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Characterizing Ammonia Emissions from Swine Farms in Eastern North Carolina: Reduction of Emissions from Water-holding Structures at Two Candidate Superior Technologies for Waste Treatment

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Abstract

Program OPEN (Odor, Pathogens, and Emissions of Nitrogen) was an integrated study of the emissions of ammonia (NH$_3$), odor and odorants, and pathogens from potential environmentally superior technologies (ESTs) for swine facilities in eastern North Carolina. This paper, as part of program OPEN, focuses on quantifying emissions of NH$_3$ from water-holding structures at two of the best ESTs and compares them with the projected emissions from two conventional lagoon and spray technologies (LSTs). The evaluated ESTs are: (1) Super Soils at Goshen Ridge; and (2) Environmental Technologies at Red Hill. The water-holding structures for these two ESTs contained no conventional anaerobic lagoon. A dynamic flow-through chamber was used to measure NH$_3$ fluxes from the water-holding structures at both the ESTs and at the conventional farms (LSTs). In order to compare the emissions from the water-holding structures at the ESTs with those from the lagoons at the conventional sites under similar conditions, a statistical-observational model for lagoon NH$_3$ was used. A mass balance approach was used to quantify the emissions. All emissions were normalized by nitrogen excretion rates. The percentage reductions relative to the conventional lagoons were calculated for the two ESTs. Results showed substantial reductions of NH$_3$ emissions at both ESTs. Super Soils had reductions of 94.7% for the warm season and 99.0% for the cool season. Environmental Technologies had slightly larger reductions of 99.4% and 99.98% for the cool and warm season, respectively. As a result of such large reductions in ammonia emissions, both technologies meet the criteria to be classified as EST for ammonia emissions.

Key words:
Ammonia emissions, ammonia flux, water-holding structures, Environmentally Superior Technologies (ESTs), Lagoon and Spray Technologies (LSTs)
1. Introduction

Atmospheric ammonia (NH$_3$) is a very important alkaline constituent, and has a significant influence on a variety of environmental processes (Aneja et al. 2006 a,b). Ammonia reacts with a variety of acidic atmospheric species, such as sulfuric acid (H$_2$SO$_4$), nitric acid (HNO$_3$), and hydrochloric acid (HCl), to form ammonium aerosols, namely, ammonium bisulfate (NH$_4$HSO$_4$), ammonium sulfate ((NH$_4$)$_2$SO$_4$), ammonium nitrate (NH$_4$NO$_3$), and ammonium chloride (NH$_4$Cl).

Ammonia and ammonium are removed from the atmosphere through both wet and dry deposition processes. Wet deposition occurs by either below cloud scavenging (washout) or by rainout (in-cloud processes). Atmospheric NH$_3$ and its deposition lead to a variety of environmental consequences such as fine particulate matter formation, soil acidification and aquatic eutrophication.

Ammonia is emitted by a large variety of sources such as soils and agricultural crops, synthetic fertilizers, animal waste, biomass burning, fossil fuel combustion, and human excreta (Oliver et al., 1996; Bouwman et al., 1997). Domestic animal waste is the leading source of global atmospheric ammonia. Studies suggest that it contributes between 20-35 Tg of nitrogen per year (Warneck, 2000; Bouwman et al., 1997). In North Carolina, swine waste is the dominant source accounting for 47% of all ammonia emissions, and it is estimated that about 75,000 tons of nitrogen per year are released by hog waste (Aneja et al., 1998). These emissions are related to a rapid increase in hog population, from approximately 3 million in 1992 to approximately 10 million in 1997, when a moratorium was placed. The increase in hog population has been concentrated in the coastal plain region of North Carolina, which contains about 85% of the current pig population (Aneja et al., 2000). The Lagoon and Spray Technology (LST) is the system currently employed to manage hog waste in North Carolina. It consists of an anaerobic lagoon to store and biologically treat the hog waste, which is then sprayed on nearby crops as a source of nutrients.

Due, in part, to the environmental problems associated with ammonia/ammonium emissions from LST farms, a moratorium in 1997 was placed on the construction of swine facilities and the expansion of existing swine facilities until September 2007.

In order to develop sustainable solutions to this problem, an agreement between the North Carolina Attorney General and several commercial hog farming companies was reached to develop potential environmentally superior technologies (ESTs) for hog facilities (Williams, 2001).
Program OPEN (Odor, Pathogens, and Emissions of Nitrogen) was an integrated study of the emissions of ammonia, odor and odorants, and pathogens from potential environmentally superior technologies for hog facilities. It’s objectives were to evaluate 16 potential EST’s at swine facilities to determine if they would be able to substantially reduce atmospheric emissions of NH₃, pathogens, and odor from their observed or estimated emissions from the conventional lagoon and spray technology used at selected conventional farms in different (warm and cool) seasons or observation periods. Previous papers present the results for the conventional LST farms (Aneja et al., 2007a), and the evaluation of six potential ESTs, that would need improvements/modifications to qualify as ESTs (Aneja et al., 2007b). This paper focuses on characterizing and quantifying emissions of NH₃ from water-holding structures at two ESTs that met the specified performance standards (Williams, 2004) for ammonia emissions reduction, and therefore qualified as ESTs. This evaluation was achieved by comparing them with projected emissions from two conventional (also called, baseline) LST farms. The evaluated ESTs are: (1) Super Soils at Goshen Ridge; and, (2) Environmental Technologies at Red Hill. The water-holding structures for both of these ESTs contain no conventional anaerobic lagoon. Therefore these might be considered to be most effective for reducing ammonia.

2. Methodology

2.1 Approach to evaluate ammonia emissions at EST farms

Ammonia flux measurements were conducted during two-week periods representing different seasons (characterized here as warm and cool) at two EST sites in eastern North Carolina and also at two conventional farms (Stokes Farm and Moore Farm), which are also referred to as “baseline” sites for comparison with EST sites (for locations see Figure 1.). Measurements at the different sites were made at different times of the year. Therefore to compare the EST and LST sites, the different environmental conditions at each site need to be taken into account. This is achieved by the development of a statistical-observational model (Aneja et al., 2007a).
2.1.1 Statistical observational model for lagoon NH₃ flux based on conventional farm measurements

Aneja et al. (2007a) developed a model based on flux measurement data from two conventional farms. For more information on the development of the model, the reader is referred to Aneja et al. (2007a). In this paper the model development is only briefly summarized.

The relationships between NH₃ flux, lagoon temperature, pH and a range of environmental parameters were examined over a relatively wide range of lagoon temperatures (~ 2°C to ~35°C) and lagoon-air temperature differences. These were observed during the warm and cool seasons at both conventional farms. The statistical-observational model was developed using multiple regression analysis on flux measurement data from two conventional farms. It is given as:

\[ \log_{10} F = 3.8655 + 0.04491(T_l) - 0.05946(D). \]  

(1)

Here, F denotes the average NH₃-N emission from the conventional lagoon in μg min⁻¹/1000 kg-lw, T_l is the lagoon temperature in °C, and D is a hot-air variable that is equal to zero if lagoon is warmer than air, but is equal to \( \Delta T = T_a - T_l \) when \( T_a > T_l \), and \( T_a \) is air temperature in °C at 10m height. This statistical-observational model was used to estimate the projected NH₃-N flux from lagoons at the LST baseline farms to compare with the measured NH₃-N flux from water-holding structures at an EST site, for the average values of T_l and D observed at the latter.

2.1.2 Estimation of % reduction in ammonia emissions at EST sites

Both the measured EST emissions and the model estimated LST emissions were normalized by the nitrogen excretion rate (E) for the farm, and are called %E, where %E represents the loss of ammonia from a source, as a percentage of N-excretion rate. Nitrogen excretion was based on a mass balance approach. Nitrogen excretion rate (E) in unit of kg-N wk⁻¹ (1000 kg-lw)⁻¹ was determined using the following equation:

\[ E = \frac{F_c \times N_f \times (1 - e_r)}{\bar{w}} \times 1000 , \]

(2)

where \( F_c \) is the feed consumed (kg pig⁻¹ wk⁻¹), \( N_f \) is the fraction of nitrogen content in feed, \( e_r \) is the feed efficiency rate (ratio of average gain of nitrogen to nitrogen intake) (PigCHAMP, 1999), and \( \bar{w} \) is the average live animal weight (kg/pig). Nitrogen excretion at each farm was calculated in term of the same units as NH₃-N emissions estimated from the water-holding structure of the EST farm and are shown in Table 1.
A potential EST was evaluated by comparison of %E value from the EST (%E_{EST}) farm to %E value from a baseline conventional farm (%E_{CONV}), and percent reduction of NH$_3$-N can be estimated as

$$\text{% reduction} = \left( \frac{%E_{CONV} - %E_{EST}}{%E_{CONV}} \right) \times 100$$  \hspace{1cm} (3)

An algorithmic flow diagram is shown in Figure 2., which summarizes the evaluation of NH$_3$ emissions from water-holding structures at EST farms.

2.2 Sampling Sites

2.2.1 LST Sites

Stokes Farm (35.43°N, 77.48°W, 17 m MSL) is located in Pitt County, North Carolina. Measurement campaigns were conducted during September 9-20, 2002 and January 6-17, 2003, respectively. Four naturally ventilated finishing barns housed 4,392 animals with an average weight of 104 kg in the fall season and 3,727 animals with an average weight of 88 kg in the winter season. The waste (urine and feces) from the hog houses was flushed periodically (4 times a day) with recycled lagoon water and discharged into a storage lagoon from a single effluent pipe. The storage and treatment lagoon was an anaerobic system with 15170 m$^2$ of lagoon surface area.

Sampling at Moore Brothers Farm (35.14°N, 77.47°W, 13 m MSL) located near Kinston in Jones County, North Carolina, was conducted during September 30 – October 11, 2002 and January 27 – February 7, 2003. The farm has eight fully slatted finishing houses (pit recharge) with tunnel ventilation system. The eight finishing barns housed 7,611 animals with an average weight of 52 kg in the fall season and 5,784 animals with an average weight of 67 kg in the winter season. Pit recharge houses are typically flushed once a week. Waste from all the hog barns was flushed out with recycled lagoon water and discharged into a storage and treatment lagoon from eight effluent pipes, one for each hog barn. The lagoon was an anaerobic system with 17150 m$^2$ of surface area.
2.2.2 EST sites

The two EST sites were Goshen Ridge Farm and Red Hill Farm. A brief description of each of the potential ESTs that have been evaluated is provided here. Williams (2006) provides comprehensive detailed information including site plans, design schematics, economics, and projected operational characteristics associated with the technology.

2.2.2.1 Goshen Ridge Farm (Solids Separation/nitrification-denitrification/soluble phosphorus removal/solids processing system (Super Soils))

Goshen Ridge Farm is located near Beautancus, NC in Duplin County. The NH₃ measurements were conducted during April 21st-May 2nd, 2003 for the warm season and February 23rd -March 1st, 2004 for the cool season. A schematic layout of the EST at Goshen Ridge Farm, including the various sampling points, is given in Figure 3.

The treatment system employed at Goshen Ridge Farm, known as Super Soils, treats the liquid portion of the waste. The liquid treatment begins with separation of the solid and liquid portions of the waste stream. Solids separation is accomplished using polyacrylamide, a flocculating agent.

The liquid portion of the waste stream flows between tanks in a circulating loop undergoing denitrification as a result of anaerobic activity in one tank, and nitrification through the use of concentrated nitrifying bacteria in the second tank under aerobic conditions. Nitrogen is removed from the waste stream during this stage of the process. The liquid then flows to a settling tank, where phosphorus is removed through the addition of calcium hydroxide and a dewatering bag system. Calcium phosphate, which has value as a fertilizer, precipitates out during this process, providing a value-added product. During phosphorus removal, the pH of the liquid is raised to 10.5 using lime, which precipitates the soluble P and disinfects the effluent. Roughly 80 percent of the liquid is recycled through the hog houses, while 20 percent is used to irrigate crop fields.

At Goshen Ridge Farm, six naturally ventilated houses were treated by the potential EST. For the warm season evaluation period there were 3,519 pigs with an average weight of 93.4 kg. For the cool season evaluations, there were 3,138 pigs with an average weight of 99.8 kg for the February to March sampling period. For the warm evaluation period, NH₃ fluxes and emissions were measured from the homogenization tank, the 1st denitrification tank, the nitrification tank, the
2nd denitrification tank, and the storage tank. For the cool period evaluation, measurements were repeated in all the water-holding structures except the 2nd denitrification tank.

2.2.2.2 Red Hill Farm (‘Closed Loop’ Swine Waste Treatment System)

Red Hill Farm is located near Ayden, NC, in Pitt County. Field campaigns were conducted from March 21st – April 8th, 2005 for the cool season, and July 18th - August 5th, 2005 for the warm season. A schematic layout of the EST at Red Hill Farm is given in Figure 4.

The EST at Red Hill farm was provided by ‘Environmental Technologies’. This EST is described as a “closed-loop” system, and its primary objective is to treat the liquid fraction of the waste in such a way that it can be used both for flushing the hog barns and for hog drinking water. This could eliminate the need for the traditional hog waste lagoon. A flush system is used for removing the manure from the barns, which, prior to installation of the treatment system, flushed the waste into a lagoon. The first step in the closed loop process is collection of the waste in a “equalization” or buffering tank. The waste in the tank is continuously pumped to an inclined separator where the solids are collected and further treated. The liquid collected from the separator is injected with a polymer flocculant and sanitizer/disinfectant and pumped into a settling tank, where flocculated solids collect at the bottom over a period of approximately four hours.

Most of the liquid fraction from the settling tank is returned to the hog barns for re-use as flush water. When the flush tanks are full, however, excess water is pumped to a tertiary treatment system. This system provides filtration and aeration and is housed in a septic tank. The treated water is blended with well water to achieve a dissolved solids content that is consistent with human drinking water standards for use as hog drinking water. Solids from the settling tanks are combined with the solids from the inclined separator for further treatment.

At this EST farm there are 3 naturally ventilated hog houses in total. During the cool season evaluation period there were 2,390 pigs with an average weight of 69.0 kg. For the warm season evaluation there were 3,113 pigs with an average weight of 66.5 kg. During both experimental periods, measurements were conducted at the water tank and at both settling tanks.

2.3 Sampling Technique and Instrumentation

A dynamic flow-through chamber system was used to measure ammonia fluxes from water-holding structures at the potential ESTs and conventional farms. Various environmental
measurements were also made simultaneously. Aneja et al. (2007a) gives a detailed description on the sampling techniques/scheme as well as instrumentation and environmental measurements used at each experimental site.

3. Results and Discussion

3.1 NH₃ fluxes and emissions from water-holding structures

Water-holding structure emissions from two EST farms (Goshen Ridge, and Red Hill) were calculated from measurements of NH₃ flux from EST farms, water-holding structure surface areas, and farm production data (number of pigs, feed consumed, and average pig weight) during experimental periods representing both cool and warm seasons. Emissions at the EST farms were normalized to steady state live animal weight (lw) in the units of kg-N/wk/1000kg-lw. Average fluxes and total estimated emissions for the water-holding structures are given in Table 2.

At Goshen Ridge farm, ammonia flux measurements for the 1st experimental period were conducted from the homogenization tank, the denitrification tank, the nitrification tank, the 2nd denitrification tank and the storage tank. Their water-holding structure surface areas were 91.6, 67.9, 28.3, 28.3, and 91.6 m², respectively.

For the 2nd experiment, period measurements were conducted for all of the same water-holding structures except the 2nd denitrification tank.

During the 1st sampling period, the highest flux was measured at the denitrification tank, with a 15 min average flux of 5838.1 μg NH₃-N m⁻² min⁻¹, and a maximum hourly average flux of 6242.1 μg NH₃-N m⁻² min⁻¹. It should be noted, though, that the concentrations in the flux chamber were beyond the upper limit of detection of the ammonia analyzer, therefore flux values from this tank are highly uncertain. The homogenization tank had the 2nd highest flux with an average 15 min flux of 3092.3 μg NH₃-N m⁻² min⁻¹, with a maximum hourly flux of 6885.6 μg NH₃-N m⁻² min⁻¹. Although the homogenization tank has the larger surface area, the higher flux from the 1st denitrification tank results in this tank having the larger emissions.

The other water-holding structures were found to have much lower fluxes and emissions relative to the denitrification and homogenization tanks. The nitrification tank, 2nd denitrification tank and the storage tank had 15 min average fluxes of 213.7, 543.1, and 33.6 μg NH₃-N m⁻² min⁻¹, respectively. Correspondingly, the emissions followed the same pattern as the flux trend.
For all of the water-holding structures, the flux and emissions were lower in the 2nd evaluation period. For this evaluation, the average 15 min flux for the homogenization tank was the highest at 881.1 μg NH₃-N m⁻² min⁻¹, with a maximum hourly average flux of 2059.5 μg NH₃-N m⁻² min⁻¹. The most significant decrease in flux and emissions was from the denitrification tank, with an average 15 minute flux of 33.5 μg NH₃-N m⁻² min⁻¹. The storage tank had the lowest average flux, 13.7 μg NH₃-N m⁻² min⁻¹. The emissions though were higher than the emissions for the nitrification tank due to the storage tanks larger surface area.

At Red Hill Farm, fluxes were measured from three water-holding structures, the two settling tanks and the treated water storage tank which all had an area of 5.8 m². Average fluxes during the Mar-Apr sampling period for settling tank 1 and settling tank 2 were 2073.9 and 5492.8 μg NH₃-N m⁻² min⁻¹, respectively. The treated water storage tank had the lowest flux value, with a flux of 80.4 μg NH₃-N m⁻² min⁻¹. For the July - August 2005 measurement period, the pattern of flux values was repeated. The fluxes were 996.9, 1223.3, and 43.3 μg NH₃-N m⁻² min⁻¹, for settling tank 1, settling tank 2, and treated water storage tank, respectively. The emissions from individual water-holding structures follow the same pattern as the fluxes.

3.2 Evaluation of ammonia emissions from water-holding structures

In order to evaluate the percentage reduction of NH₃ emissions for the water-holding structures, measured or estimated EST emissions were compared to projected emissions at the conventional LST farms. The estimated emissions from the LST farms were adjusted to the environmental conditions, i.e. air and lagoon temperature, which have been determined to be statistically correlated with ammonia emissions. For Environmental Technologies, lagoon temperature measurements were made at a lagoon on the farm that was not part of the EST. At Super Soils, no measurements were made at a lagoon. Therefore in order to make a fair and logical comparison, lagoon data was used from an earlier reported EST with similar air temperatures. For the 1st evaluation at Super Soils (April-May, 2003), the Barham farm (April, 2002) lagoon (waste water holding pond component) temperatures were used (Aneja et al.2007b). For the 2nd evaluation (February-March, 2004) at Super Soils, Barham farm (November, 2002) lagoon temperatures were used.
Table 3 shows the summary of the water-holding structure NH$_3$ emissions measured from EST farms, projected emissions from the water-holding structures at the conventional (LST) farms, and % reduction values for their evaluation of potential N reduction.

For both farms there is substantial reduction in NH$_3$ emissions from water-holding structures. The Super Soils technology employed at Goshen Ridge farm had reductions of 94.7% and 99.0% for the warm and cool season, respectively. The Environmental Technologies closed loop system had slightly larger reductions, with a reduction of 99.4% in the cool season, and 99.98% in the warm season.

4. Conclusions

Two potential ESTs with no conventional anaerobic lagoon component were evaluated to determine if they would substantially reduce atmospheric emissions of ammonia at the hog facilities and meet the performance standards as compared to estimated or projected emissions from the conventional lagoon and spray technology used at two selected hog farms in two different (warm and cool) measurement periods. Both farms showed substantial reductions in NH$_3$ emissions from their water-holding structures. The Environmental Technologies closed loop system had the largest reductions, with reduction of 99.4% and 99.98% for the cool and warm season, respectively. Super Soils technology had a reduction of 94.7% in the cool season, and 99.0% in the warm season. This study did not address the potential reductions in odor and pathogens that were evaluated by other scientists in the OPEN project (Williams, 2006).

Under the conditions reported herein these two potential ESTs meet the criteria established for ammonia emissions as described for ESTs (Williams, 2004).

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Figure 3. A schematic layout of the potential EST at Goshen Ridge farm.

Figure 4. A schematic layout of the potential EST at Red Hill farm.
Table 1. The summary of production data at Environmentally Superior Technologies (ESTs) farms.

<table>
<thead>
<tr>
<th>Farm Information</th>
<th>No. of pigs</th>
<th>Average pig weight (kg/pig)</th>
<th>Total pig weight (kg)</th>
<th>Feed consumed (kg/pig/wk)</th>
<th>N-content in feed (%)</th>
<th>N-excretion (kgN/wk/1000kg-lw)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Goshen Ridge</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apr. 2003</td>
<td>3,519</td>
<td>93.4</td>
<td>328 675</td>
<td>17.03</td>
<td>2.67</td>
<td>3.41</td>
</tr>
<tr>
<td>Feb-Mar. 2004</td>
<td>3,138</td>
<td>99.8</td>
<td>313 172</td>
<td>16.18</td>
<td>2.49</td>
<td>2.83</td>
</tr>
<tr>
<td><strong>Red Hill</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mar-Apr. 2005</td>
<td>2,390</td>
<td>69.0</td>
<td>164 910</td>
<td>15.88</td>
<td>3.17</td>
<td>5.09</td>
</tr>
<tr>
<td>July-Aug. 2005</td>
<td>3,113</td>
<td>66.5</td>
<td>207 015</td>
<td>15.88</td>
<td>2.81</td>
<td>4.69</td>
</tr>
</tbody>
</table>
Table 2. Average fluxes and total estimated emissions for the water-holding structures.

<table>
<thead>
<tr>
<th>Farm name and sampling period</th>
<th>Water holding structure</th>
<th>Average 15 min flux (μg NH₃-N m⁻² min⁻¹)</th>
<th>Water holding structure surface area (m²)</th>
<th>Weekly NH₃ emissions (kg-N/wk)</th>
<th>Total emissions from water holding structures (kg-N/wk)</th>
<th>Total emission/pig (kg-N/pig/wk)</th>
<th>Total emission/1000kg-lw (kg-N/1000kg-lw/wk)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Goshen Ridge</strong>&lt;br&gt;<strong>Apr-May. 2003</strong></td>
<td>Homogenization tank</td>
<td>3092.3</td>
<td>91.6</td>
<td>2.86</td>
<td>7.11</td>
<td>0.002</td>
<td>0.02</td>
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<tr>
<td></td>
<td>Denitrification tank</td>
<td>5838.1</td>
<td>67.9</td>
<td>4.01</td>
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<td></td>
<td>Nitrification tank</td>
<td>213.7</td>
<td>28.3</td>
<td>0.15</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>2nd Denitrification tank</td>
<td>543.1</td>
<td>28.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Storage tank</td>
<td>33.6</td>
<td>91.6</td>
<td>0.03</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Goshen Ridge</strong>&lt;br&gt;<strong>Feb-Mar. 2004</strong></td>
<td>Homogenization tank</td>
<td>881.1</td>
<td>91.6</td>
<td>1.36</td>
<td>1.41</td>
<td>0.0004</td>
<td>0.004</td>
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<td></td>
<td>Denitrification tank</td>
<td>33.5</td>
<td>67.9</td>
<td>0.02</td>
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<tr>
<td></td>
<td>Nitrification tank</td>
<td>32.4</td>
<td>28.3</td>
<td>0.01</td>
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<td></td>
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<td>Storage tank</td>
<td>13.7</td>
<td>91.6</td>
<td>0.02</td>
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<tr>
<td><strong>Red Hill</strong>&lt;br&gt;<strong>Mar-Apr. 2005</strong></td>
<td>Settling tank 1</td>
<td>2073.9</td>
<td>5.8</td>
<td>0.12</td>
<td>0.44</td>
<td>0.0002</td>
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<tr>
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<td>Settling tank 2</td>
<td>5492.8</td>
<td>5.8</td>
<td>0.32</td>
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<tr>
<td></td>
<td>Water tank</td>
<td>80.4</td>
<td>5.8</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Red Hill</strong>&lt;br&gt;<strong>July-Aug. 2005</strong></td>
<td>Settling tank 1</td>
<td>996.9</td>
<td>5.8</td>
<td>0.06</td>
<td>0.13</td>
<td>0.00004</td>
<td>0.0006</td>
</tr>
<tr>
<td></td>
<td>Settling tank 2</td>
<td>1223.3</td>
<td>5.8</td>
<td>0.07</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Water tank</td>
<td>43.3</td>
<td>5.8</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* The pig weight used to estimate per pig emissions was based on average pig weight in Table 1.
Table 3. Summary of total NH₃ emissions from the EST farms and % reduction during the experimental periods.

<table>
<thead>
<tr>
<th>EST Farms</th>
<th>Sampling Periods</th>
<th>Measured emission ($F_{\text{meas}}$) kg-N/wk/1000kg-lw</th>
<th>%EEST</th>
<th>EST avg. lagoon temp (°C)</th>
<th>EST avg. D (°C)</th>
<th>Conventional lagoon emission (model/projected ($F_{\text{proj}}$)) kg-N/wk/1000kg-lw</th>
<th>%ECONV</th>
<th>% reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goshen Ridge</td>
<td>Apr-May,03</td>
<td>0.02</td>
<td>0.6</td>
<td>17.2</td>
<td>0.7</td>
<td>0.40</td>
<td>11.3</td>
<td>94.7</td>
</tr>
<tr>
<td></td>
<td>Feb-Mar,04</td>
<td>0.004</td>
<td>0.1</td>
<td>14.2</td>
<td>0.3</td>
<td>0.31</td>
<td>9.7</td>
<td>99.0</td>
</tr>
<tr>
<td>Red Hill</td>
<td>Mar-Apr,05</td>
<td>0.003</td>
<td>0.06</td>
<td>14.9</td>
<td>0.5</td>
<td>0.32</td>
<td>10.0</td>
<td>99.4</td>
</tr>
<tr>
<td></td>
<td>July-Aug,05</td>
<td>0.0006</td>
<td>0.01</td>
<td>31.6</td>
<td>0.0</td>
<td>1.95</td>
<td>54.9</td>
<td>99.98</td>
</tr>
</tbody>
</table>
Figure 1. Map of North Carolina indicating the location of the Environmentally Superior Technologies (ESTs), and Lagoon and Spray Technologies (LSTs). Blue hexagon indicates an LST farm, red cross an EST farm.
Analysis of conventional farm (Moore & Stokes Farm) measurement data for NH₃ lagoon emissions with lagoon and air temperature

Establish an observational model based on conventional farm measurement data of NH₃ emission and lagoon and air temperature during different seasons

Analysis of each technology farm (EST farms) measurement data for NH₃ lagoon emissions with lagoon and air temperature

Multiple linear regression analysis

Log₁₀ (NH₃ emission) = a + b • TₕLAG + c • D;

- a, b and c; experimental constants,
- TₕLAG; lagoon temperature, T_air; air temperature
- D; ΔT when ΔT>0, 0 when ΔT<0; ΔT= T_air− TₕLAG

Plug temperatures into model

Estimate conventional NH₃ emission for evaluation EST by using lagoon and air temperatures from EST, and multiple linear regression model

Measured EST average NH₃ emission (F_meas) during the experimental period

Estimated conventional average NH₃ emission (F_proj) projected by the regression model

Subtract the measured EST emissions from the projected conventional model emissions, then divide by the projected conventional model emissions and multiply by 100 to find the % reduction

Reduction of NH₃ emission by alternative technology (The higher the % reduction, the more effective the technology.)

% reduction > 0

No reduction of NH₃ emission

Yes

Figure 2. Algorithm flow chart for evaluation of EST emissions from water-holding structures.
Figure 3. A schematic layout of the potential EST at Goshen Ridge farm.
Figure 4. A schematic layout of the potential EST at Red Hill farm. TCM = trichloromelamine