# REDUCTION OF AMMONIA EMISSIONS FROM TREATED ANAEROBIC SWINE LAGOONS

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## ABSTRACT

There is a need for treatment technologies that can effectively address environmental concerns associated with anaerobic lagoons typically used to manage manure. These technologies must be able to capture nutrients, kill pathogens, and reduce emissions of ammonia ($NH_3$) and nuisance odors. To meet these needs, a wastewater treatment plant was demonstrated at full-scale in one of two 4,360-pig production units in a finishing farm in Duplin Co., NC. The second production unit was used as a control. Both production units had similar animal production management and lagoons with similar surface area (about 0.9 ha each). The treatment plant processed raw manure and the corresponding lagoon was used to store the treated water. The quality of the lagoon liquid was rapidly improved as clean effluent replaced dirty liquid. Our objective was to study changes in $NH_3$ emissions as a result of improved water quality. The study was done one year after lagoon conversion and included cold and warm weather conditions. Passive flux samplers were used to measure simultaneously the $NH_3$ gas fluxes from both the treated and traditional anaerobic lagoons. Average total $NH_3$-N (TAN) concentrations in lagoon liquid were 31 and 388 mg/L in the treated and traditional systems, respectively. Lower N concentrations in the treated lagoon substantially reduced annual $NH_3$ emissions by 90% with respect to those found in the traditional anaerobic lagoon. Ammonia emissions from the treated lagoon totaled 1,210 kg N/lagoon/year (or 1,300 kg N/ha/year). This compares with ammonia emissions of 12,540 kg N/lagoon/year (13,600 kg N/ha/year) from the traditional lagoon. These results overall demonstrate that production of clean water using new wastewater technologies can accelerate lagoon clean up and substantially reduce ammonia emissions.

**Key words:** Ammonia emissions, ammonia volatilization, nitrogen, anaerobic swine lagoons, ammonia flux, free ammonia, manure

## INTRODUCTION

Anaerobic lagoons are widely used to treat and store liquid manure from confined swine production facilities. During lagoon treatment, urea and other organic N compounds contained in urine and feces are converted into ammoniacal N that can contribute to emissions of ammonia gas ($NH_3$). Increase of ammonia emissions due to intensification of animal production has been related to an increase on atmospheric $NH_3$ deposition and air pollution on a local scale (Walker et al., 2000). Thus, it is critical to develop alternative methods of N management that will reduce $NH_3$ emissions. In particular, there is major interest in developing swine manure treatment systems that can eliminate environmental problems associated with anaerobic lagoons (Williams, 2001).

In North Carolina, a state government-industry framework was established to give preference to alternative technologies that would directly eliminate anaerobic lagoons as a method of treatment. This framework established an agreement between government and swine industry to develop and demonstrate environmentally superior waste management technologies (EST) that would capture nutrients, kill pathogens, and reduce nuisance odors and $NH_3$ emissions (Williams, 2001). In July 2005, only one on-farm technology out of eighteen diverse technologies evaluated was determined to meet the environmental performance criteria necessary for EST. This on-farm treatment technology treated the entire waste stream from a swine production unit using a solids separation, nitrification/denitrification, and soluble phosphorus removal system (Vanotti et al., 2005; Williams, 2004). It effectively replaced anaerobic lagoon treatment by discontinuing loading of liquid raw manure into the lagoon. In turn, the recycled clean water converted the anaerobic lagoon into an aerobic water storage pond in less than a year (Vanotti, 2004). As a result of storing treated effluent in the old lagoon, remarkable changes on water quality led to this investigation on $NH_3$ emissions from the converted lagoon.

Ammonia emissions from traditional anaerobic swine lagoons depend on several factors, such as $NH_3$-N concentration, pH, temperature, wind speed, chemical and microbiological activities, and material transport processes (Arogo et al., 2003; Harper et al., 2000). In particular, $NH_3$ emissions from anaerobic swine lagoons have been shown to increase with $NH_3$-N concentrations and temperatures (Harper et al., 2004). Therefore, it appears obvious that improved water quality and lower nitrogen levels in a converted lagoon will substantially reduce ammonia emissions. The purpose of this research was to quantify the magnitude of this reduction in a converted lagoon compared with a traditional anaerobic lagoon, both under similar animal production management. In addition, we determined the influence of lagoon N levels and climatic factors on $NH_3$ losses from both converted and traditional anaerobic lagoon systems.

## MATERIALS AND METHODS

The operation had three units under identical animal production and waste treatment managements in Duplin Co., NC, but only two units were used in this study. Each unit had six barns with 4,360-head finishing pigs and a traditional anaerobic lagoon for treatment and storage of manure. Manure was collected in barns using slatted floors and a pit-recharge system typical of many farms in North Carolina. In each production unit, pits were drained weekly by gravity to the traditional anaerobic lagoons, hereafter called lagoons 1 and 2. Lagoon effluent was then used to recharge the pits of both production units. Lagoon dimensions and monthly average live animal weight (LAW) computed from farm production records are presented in table 1. The relationship between N production by pigs and their weight was 0.3 kg N/1000 kg LAW/day (Vanotti, 2004).

Table 1. Main characteristics of the two production units.

| Production Unit | Lagoon Surface ha | Lagoon Volume $m^3$ | Steady State Live Animal Weight kg |
|---|---|---|---|
| 1 | 0.90 | 24,145 | 224,581 |
| 2 | 0.92 | 22,356 | 196,636 |

In 2003, one year before this study was conducted, a full-scale wastewater treatment system was started to treat all raw manure produced in unit 1. Even though waste treatment in both production units was substantially different, animal production management remained the same. The treatment system combined solid-liquid separation with removal of nitrogen and phosphorus from the liquid phase. The system treated an average of 39 $m^3$ per day of raw manure flushed from the barns in three steps (Vanotti, 2004). The first step flocculated solids from raw flushed manure using polyacrylamide and separated solids from liquid. This step produced 657 tons of separated solids per year that were transported off-site and converted to organic plant fertilizer, soil amendments, or energy. In the second step, nitrogen management to reduce $NH_3$ emissions was accomplished by passing the liquid through a module where immobilized nitrifying bacteria transformed $NH_3$ into nitrate. Subsequent alkaline treatment of the wastewater in a phosphorus module precipitated calcium phosphate and killed pathogens. Changes in water quality before and after full-scale plant treatment are summarized in Table 2.

Table 2. Typical wastewater characteristics before and after full-scale plant treatment, Duplin Co., NC (Vanotti, 2004).

| Constituent | Influent[1] (mg/L) | Effluent[2] (mg/L) |
|---|---|---|
| Total Ammoniacal N | 872 | 11 |
| Total Kjeldahl N | 1,584 | 23 |
| Nitrate plus Nitrate N | 1 | 224 |
| Total Suspended Solids | 11,051 | 264 |
| Chemical Oxygen Demand mand | 16,138 | 445 |
| Biochemical Oxygen Demand | 3,132 | 10 |
| pH | 7.6 | 10.5 |

[1] Raw wastewater flushed from the hog house. Data are means, n = 121.
[2] After sequential treatment: solid/liquid separation – biological N removal – lime precipitation.

The treated water was recycled to refill the barn pit recharge system (13 $m^3$/d), and excess water (26 $m^3$/d) was stored in the lagoon and later used for crop irrigation. As the treatment system recovered the manure solids and replaced the anaerobic lagoon liquid with clean water, it transformed the anaerobic lagoon into a treated water pond. In 2004, one year after the treatment system was started, we measured $NH_3$ emissions in both lagoons.

All water analyses were performed according to Standard Methods for the Examination of Water and Wastewater (APHA, 1998). Analysis of ammonia in water determined both ionized and un-ionized ammonia forms (TAN = $NH_4^+$-N + $NH_3$-N). The concentration of un-ionized form ($NH_3$-N) or free-ammonia (FA) was calculated using water temperature, pH, and TAN concentrations according to Anthonisen et al. (1976).

Meteorological measurements consisted of air temperature, wind speed and direction, and relative humidity at about 2 m above the liquid surface of each lagoon. Environmental parameters dataset was completed with temperature of lagoon liquid measured at 0.15-m depth. All environmental parameters were recorded and stored in data loggers at five-minute intervals throughout each emission sampling period and averaged every 24 h.

Ammonia emissions were determined with passive flux samplers using the method of Sommer et al. (1996). The passive samplers were placed at four fixed locations perpendicular to each other around the lagoon. This layout enclosed most of the lagoon surface within a circular sampling plot (Figure 1). This circular sampling plot was required for the mass balance method used to estimate $NH_3$–N vertical fluxes using passive sampler data (Sommer et al., 1996). Values of lagoon areas enclosed within the circular plot were used to estimate vertical fluxes (0.62 ha for lagoon 1 and 0.57 ha for lagoon 2; Figure 1). At each fixed sampling location, samplers were mounted onto a mast evenly separated (0.75 m) at four heights. Lagoon water levels were recorded to determine the exact height of samplers with respect to the surface of the lagoons. Nine data collection periods lasting 23 h each were scheduled from February to November 2004 for the two lagoons.

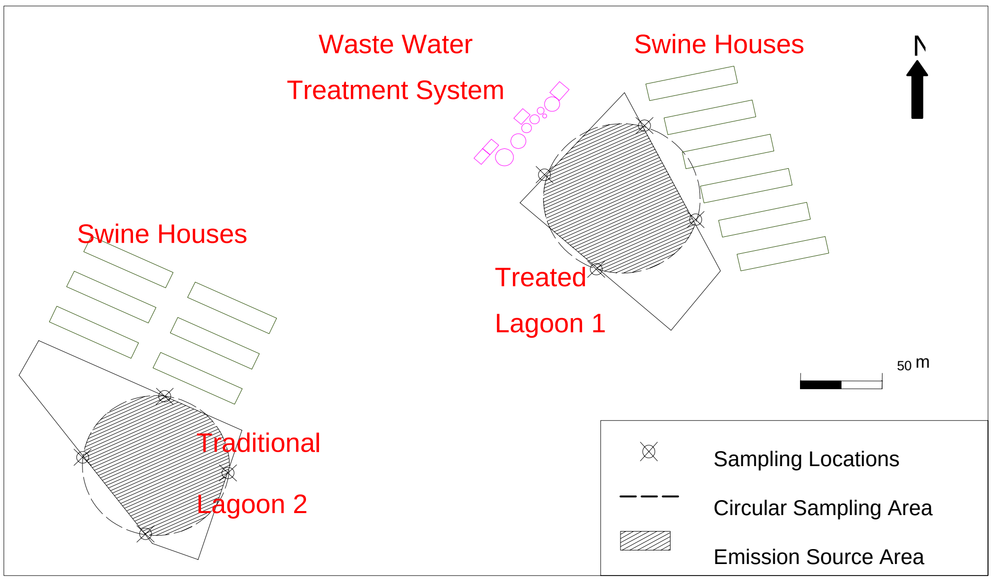


Figure 1. Schematic diagram of monitoring set-up for ammonia emission study for treated lagoon 1 and traditional lagoon 2, Duplin Co, NC.

## RESULTS AND DISCUSSION

Lagoon Water Quality

In 2002, both lagoons received flushed manure from the barns. Thus, the two anaerobic lagoons had similar annual mean pH, TAN, TKN, and $NO_2$+$NO_3$-N concentrations (Jan.-Dec. 2002 ; table 3). Beginning in February 2003, manure flush to lagoon 1 was halted and 100% of the liquid manure generated in the adjacent six barns was processed through the wastewater treatment plant (Figure 1). The quality of the liquid in lagoon 1 rapidly improved during 2003 as clean effluent from the treatment plant replaced dirty liquid. On the other hand, water quality in lagoon 2 remained mostly unchanged. In lagoon 1, the transition from anaerobic to aerobic water storage pond was noticeable in 2003. Dissolved oxygen (DO) concentrations in fall 2003 and winter 2004 (Oct. 2003 – Mar. 2004, n = 5) averaged 3.45 mg/L in lagoon 1 and 0.52 mg/L in lagoon 2. Annual (2003) average TAN and TKN levels in lagoon 1 declined 58% and 56%, respectively, with respect to lagoon 2.

Table 3. Changes in water quality in three consecutive years for lagoon 1 before and after treatment, and traditional anaerobic lagoon 2 (control), Duplin Co., NC[1].

| Sampling Period | Lagoon | Treated | pH | TAN[2] | TKN | $NO_2 + NO_3$ |
|---|---|---|---|---|---|---|
| Jan.-Dec. 2002 | 1 | N | 8.0 (0.1) | 464 (98) | 506 (108) | 0.08 (0.20) |
| | 2 | N | 8.0 (0.2) | 467 (118) | 521 (122) | 0.07 (0.21) |
| Jan.-Dec. 2003 | 1 | Y | 8.1 (0.1) | 186 (129) | 230 (138) | 4.1 (5.8) |
| | 2 | N | 7.9 (0.1) | 446 (102) | 522 (127) | 0.43 (1.4) |
| Jan.-Dec. 2004 | 1 | Y | 8.1 (0.3) | 37 (32) | 76 (34) | 20 (16) |
| | 2 | N | 8.0 (0.2) | 364 (88) | 406 (79) | n.d.[3] |

[1] Data are annual means (standard deviation) of duplicate monthly composite samples.
[2] TAN = Total ammoniacal N; TKN = Total Kjeldahl N; $NO_2 + NO_3$ = Nitrite plus Nitrate.
[3] n.d. = not detected.

In 2004, differences in TAN and TKN concentrations between lagoons were even larger than in 2003. Table 4 shows water quality data for lagoons 1 and 2 during the $NH_3$-N emission monitoring period (February-November 2004). In average, TAN declined 90% and TKN 81% with respect to lagoon 2 (table 4). Statistical tests showed significant differences in TAN, TKN, TS, COD, and BOD concentrations between lagoons 1 and 2 that indicate the improved water quality in lagoon 1 during the emission study.

TABLE 4. Mean and standard deviation (SD) of water quality characteristics in treated lagoon 1 and traditional anaerobic lagoon 2 during ammonia emissions monitoring period (February-November 2004)[1].

| Lagoon | Treated | pH | TAN | TKN | TS | COD | BOD |
|---|---|---|---|---|---|---|---|
| | | | mg/L | | | | |
| 1 | Y | 8.1 (0.3) | 31 (26) | 73 (31) | 2312 (180) | 545 (202) | 50 (30) |
| 2 | N | 8.0 (0.2) | 388 (109) | 431 (103) | 2931 (218) | 1399 (406) | 186 (115) |
| | | Level of significance (P) | | | | | |
| Paired t-test | | 0.33 | 0.0001 | 0.0001 | 0.0001 | 0.0015 | 0.0148 |
| Wilcoxon Sign Test | | 0.40 | 0.0039 | 0.0039 | 0.0039 | 0.0039 | 0.078 |

[1] Data are annual means (standard deviation) of duplicate monthly composite samples.
[2] TAN = Total ammoniacal N; TKN = Total Kjeldahl N; TS = Total Solids; COD = Chemical Oxygen Demand; BOD = Biochemical Oxygen Demand.

Temperature Effect

For lagoon 1, $NH_3$ emission rates varied from 0.0 to 12.5 kg $NH_3$-N/ha/d. For lagoon 2, $NH_3$ emission rates varied from 2.5 to 73.4 kg $NH_3$-N/ha/d. Ammonia emission rates from the traditional lagoon 2 were within the range of 0.6 to 104 kg $NH_3$-N/ha/d reported for North Carolina's anaerobic lagoons (Arogo et al., 2003). Environmental parameters (air and water temperature, relative humidity, and wind speed and direction) were similar for both lagoons (Table 5). This similarity in environmental conditions, plus the fact that animal production management in both units was also similar, made interpretation of ammonia emissions simpler. Ammonia emission rates were markedly different between seasons and between lagoons. During cold weather (February, March and November, air temperature < 10 $^oC$), emission rates in both lagoons were < 7.2 kg $NH_3$-N/ha/day. With warm weather (April to September 2004, air temperature > 10 $^oC$), a significant (t-test, $P < 0.01$) ten-fold difference was observed in $NH_3$-N emission rates between treated lagoon 1 (6.3 $NH_3$-N/ha/d) and traditional lagoon 2 (62.8 $NH_3$-N/ha/d; Table 5).

Table 5. Mean ammonia emissions and weather conditions during cold and warm weather for converted lagoon 1 (treated) and traditional lagoon 2 (control), Duplin Co., NC.

| Lagoon | Treated | Emission Rate | Mean Daily Temp Water | Mean Daily Temp Air | Mean Relative Humidity | Mean Wind Speed |
|---|---|---|---|---|---|---|
| | | kg $NH_3$-N/ha/d | $^oC$ | $^oC$ | % | m/s |
| Cold Weather [1] | | | | | | |
| 1 | Y | 2.4 (1.5) | 11.8 (3.6) | 6.6 (1.3) | 65.8 (9.5) | 2.1 (1.3) |
| 2 | N | 7.2 (5.3) | 12.1 (3.9) | 6.2 (1.5) | 66.5 (10.2) | 1.8 (0.5) |
| *t*-test | | NS[3] | NS | NS | NS | NS |
| Warm Weather [2] | | | | | | |
| 1 | Y | 6.3 (5.6) | 27.0 (1.9) | 23.6 (2.1) | 77.4 (7.0) | 1.3 (0.3) |
| 2 | N | 62.8 (10.8) | 27.1 (2.7) | 23.6 (2.4) | 79.3 (6.6) | 0.5 (0.1) |
| *t*-test | | 0.0001 | NS | NS | NS | 0.001 |

[1] Means (standard deviation) of February, March and November 2004, air temperature < 10$^o$C (n = 4)
[2] Means (standard deviation) of April to September 2004, air temperature > 10$^o$C (n = 5)
[3] Non-significant differences = NS (P > 0.01).

In addition to TAN concentration, air temperature and pH of liquid manure are two of the most important factors that influence $NH_3$ emissions (Sommer, 1997). Since pH of the liquid did not significantly change in the lagoons studied, $NH_3$-N emission rates were poorly correlated to pH ($R^2$ = 0.03). To analyze the effect of temperature on $NH_3$-N emission rates, pooling all data from both lagoons was meaningless and provided poor understanding of cause-effect. This is because water quality, in particular TAN concentration, was markedly different between lagoons (Table 4). A better understanding of temperature-$NH_3$ emission cause-effect is obtained when data for both lagoons is plotted separately (Figure 2). There was a significant relationship ($R^2$ = 0.97, n = 9, P < 0.01) between $NH_3$-N emission rates and air temperature for traditional lagoon 2. Ammonia emission rates were not related to air temperature in lagoon 1 because TAN concentration was uniformly low. Same trend was obtained when air temperature was replaced with water temperature as the independent variable (Figure 3).

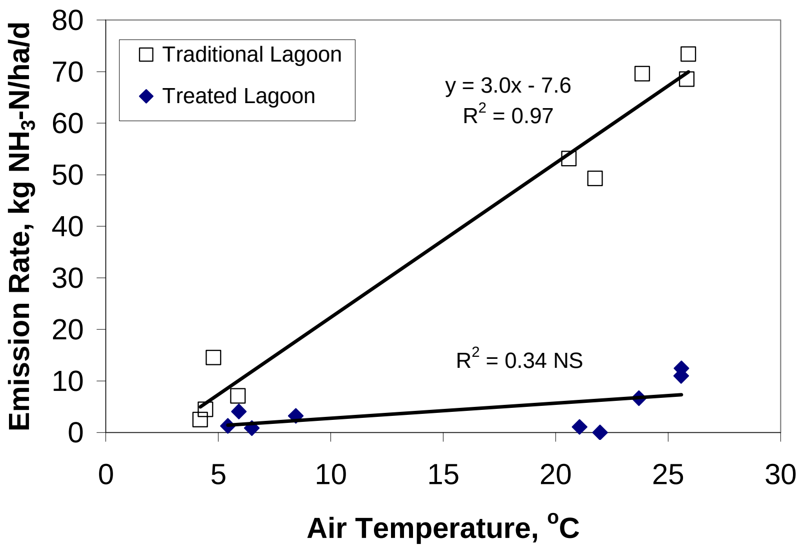


Figure 2. Air temperature effect on ammonia emission rates. NS = non significant air temperature effect.

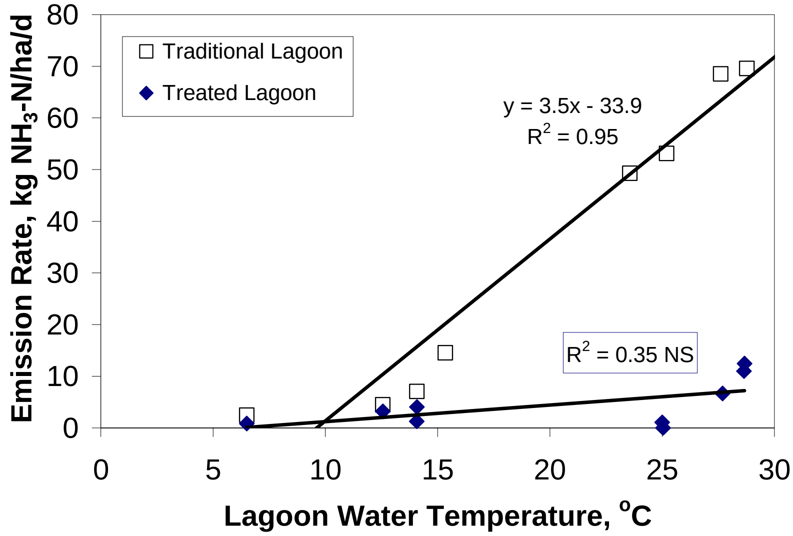


Figure 3. Lagoon water temperature effect on ammonia emissions. NS = non significant water temperature effect.

Free Ammonia Effect

Although wind speed and TAN are additional factors known to influence $NH_3$–N losses from anaerobic lagoons, our study showed that wind speed and TAN poorly explained the variation of $NH_3$ emissions. For example, wind speed had a modest inverse correlation with $NH_3$-N emission rates ($R^2$ = 0.38, y = 48.5 – 19.6x, n = 18, P < 0.01), and TAN alone did not correlate with $NH_3$–N emission rates ($R^2$ = 0.22; Figure 4). Nevertheless, we found that $NH_3$-N losses had a significant response to increasing free-ammonia (FA) levels in lagoon liquid. Concentration of FA in lagoon liquid explained 90% of the variation in $NH_3$-N emissions observed in the study ($R^2$ = 0.90, y = 1.7x + 0.82, P < 0.01; figure 5). Free ammonia accounted for the joint effect of TAN, pH, and temperature (Anthonisen et al., 1976) and constituted the pool of ammoniacal N readily available to loss by volatilization.

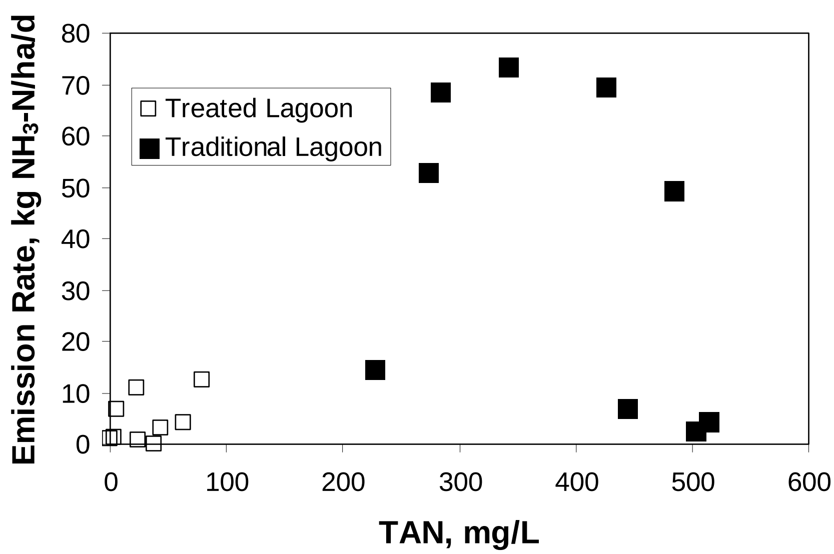


Figure 4. Total ammoniacal N (TAN) concentrations effect on ammonia emission rates using combined data from both lagoons (NS = non significant regression coefficient).

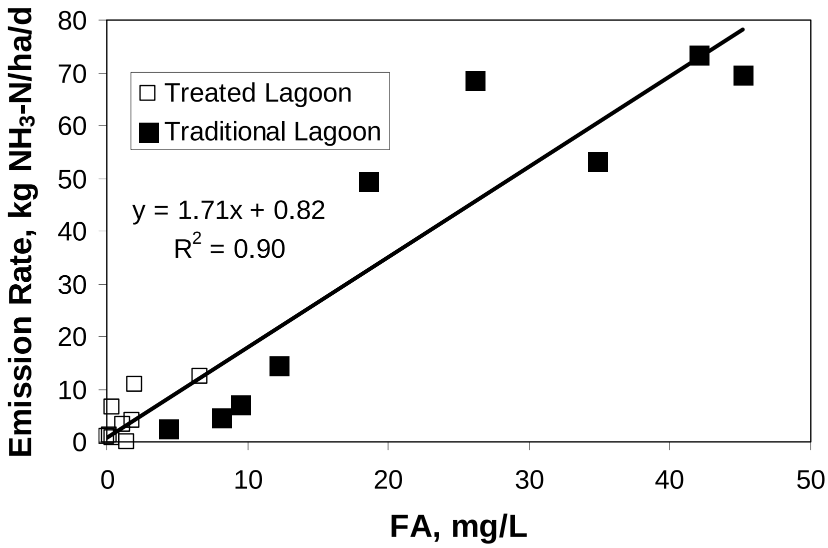


Figure 5. Free ammonia (FA) concentrations effect on ammonia emission rates using combined data from both lagoons. FA calculated according to Anthonisen et al. (1976).

Reduction of Ammonia Emissions

Total annual $NH_3$ emissions in both lagoon 1 and lagoon 2 were calculated by fitting a Gaussian distribution to measured daily $NH_3$ emission values. The total annual $NH_3$ emission for each lagoon is represented by the area under the curves in Figure 6. On an annual basis (year 2004), $NH_3$ emissions from the traditional lagoon totaled 13,600 kg N/ha compared to 1,300 kg N/ha for the treated lagoon. Compared with traditional lagoon 2, annual $NH_3$ emissions from the treated lagoon 1 were reduced 90%.

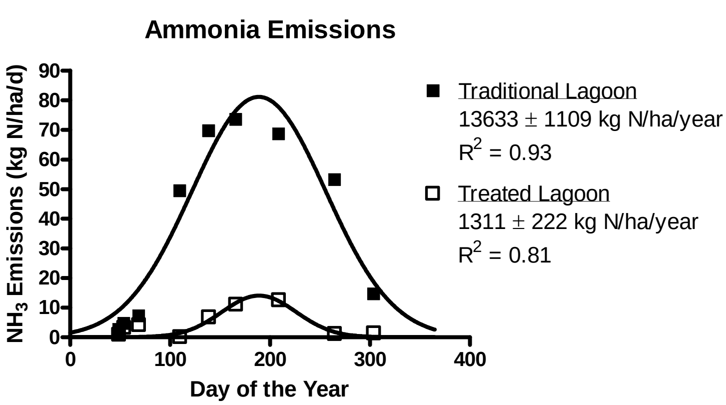


Figure 6. Reduction in ammonia emissions with new on-farm wastewater treatment system. Data shows 2004 $NH_3$ emission from lagoon 1 (treated) and lagoon 2 (traditional).

## CONCLUSIONS

There is a need for treatment technologies that can effectively address environmental concerns associated with anaerobic lagoons. In particular, reduction of $NH_3$-N emissions is a major environmental concern associated with confined swine production. In order to meet this need, a full-scale wastewater treatment plant was demonstrated at full-scale in one of two 4,360-pig production units on a finishing farm in Duplin Co., NC. The second unit was kept as a control using traditional anaerobic lagoon treatment. Once the treatment plant was operational, flow of raw manure into the corresponding lagoon was discontinued and the lagoon was converted to a treated water storage pond. This conversion substantially reduced $NH_3$ emissions. Collectively our findings indicate:

- Lower N concentrations in the converted lagoon substantially reduced annual $NH_3$ emissions by 90% with respect to those found in the traditional anaerobic lagoon.
- Ammonia-N losses were greatly influenced by temperatures. During cold weather, emissions in both lagoons were below 7 kg $NH_3$-N/ha/day. However, during warm weather, there was a significant ten-fold difference in mean daily $NH_3$–N emissions between the treated lagoon 1 (6.2 $NH_3$-N/ha/d) and traditional lagoon 2 (62.8 $NH_3$-N/ha/d).
- Free ammonia concentrations in lagoon liquid was a better indicator of $NH_3$ emissions than TAN concentrations and explained 90% of the variation in $NH_3$-N losses from both lagoons ($R^2$ = 0.90).
- The potential environmental benefits of using new wastewater technologies that produce clean water can accelerate lagoon clean up and substantially reduce ammonia emissions from lagoons.

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