m^2$-s at the top of the liquid to 0 $\mu g\ NH_3/m^2$-s at the top of the straw). Emission from the basin at the nursery site was comparable to emission from the north basin at the farrow-to-finish site, about 20 $\mu g\ NH_3/m^2$-s. The highest NH_3 emission rate was measured from the south basin at the farrow-to-finish site (84.6 $\mu g\ NH_3/m^2$-s). These values compare reasonably well (same order of magnitude) with emission rates reported by Balsari *et al.* (1994) for an earthen storage basin holding pig slurry. They are also well within the range reported by Phillips *et al*. (1997) (8.6 to 1,450 $\mu g\ NH_3/m^2$-s). Harper and Sharpe (1998) reported significantly lower emission rates (between 1.2 to 7.2 μg

NH_3/m^2-s) than those measured in the present study. However, their measurements were taken from large anaerobic lagoons with possibly significantly less concentrated manure.

SUMMARY

Results obtained from odor and gaseous emission measurements at five different farms in Minnesota indicate the following:

- The gestation/finishing barn and the south basin at the farrow-to-finished site gave the highest odor emissions, 34.2 and 82.2 OU-m^3/m^2-s respectively. The gestation/finishing barn had higher emission rates than any other type of barns within this study.

- The wean-to-finish and finishing barns (including the hoop barns) emitted significantly fewer odors (about 10 OU-m^3/m^2-s) than the gestation/finishing barn at the farrow-to-finish site.

- Odor plume measurements at the finishing and wean-to-finish sites indicated a significant effect of dispersion/dilution on odor concentration. Odor levels decreased from 80 to 20 OU in 150 m at the finishing site, and from 200 OU to 20 OU in 100 m at the wean-to-finish site.

- The highest H_2S emissions were observed at the farrow-to-finish and nursery sites (about 12 and 18 μg H_2S/m^2-s). H_2S emission rates from basins storing nursery manure were the highest among all measurements taken (between 90 and 100 μg H_2S/m^2-s). Emissions from the manure storage basins appeared to have a significant effect on the downwind H_2S concentration at the farrow-to-finish site.

- The wean-to-finish and finishing (both curtain-sided and hoop barns) sites had the largest NH_3 emission rates (60 to 76 and μg NH_3/m^2-s). A maximum emission rate of 187 μg NH_3/m^2-s was measured at the wean-to-finish site.

- NH_3 emission rates from the manure storage basins varied from 20 to 84.6 μg NH_3/m^2-s. Although only one measurement was taken from the manure storage basins, it is shown that the straw cover reduced significantly both H_2S and NH_3 emissions.

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