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Ammonia emissions from anaerobic waste lagoons at pork production operations: Influence of climate

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ABSTRACT

Swine waste storage is a major source of agricultural ammonia (NH_3) emissions. Understanding the factors that influence the magnitude of emissions is important to our understanding of NH_3 loading of the atmosphere and it's deposition on the landscape. Since swine operations occur across the United States, a better understanding of how differing climates influence NH_3 emissions and how future climate change in might impact emissions is needed. Ammonia was measured from 2007 through 2009 at five swine farms using anaerobic lagoons for manure storage and processing. Three farms, located in North Carolina (NC), Indiana (IN), and Oklahoma (OK), handled the breeding to weaning of the pigs (sow farm). These farms had an annual mean sow live mass-specific emissions ranging from 62 g d^{-1} AU^{-1} (AU = 500 kg live mass) to 120 g d^{-1} AU^{-1}. Two farms, located in NC and OK, handled the growing of the pigs to market size (finisher farm). These farms had annual mean live mass-specific emissions of36 g d^{-1} AU^{-1} (OK) and 104 g d^{-1} AU^{-1} (NC). An emissions model incorporating the influence of winds and temperature accounted for 74% of the measured emissions variability. A second emissions model including the influence of pH, suspended organic matter, and farm type-specific nitrogen excretion rates accounted for 66% of the measured emissions variability. An evaluation of the influence of warmer or cooler winters and summers using the second model shows that a 1 °C increase in maximum daily mean temperature results in a 6.9% increase in annual emissions and a 9.5% increase in maximum emissions. Additional detailed studies focused on better estimating the loading of the lagoons and chemistry of the surface of the lagoons are needed to improve the estimation of NH_3 emissions.

1. Introduction

Measurements of ammonia (NH_3) emissions from anaerobic treatment lagoons for swine manure (waste) are of interest because farms are required to report emissions in excess of 220 kg/day (100 lb/day) for the "Right-to-Know" regulations (Emergency Planning and Community Right-to-Know Act) of the United States (USA) (Centner and Patel, 2010). From a community and producer's point of view, it is important to know the corresponding size of farm that would be expected to reach this threshold of emissions. However, it is difficult to accurately determine the threshold size since emissions are related to climate so that the threshold size in one part of the country will not be the same as that in another warmer or colder part of the country. The National Air Emissions Monitoring Study (NAEMS) was conducted to assist in characterizing livestock facility emissions across the USA under different farm management plans.

Since NH_3 emissions from swine lagoons are influenced by atmospheric turbulence, the emissions need to be measured using micrometeorological approaches. However, there have been only a few studies of NH_3 emissions using such methods from lagoons at sow farms. Harper and Sharpe (1998), using a micrometeorological method over an unspecified number of days, determined a mean emission of 4.2 g hd^{-1} d^{-1} (hd, head representing1 finishing hog, gestating sow, or sow and litter). Harper et al. (2004), from twenty daily measurements over two years, determined an annual emission of 6.0 g hd^{-1} d^{-1} (hd representing unstated combination of sow, litter and hogs) at a breed-to-wean sow farm in North Carolina. Grant et al. (2013a) observed an average daily mean emission from a sow lagoon in Oklahoma of 69 g hd^{-1} d^{-1} over 181 d of measurements across two years.

There have been more NH_3 emission studies using micrometeorological methods at finisher farms than at sow farms. Szögi et al. (2005) measured emissions of 9.75 g NH_3 hd^{-1} d^{-1} during nine

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Table 1
Summary of farm characteristics. Loading rates based on nominal farm capacity, farm-reported pig weights, and manure production estimates (ASAE, 2005).

	IN4	NC3	NC4	OK3	OK4
Farm Capacity, number of sows	1400		2000		2784
Average Sow Weight, kg	216		197		223
Piglet Capacity	1960		2800		3898
Average Piglet Weight, kg	5		5		5
Farm Capacity, number of pigs		8000		3000	
Average Finisher Weight, kg		135		170	
Calculated Animal Units, AU	624	982	815	464	1279
Source Surface Area, m^2	12,009	18,878	22,641	11,139	21,381
Source Capacity, m^3	40,208	46,003	60,779	28,663	84,453
Mean Source Depth, m	3.3	2.4	2.7	5.9	3.9
Calculated N[1] Excretion Rate[3], kg/d	63.9	202	83.9	95.3	131
Calculated N Loading Rate, g/d-AU[3]	102	205	102	205	102
Calculated N Loading Rate, g/m^2/d	5.32	10.7	3.71	8.55	6.11
Calculated N Loading Rate, g/m^3/d	1.59	4.39	1.38	3.32	1.55

1: Nitrogen.
2: Rotz (2004).
3: ASAE (2005).

measurement days distributed across a year. Shores et al. (2005) measured a NH_3 emission of 44.1 g hd^{-1} d^{-1} during one day of measurements during July at a finishing farm in North Carolina. Zahn et al. (2001) measured an average emissions of 22.7 g NH_3 hd^{-1} d^{-1} during a 14-day measurement campaign in late summer and early fall at a Missouri finishing operation. Grant et al. (2013a) found an average daily mean emission from a finishing farm in Oklahoma of 18 g hd^{-1} d^{-1} over 155 d of measurements across two years.

The NH_3 emissions from lagoons have been modeled using statistical regressions (Harper and Sharpe, 1998), semi-empirical functions (Grant et al., 2013a), and detailed theoretical schemes (DeVisscher et al., 2002; Bajwa et al., 2006; and Sommer et al., 2006). Statistical emissions models have little transportability since the statistical regressions depend on the location- and time-specific variations of the variables used in the regressions. Detailed theoretical models provide the greatest transportability across climates, but typically require extensive information about the lagoon. Furthermore, ambient atmospheric turbulence introduces a significant amount of chaos into the mixing and exchange processes within the liquid and between the liquid and air. Consequently modeling of the emissions into the turbulent atmosphere requires adequate understanding so that the dominant processes can be theoretically described and a wide range of conditions to evaluate the model. The objective of this study was the development of a theoretically-based NH_3 emissions model for swine lagoons across the USA. Five hog operations, including sow farms and finisher farms located in the southeastern, mid-western, and southwestern USA were included in this analysis.

2. Methods

2.1. Farms

The southeastern swine finishing lagoon facility (NC3; Table 1) consisted of five barns (Fig. 1c), an office, and an anaerobic treatment lagoon. Manure from the barns was drained by gravity daily to the lagoon by a pull plug and lagoon water recharge system in the barns. The clay-lined lagoon was oriented east-west and separated by a drainage swale from the barns (Fig. 1c). Lagoon effluent was removed for irrigation as weather permitted. Sludge from the lagoon had not been removed since construction in 1996. The barns to the south of the lagoon resulted in a fetch ratio (distance: rise) of 10:3 to the lagoon. Fetch ratio to the east for the wind measurements was more than 4:1 for all measurement heights. While the 16-m measurement height was above the tops of the barns, the fetch ratio was 33:1 for the 4-m measurement height and 6:1 for the 2-m wind measurement. As a result of the proximity of the barns, all measurements taken when the wind direction between 135° and 225° were excluded from analysis. The only significant producer events at the farms during the measurement periods were a pump-out of the lagoon and a period of empty barns (Table 3).

The western swine finishing facility (OK3; Table 1) consisted of three barns (Fig. 1d). Manure from the barns along with lagoon water recharge was transferred three times a week to the lagoon by pulling drain plugs in the barns' underfloor pits. The waste lagoon was rectangular and located to the west of the barns (separated by a drainage swale). The clay-lined lagoon was oriented north-south. Liquid was typically removed from the lagoon approximately every six months. Sludge from the bottom of the lagoon had not been removed since construction in 1998. The barns resulted in a fetch ratio of 10:6 for the east side of the lagoon. Fetches in all other directions were better than 100:1 (Fig. 1d). Due to the proximity of the barns, emissions from wind directions of 90° to 135° were excluded from analysis. All fans exhausted barn ventilation air from the east side of the barns and therefore did not influence the lagoon PIC measurements except under easterly winds (which were not the prevailing winds at any time of the year). The nominal 120 day cycle of hogs through the farm was evident in the producer-reported activity during the study (Table 3).

The southeastern sow farm (NC4; Table 1) consisted of three barns (Fig. 1a). Manure was transferred once a week from the barns to the clay-lined lagoon by pull plug with lagoon water recharge of the pits. Wastewater pipes from all three buildings combined into one inlet pipe that discharged into the SW corner of the lagoon (Fig. 1a. Sludge from the lagoon had not been removed since construction in 1994. The sludge depth was approximately 0.7 m at the beginning of the study. Liquid was removed as weather permitted. The fetch ratio of 10:3 to the south of the lagoon resulted in the exclusion of emissions when wind directions were between 225° and 315°. Fetches for wind measurements from the east (cropland) and north were greater than 100:1 for all measurement heights. Fetch for wind measurements to the west was 100:1, 100:2.4, and 100:2 for wind measurements at the 2-m, 4-m, and 16-m heights. Consequently, all wind measurements were relatively unaffected by upwind conditions. The fan exhaust blew from the northernmost barn to the east and west. Ventilation fans exhausted from the west wall of the middle barn. The lagoon was pumped out several times during the study (Table 2).

The Midwestern sow farm (IN4; Table 1) consisted of nine barns and a lagoon (Fig. 1e). In 1998 the facility was converted from a finisher farm to a sow farm. Liquid waste from the deep pits of the barns was gravity drained once every two weeks to the lagoon