Reduction of Ammonia Emissions from Swine Lagoons Using Alternative Wastewater Treatment Technologies

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Abstract

There is a need for treatment technologies that can effectively address environmental concerns associated with ammonia (NH_3) emissions from anaerobic lagoons, typically used to manage manure. T*o* meet this need, we conducted a study to determine the effects of water quality improvement in swine lagoons on NH_3 emission rates using alternative wastewater treatments. This determination was done in three contiguous swine production units that had similar animal production management and lagoons with similar surface area (about 0.9 ha each), but their waste management was substantially different. In the first production unit, a full-scale wastewater treatment plant produced a clean effluent that in turn converted the old lagoon into a water storage pond. In the second production unit, the traditional anaerobic lagoon treatment method was maintained as a control. In the third production unit, raw flushed manure was treated through a solid-liquid separation system before anaerobic lagoon storage. Passive flux samplers were used to measure simultaneously the NH_3 gas fluxes from the lagoons receiving treated water and the traditional anaerobic lagoon. Ammonia emissions from the traditional anaerobic lagoon (control) totaled 12,540 kg N/lagoon/year (13,633 kg N/ha/year). This result compares to lower NH_3 emissions of 3,355 kg N/lagoon/yr (or 3,647 kg N/ha/yr) from the anaerobic lagoon with solid-liquid separation and 1,210 kg N/lagoon/yr (or 1,311 kg N/ha/yr) from the converted lagoon. In the anaerobic lagoon with solid-liquid separation, total annual NH_3 emissions were reduced by 73% with respect to those of the traditional lagoon. In the converted lagoon, remarkable water quality improvements such as lower N concentrations substantially reduced annual NH_3 emissions by 90% with respect to those found in the traditional anaerobic lagoon. These results overall demonstrate that alternative new wastewater technologies can substantially reduce ammonia emissions from confined swine production.

Introduction

Anaerobic lagoons are widely used to treat and store liquid manure from confined swine production operations. During lagoon storage and treatment, urea and other organic nitrogen (N) compounds contained in liquid manure are converted into ammoniacal N that can be released as ammonia gas (NH_3) into the atmosphere. Increase of NH_3 emissions due to intensification of animal production on a local scale has been related to increasing atmospheric NH_3 deposition and air pollution in North Carolina's Coastal Plain region (Battye et al., 2003; Walker et al., 2000). Because of these environmental concerns, there is major interest in new swine manure treatment technologies that can reduce environmental problems associated with NH_3 emissions from anaerobic lagoons (Williams, 2001).

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). 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 lower N levels in lagoons will substantially reduce NH_3 emissions compared with a traditional anaerobic lagoon. The purpose of this research was to quantify the magnitude of NH_3 emissions reduction in two lagoons that received treated water from two new alternative wastewater treatment systems. One treatment system combined solid-liquid separation with removal of N and phosphorus (P) from the liquid phase (Vanotti et al., 2005) and the other wastewater treatment system consisted of solid-liquid separation treatment before anaerobic lagoon storage. Emissions from the two lagoons receiving treated water were compared with NH_3 emissions from a traditional treatment anaerobic lagoon; all three lagoons had similar construction design and animal production management.

Materials and Methods

The study was conducted on Goshen Ridge Farm near Mount Olive, Duplin County, North Carolina. The farm had three finishing units under identical animal production and waste treatment managements. 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. Lagoon effluent was then used to recharge the pits of each production unit. 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 (Szogi et al., 2006).

Table 1. Main characteristics of the three 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
3	0.93	22,236	229,425

In unit 1, a full-scale wastewater treatment system was started in 2003 to treat all raw manure produced. The treatment system combined solid-liquid separation with removal of N and P from the liquid phase. The system treated raw manure flushed from the barns in three steps (Vanotti et al., 2006). The first step flocculated solids from raw flushed manure using polyacrylamide. This step produced separated solids that were transported off-site and converted to organic plant fertilizer, soil amendments, or energy at a centralized facility. In the second step, N 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 P module precipitated calcium phosphate and killed pathogens. The treated water was recycled to refill the barn pit recharge system, and excess water 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 cleaner water, it converted the anaerobic lagoon in unit 1 into a treated water pond (hereafter called lagoon 1 or converted lagoon). Unit 2 remained with the traditional anaerobic lagoon treatment and was used as a control (hereafter called lagoon 2 or traditional lagoon).

In unit 3, a full-scale solid-liquid separation system was started in 2004 to treat all raw manure produced. The system treated raw manure flushed from the barns using solid-liquid separation (one step). The manure was reacted with flocculant polymer (polyacrylamide) and separated with a self cleaning rotating screen (0.25-mm opening). Subsequently, a small filter press dewatered the manure solids. The separated liquid was stored in lagoon 3 (hereafter called lagoon 3 or anaerobic lagoon with solid separation) and later used to refill the barn pit recharge system. Separated solids generated in unit 3 were also transported off-site and processed into value-added products.

During 2004, NH_3 emissions were measured in all three lagoons. 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 each lagoon. This layout enclosed most of the lagoon surface within a circular sampling plot (figure 1). Nine data collection periods lasting 23 h each were scheduled from February to November 2004 for the three lagoons. Further details on NH_3 emission measurements using the passive flux method are described in Szogi et al. (2006).

Even though waste treatment in all three production units was substantially different, animal production management remained the same during the study. Total annual NH_3 emissions were obtained by fitting a Gaussian curve to daily NH_3-N emission data versus day of the year using Prism 4.0 software (GraphPad Software, Inc., San Diego, CA). All water analyses were performed according to Standard Methods for the Examination of Water and Wastewater (APHA, 1998).

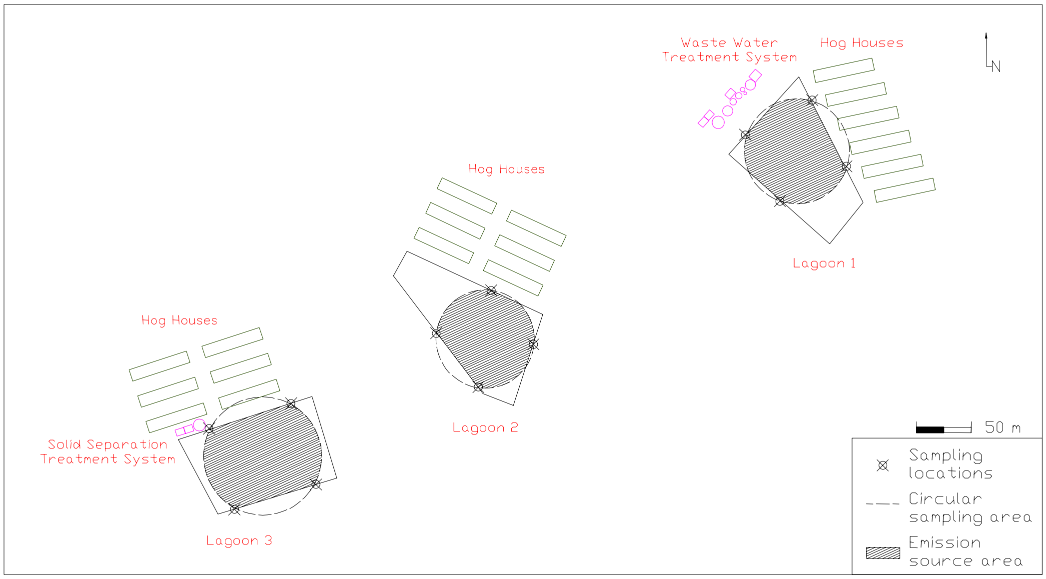

Figure 1. Schematic diagram of monitoring set-up for ammonia emission study for converted lagoon 1, traditional lagoon 2, and traditional lagoon 3 with solids separation, Duplin Co, NC.

Results and Discussion

Lagoon Water Quality

Monitoring of water quality was initiated in 2002, one year before the wastewater treatment plant started to operate in unit 1. The criterion to determine water quality improvement was the reduction in concentration of various water quality indicators (table 2). In 2002, the three lagoons were receiving flushed manure from the barns. Thus, the three anaerobic lagoons had similar annual mean pH, total ammoniacal N (TAN), total Kjeldahl N (TKN), and nitrate plus nitrate (NO_2+NO_3-N) concentrations (Jan.-Dec. 2002; table 2).

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 anaerobic lagoon liquid, while water quality in lagoons 2 and 3 remained mostly unchanged. Annual (2003) average TAN and TKN levels in lagoon 1 declined 58% and 56%, respectively, with respect to lagoon 2 (control). In 2004, differences in TAN and TKN concentrations in lagoon 1 were even larger than in 2003; TAN declined 90% and TKN 81% with respect to lagoon 2 (table 2). In lagoon 1, the transition from anaerobic to aerobic water storage was noticeable in the first year of treatment. Dissolved oxygen (DO) concentrations in fall 2003 and winter 2004 (Oct. 2003 to March 2004, n = 5) at 0.15 m below the liquid surface averaged 3.5 mg/L in lagoon 1 and 0.5 mg/L in lagoon 2 (Szogi et al., 2006).

During 2004, the modular solid-liquid separation system in unit 3 separated > 90% of the manure solids but produced modest improvements on TAN and TKN levels in lagoon 3 (table 2). However, differences in average total solids (TS) content levels in lagoon 3 were 20% lower than lagoon 2 (control) and comparable to lagoon 1 as a result of solids removal (table 2).

Table 2. Change in water quality in three consecutive years for lagoon 1 before and after treatment plant was operational, lagoon 2 (control), and lagoon 3 before and after solids separation treatment, Goshen Farm, Duplin Co., NC[1].

Sampling Period	Lagoon	Treated	pH	TAN[2] (mg/L)	TKN (mg/L)	$NO_2 + NO_3$ (mg/L)	TS (g/L)
Jan.-Dec. 2002	1	N	8.0 (0.1)	464 (98)	506 (108)	0.08 (0.20)	4.2 (1.6)
	2	N	8.0 (0.2)	467 (118)	521 (122)	0.07 (0.21)	3.5 (0.9)
	3	N	8.0 (0.2)	469 (121)	517 (115)	0.07 (0.18)	3.6 (0.8)
Jan.-Dec. 2003	1	Y	8.1 (0.1)	186 (129)	230 (138)	4.1 (5.8)	2.7 (0.5)
	2	N	7.9 (0.1)	446 (102)	522 (127)	0.43 (1.4)	3.2 (0.7)
	3	N	7.9 (0.1)	375 (124)	439 (140)	0.41 (1.4)	2.8 (0.4)
Jan.-Dec. 2004	1	Y	8.1 (0.3)	37 (32)	76 (34)	20 (16)	2.3 (0.2)
	2	N	8.0 (0.2)	364 (88)	406 (79)	n.d.[3]	2.9 (0.2)
	3	Y	8.1 (0.2)	344 (141)	391 (140)	n.d.	2.3 (0.4)

[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; TSS = Total suspended solids.
[3] n.d. = not detected.

Reduction of Ammonia Emissions

Total annual NH_3 emissions in lagoons 1, 2 and 3 were calculated by fitting a Gaussian distribution to measured daily NH_3 emission values (figure 2). This curve was selected because it provided a good fit to the changes in daily NH_3 emissions throughout the year both in terms of R^2 and normality of residuals (residuals = emissions observed - emissions predicted) using the Shapiro-Wilk test statistic (Delong and Yuan, 1988). The total annual NH_3 emission for each lagoon is represented by the area under the curves in figure 2. On an annual basis, NH_3 emissions from the traditional lagoon (control) totaled 12,540 kg N/lagoon/yr (or 13,633 kg N/ha/yr) compared to 3,355 kg N/lagoon/yr (or 3,647 kg N/ha/yr) from the anaerobic lagoon 3 with solid separation treatment. Although water quality changes were modest in lagoon 3 with respect to the control (TAN, TKN and TS, Jan. – Dec. 2004, table 2), total annual NH_3 emissions reduction in lagoon 3 was 73% with respect to traditional lagoon 2. These results indicated that NH_3 emission reduction was more sensitive than the water quality to effect of the solid removal treatment. For the converted lagoon 1, reduction on annual NH_3 emissions was even larger with respect to traditional lagoon 2. Annually, NH_3 emissions from the converted lagoon totaled 1210 kg/lagoon/yr (or 1,311 kg N/ha/yr) compared to 12,540 kg N/lagoon/yr of the traditional lagoon. Lower N concentrations in the converted lagoon (lagoon 1, Jan.–Dec. 2004, table 2) substantially reduced annual NH_3 emissions by 90% with respect to those found in the traditional anaerobic lagoon. These results overall demonstrate that use of new wastewater technologies can substantially reduce ammonia emissions from confined swine production.

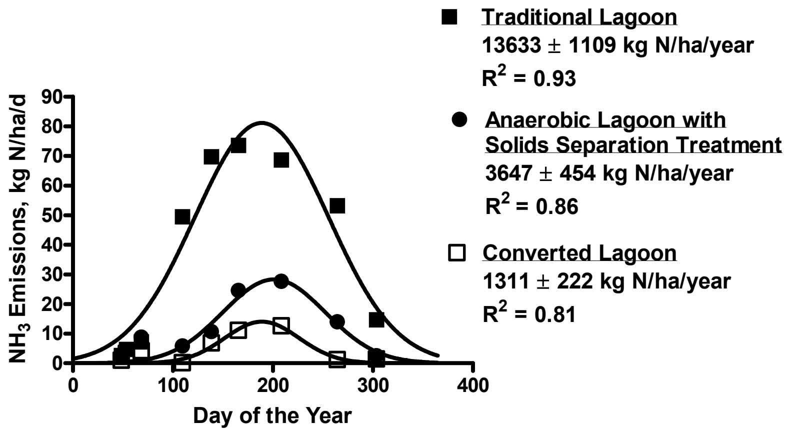

Figure 2. Change in daily rate of ammonia emissions throughout the year for the traditional lagoon, anaerobic lagoon with solids separation, and converted lagoon. The total annual ammonia (NH_3) emission for each lagoon system is represented by the area under each curve and indicated in the legend.

Conclusions

There is a need for treatment technologies that can effectively address environmental concerns associated with anaerobic lagoons. In particular, reduction of NH_3 emissions is a major environmental concern associated with confined swine production. In order to meet this need, two new wastewater treatment systems were demonstrated at full-scale in two of three 4,360-pig production units on a finishing farm in Duplin Co., NC. One treatment system combined solid-liquid separation with removal of N and P from the liquid phase, and the other wastewater treatment system consisted of solid-liquid separation before anaerobic lagoon storage. The third production unit was kept as a control using traditional anaerobic lagoon treatment.

In summary our findings indicate:

1) Ammonia emissions from the traditional anaerobic lagoon totaled 12,540 kg N/lagoon/year (13,633 kg N/ha/year). This result compares to lower NH_3 emissions of 3,355 kg N/lagoon/yr (or 3,647 kg N/ha/yr) from the anaerobic lagoon with solid-liquid separation, and 1,210 kg N/lagoon/yr (or 1,311 kg N/ha/yr) from the converted lagoon.
2) Although water quality improvements were modest in anaerobic lagoon with solid-liquid separation, total annual NH_3 emissions were reduced by 73% with respect to those of the traditional lagoon
3) Remarkable water quality improvements such as 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.

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