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An ASABE Meeting Presentation

Paper Number: 1008946

Sludge Reduction and Water Quality Improvement in Anaerobic Lagoons through Influent Pre-Treatment

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Written for presentation at the
2010 ASABE Annual International Meeting
Sponsored by ASABE
David L. Lawrence Convention Center
Pittsburgh, Pennsylvania
June 20 – June 23, 2010

Abstract. *Confined swine production generates large volumes of wastewater typically stored and treated in anaerobic lagoons. These lagoons may require cleanup and closure measures in the future. In practice, liquid and sludge need to be removed by pumping, usually at great expense of energy, and land applied at agronomic rates on adjacent fields without damage to ground or surface water. Alternative lagoon cleanup methods were investigated in a pilot lagoon study by pre-treating the liquid swine manure prior entering the lagoon. The study consisted of comparing side by side the effect of solid-liquid separated effluent and a new advanced system (solid-liquid separation followed by biological N treatment) on water quality improvement and sludge mass reduction. As a control, an anaerobic lagoon regularly loaded with raw manure was included in the study. Lagoon liquid was monitored for water quality improvements on a monthly basis. After 15 months, water quality improvements with respect to the anaerobic lagoon control (such as reduction of suspended solids, chemical oxygen demand and N concentration) were moderate with separated liquid but highly significant with the biological N pre-treatment. Anaerobic sludge mass reduction with respect to the control was significant for both pre-treatments; sludge mass reduction was 34% with separated liquid alone and 45% with biological N pre-treatment. Implementation of this technology could resolve the problems of excess sludge distribution during lagoon clean up or extend lagoon life.*

Keywords. Lagoons, Swine manure treatment, Solid-liquid separation, Nitrification/denitrification, Closure, Lagoon sludge, Solids.

Introduction

Confined swine production generates large volumes of wastewater typically stored and treated in anaerobic lagoons. Closure of these structures is a major environmental issue from both environmental and human health concerns due to disposal of excess nutrients, pathogens, and closure procedure (Henry and Reimers, 2000). Specific procedures for the closure of treatment anaerobic lagoons in an environmentally safe manner include the following three options: (1) complete closure and fill; (2) breach the anaerobic lagoon berm; and (3) conversion to a farm pond (Jones et al., 2006; NRCS, 2002). In all three options, liquid and sludge need to be removed by pumping, and land applied. However, implementation of alternative technologies for recycling and recovery of nutrients from anaerobic lagoons would resolve the lagoon closure problems of excess byproduct (sludge) distribution when land is limiting.

Major public interest in reducing the environmental impact of confined swine production in North Carolina promoted a government industry framework for the development of best manure management technologies that could replace anaerobic lagoons. As a consequence, the State of North Carolina enacted Senate Bill 1465 in 2007 that made permanent the anaerobic lagoon moratorium and established five environmental performance standards of environmental superior technologies (EST) as a requirement for the construction of new swine farms or expansion of existing swine farms in North Carolina (NC General Assembly, 2007). An EST needs to be able to meet the following environmental standards:1. Eliminates the discharge of animal waste to surface waters and groundwater through direct discharge, seepage, or runoff; 2. Substantially eliminates atmospheric emissions of ammonia; 3. Substantially eliminates the emission of odor that is detectable beyond the boundaries of the parcel or tract of land on which the swine farm is located; 4. Substantially eliminates the release of disease-transmitting vectors and airborne pathogens; and 5. Substantially eliminates nutrient and heavy metal contamination of soil and groundwater (Williams, 2009). In addition, the NC legislation established a Lagoon Conversion Program that provides financial incentives to assist producers in the conversion of anaerobic swine lagoons to EST.

A new on-farm wastewater treatment technology was evaluated to replace anaerobic swine lagoons that met North Carolina State's EST. This technology consisted of solid-liquid separation with polyacrylamide (PAM), nitrification-denitrification, and soluble phosphorus removal (Vanotti et al., 2006). Szogi et al. (2006) evaluated annual NH_3 emissions reduction from a treatment lagoon serving 4,360 finishing swine that was replaced with this new on-farm technology. They found that this combination of treatment technologies (solid-liquid separation followed biological N treatment) tackled both the organic N and the soluble ammonia N and reduced annual NH_3 emissions from the lagoon by 90% with respect to typical anaerobic lagoons. A full scale evaluation of a second generation of this new wastewater treatment system demonstrated that anaerobic lagoons can be economically converted to storage ponds (Vanotti et al., 2009).

A second alternative strategy that could reduce the accumulation of sludge is continuous solid-liquid separation prior lagoon treatment. Traditionally, solid-liquid separation has been used as a method to reduce lagoon solids buildup by separating solids from raw or flushed manure prior to lagoon input (Barker, 1996). Solid-liquid separation methods include physical processes such as sedimentation, centrifuging, screening, or filtering (Day and Funk, 2002). Usually, solid-liquid separation efficiencies of manure separators are in the range of about 20% to 68% removal (Chastain et al., 2001; Westerman and Arogo, 2005). However, solid-liquid separation combined with flocculation using PAM has been reported to separate 85% to 88% of organic N from the liquid phase (Vanotti et al., 2002). Although polymer-enhanced solid-liquid separation alone has been found to significantly reduce solids and ammonia emissions from anaerobic lagoons (Szogi and Vanotti, 2007), sludge reduction in lagoons storing separated liquid still needs to be evaluated. Therefore, our objective was to compare side by side in a replicated experiment the effect of separated liquid alone and the new wastewater system (solid-liquid separation followed by biological N) on water quality improvement and sludge reduction of converted lagoons. As a control, an anaerobic lagoon regularly loaded with liquid raw manure was included in the study.

Materials and Methods

Pilot Lagoon Study

A pilot lagoon study to convert anaerobic lagoons into storage farm ponds was performed during 15 months (Feb. 2007 – May 2008) using effluents from an adjacent full-scale second generation wastewater treatment plant described by Vanotti et al. (2009). The pilot lagoons consisted of six vessels (0.15 m o.d. x 2.1 m length) made of clear polyvinyl chloride (PVC) pipe. Each vessel had a volume of 37 L that contained sludge plus lagoon liquid. At the beginning of the experiment, each vessel was filled with 14 L of anaerobic lagoon sludge and 23 L of lagoon liquid (table 1).

Table 1. Composition of lagoon sludge and liquid at the beginning of the pilot lagoon study.

Constituent [a]	Sludge	Liquid
pH	7.69	8.15
EC	6.9	6.12
Alkalinity	66,657	2,434
TS	44,180	3,720
TSS	40,900	240
COD	44,250	836
TKN	1,644	316
TP	1,406	40

[a]EC=Electrical conductivity TS=Total solids; TSS=Total suspended solids; COD=Chemical oxygen Demand; TKN=Total Kjeldahl N; TP=Total phosphorus. Constituent expressed in mg L^{-1}, except pH and EC (mS/cm).

Table 2. Mean chemical composition of liquids prior to lagoon input (after Vanotti et al., 2009).

Constituent [a]	Raw Manure	After Solid-Liquid Separation	After Biological N
pH	7.85	7.81	7.96
EC	14.6	13.7	6.9
Alkalinity	6,882	5,372	1,288
TS	28,888	13,815	9,520
TSS	11,113	1,212	219
COD	20,666	7,885	997
TKN	2,007	1,414	121
TAN	1,251	1,190	103
NO_3-N	1	0	229
TP	494	170	85
SP	86	79	73

[a]EC=Electrical conductivity TS=Total solids; TSS=Total suspended solids; COD=Chemical oxygen Demand; TKN=Total Kjeldahl N; TP=Total phosphorus. Constituent expressed in mg L^{-1}, except pH and EC (mS/cm).

Once the six vessels were filled with lagoon sludge and liquid, they received the following three treatments in duplicate: 1) liquid raw manure (control), 2) liquid from a flocculant-enhanced solid-liquid separation module (separated liquid pre-treatment); 3) liquid from solid-liquid separation followed by nitrification/denitrification (biological N pre-treatment). The hydraulic retention time (HRT) of the pilot lagoons was about 180 d. This HRT was determined by taking 0.42-L samples of lagoon supernatant (top 0.6 m below liquid level) every week and replacing the same volume with the corresponding liquid treatment (Table 2).

The temperature of lagoon liquid was measured at about 0.50-m depth and stored in a StowAway TidbiT data logger (Onset Computer Corp., Bourne, MA). Weekly temperature averages were computed from hourly water temperature records.

At the end of the 15-month study, the sludge from each one of the pilot lagoons was recovered after removing the supernatant liquid, placed in plastic containers and transported to the laboratory for chemical analysis. The total mass and volume of sludge were used to determine the total mass of each constituent (alkalinity, TS, TSS, COD, TKN, TAN, TP, and SP) accumulated at the end of the 15-month study.

Analytical Methods

Wastewater analyses were performed according Standard Methods for Examination of Water Wastewater (APHA, 1998). All water quality and sludge analyses were performed according to Standard Methods for the Examination of Water and Wastewater (APHA, 1998). The pH was determined electrometrically (Standard Method 4500-H+ B), and EC was determined by Standard Method 2510 B. Alkalinity was determined by acid titration to the bromocresol green endpoint (pH 4.5) and expressed as mg CaCO3 L̃1 (Standard Method 2320 B). Total solids (TS) and total suspended solids (TSS) were determined according to Standard Method 2540 B and D, respectively. The TSS were that portion of TS retained on a 1.5-μm glass micro fiber filter (Whatman grade 934-AH; Whatman, Inc., Clifton, NJ) after filtration and drying to constant weight at 105°C. Chemical analyses consisted of chemical oxygen demand (COD), total ammoniacal nitrogen (TAN), nitrate plus nitrite (NO_3–N), total Kjeldahl N (TKN), total P (TP), soluble P (SP), pH, and electrical conductivity (EC). For chemical oxygen demand (COD) determination, we used the closed reflux, colorimetric method (Standard Method 5220 D). The soluble P (SP) fraction was determined by the automated ascorbic acid method (Standard Method 4500-P F) after filtration through a 0.45-μm membrane filter (Gelman type Supor-450; Pall Corp., Ann Arbor, MI). The same filtrate was used to measure TAN by the automated phenate method (Standard Method 4500-NH3 G) and NO_3–N by the automated cadmium reduction method (Standard Method 4500-NO3̃ F). Total P and TKN were determined using acid digestion and the automated ascorbic acid and phenate methods adapted to digested extracts (Technicon Instruments Corp., 1977).

Statistical Analysis

Experimental design was a randomized complete block (RCB) with two replications. Water quality and sludge data were analyzed using the ANOVA procedure of SAS (SAS Institute, Cary, NC). Means were compared using the least square difference (LSD) option, and means were considered different when the probability t values were < 0.05.

Results and Discussion

Water Quality

Results on water quality at the end of the 15-month study conducted to evaluate the conversion of lagoons versus the anaerobic lagoon control are presented in Table 1. The criterion to determine water quality improvement was the reduction in concentration of selected water quality indicators. Differences in TS mean levels between the control lagoon and the two conversion lagoon methods were statistically not significant ($P > 0.05$, table 3). However, differences in mean levels EC, TSS, COD, TKN, TAN, and NO_3-N were significant with respect to the control and between the two converted lagoons ($P < 0.05$, table 3). These differences were consistent with a moderate improvement in water quality in lagoons with solid-liquid separation alone versus the remarkable improvement in water quality in lagoons with biological N treatment. For instance, as a result of solids removal TSS and COD levels were reduced 53% and 40% for the separated liquid treatment, respectively, when compared to the control. Reduction in TSS and COD were even higher for the lagoons converted using biological N treatment; an 80% TSS and 72% COD concentration reduction with respect to the control was measured at the end of the 15-month pilot study (table 3).

Considerable variability in water quality parameter concentrations occur in anaerobic lagoons. For instance, C and N concentration in lagoon liquid shows seasonal variations (Bicudo et al., 1999), usually increasing in winter with the highest concentration at the beginning of spring (April) and decreasing in summer with the lowest at the beginning of fall (October). Westerman et al. (2006) indicate that this fluctuation of N concentration in lagoons is due to the effect of temperature on both microbial activity and NH_3 volatilization increase during warm weather. In our study, we found similar seasonal trends in the control and liquid separation treated lagoons for TAN, TKN, TSS, and COD concentrations, all of which decreased during warm weather (figs. 1 and 2). Perhaps more important to note is the rate of seasonal change in N concentrations, which was more pronounced in the converted lagoons than in the control lagoon. For example, TAN concentration from April (day 63) to October (day 232) declined 51% in the control lagoon, 60% in the lagoon with solid-liquid separation pre-treatment and 96% in the lagoon with biological N pre-treatment (fig. 1). The quality of the liquid in lagoons with biological N pre-treatment rapidly improved as cleaner effluent from the treatment plant replaced anaerobic lagoon liquid, while water quality in the control lagoon and the solid-liquid treated lagoon increased in TKN, TAN and COD during the winter and fall season after day 232 (fig. 1). At the end of the 15-month study, average TKN and TAN levels in the lagoon with separated liquid-treatment declined 35% and 37%, respectively, with respect to the control. Differences in TAN and TKN concentrations in the converted lagoon with N biological pre-treatment were even larger than the control; on average, TKN declined 97% and TAN declined 99% (table 3). Thus Water quality improvements with respect to the anaerobic lagoon control (such as reduction of TSS, COD TKN and TAN concentrations) were moderate with separated but highly significant with the biological N technology pre-treatment.

In this study, P was removed during manure solid separation in both the separated liquid and the biological N pre-treatments (table 2). At the end of the lagoon conversion study the differences in TP levels were significant for both pre-treatment, but not significant for SP. This result may be related to the reduction in solids entering the two converted lagoon and dissolution of P from the lagoon sludge.

Table 3. Mean chemical composition of the lagoon liquid in the control (raw manure) and the two treatments for lagoon conversion at the end of the 15-month pilot study.

Constituent[a]	Lagoon Conversion Treatment		
	Raw Manure (Control)	Separated Liquid	Biological N
pH	8.01a[b]	8.23a	8.41b
EC	9.59a	8.06b	6.14c
Alkalinity	3,522a	2,725b	1,584c
TS	10,233a	9,398a	8,204a
TSS	480a	223b	100c
COD	1,953a	1,204b	552c
TKN	603a	389b	13c
TAN	468a	293b	0.0c
NO_3-N	10.5a	4.7b	0.0c
TP	83a	58b	60b
SP	64a	66a	59a

[a]EC=Electrical conductivity TS=Total solids; TSS=Total suspended solids; COD=Chemical oxygen Demand; TKN=Total Kjeldahl N; TP=Total phosphorus. Constituent expressed in mg L^{-1}, except pH and EC (mS/cm). [b] Means followed by the same letter are not significantly different ($LSD_{0.05}$)

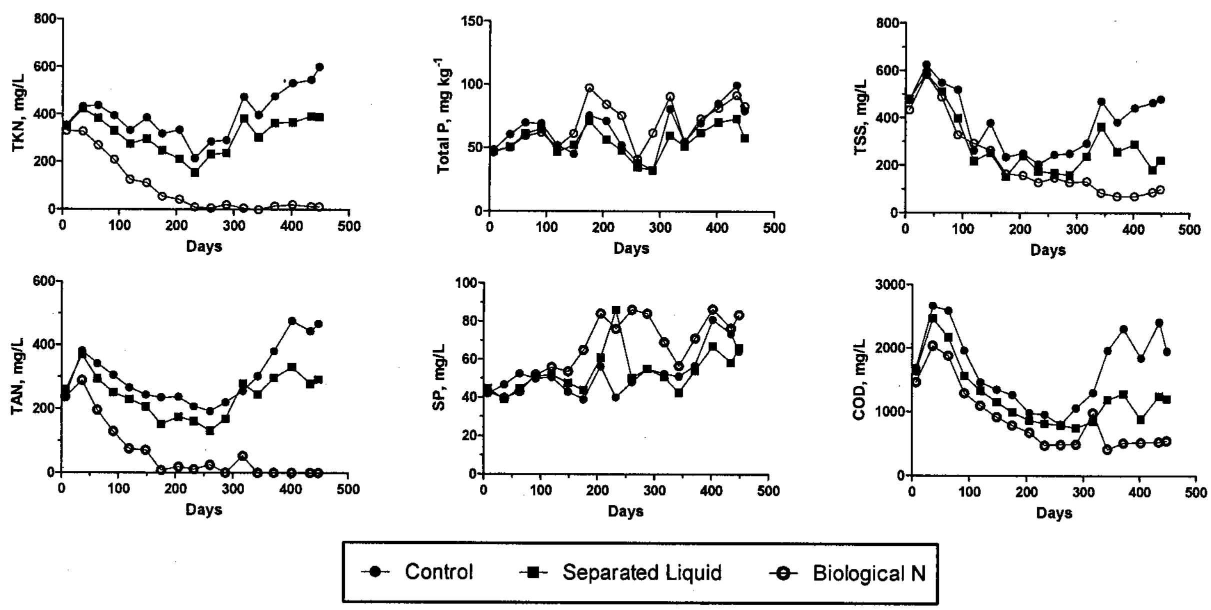

Figure 1. Water quality changes in liquid of pilot lagoons during the 15-month study (Feb. 2007 – May 2008). Each data point is the average of two replicates. The day the pilot study started is Day 1 (Feb.26, 2007).

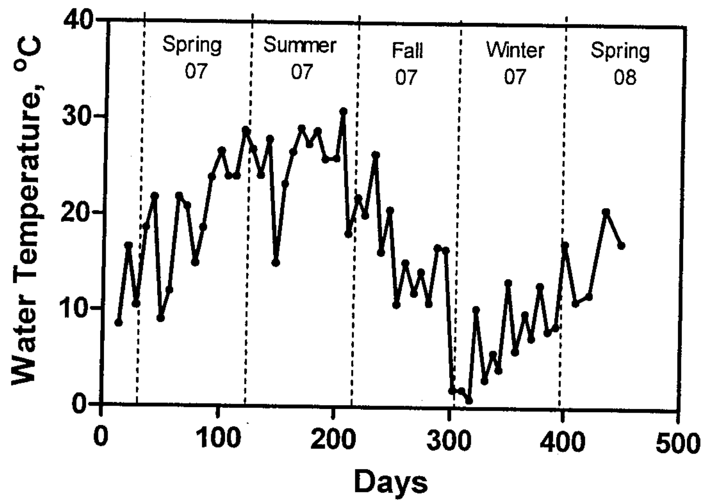

Figure 2. Pilot lagoon liquid temperature during the water quality monitoring period. Data are weekly average of daily temperatures.

Sludge Reduction

According to ANOVA analysis, there were not statistical differences in concentration on any of the chemical parameters of the sludge. However, there was a significant difference between the sludge mass of the control and the treatments at the end of the 15-month study (Table 4). Mass reduction with respect to the control was significant for the two pre-treatments; reductions were 34% and 45% with separated liquid and biological N treatment. The concentration of each component of the sludge was then used to compute their contribution on a mass basis. Except for TP, all sludge parameters showed a significant reduction due to treatment with respect to the control ($P < 0.05$). Although, differences between the two treatments were not significant, the general trend was a greater reduction of all sludge parameters when using biological N pre-treatment, which is consistent with the water quality improvement of the supernatant liquid.

Table 4. Mass of sludge and sludge components on a mass basis at the end of the 15-month pilot study.

	Lagoon Conversion Treatment		
Constituent [a]	Raw Manure (Control)	Separated Liquid	Biological N
Mass	7.18a	4.73b	3.74b
Alkalinity	78.5a	56.3b	41.7b
TS	793a	595ab	459b
TSS	526a	320b	249b
COD	531a	368b	300b
TKN	36a	25b	19b
TAN	0.7a	0.2b	0.2b
TP	17a	14a	11a
SP	4.4a	2.5b	0.8b

[a] TS=Total Solids; TSS=Total suspended solids; COD=Chemical oxygen demand; TKN=Total Kjeldahl N; TAN= Total ammoniacal nitrogen; TP=Total phosphorus; SP=Soluble phosphorus. Except for mass (kg), constituents are expressed in grams. [b] Means followed by the same letter are not significantly different ($LSD_{0.05}$).

Conclusion

Water Quality: Water quality improvements with respect to the anaerobic lagoon control (such as reduction of TSS, COD TKN and TAN concentrations) were moderate with separated but highly significant with the biological N technology pre-treatment.

Sludge Mass Reduction: Mass reduction with respect to the control was significant for the two pre-treatments; reductions were 34% and 45% with separated liquid and biological N treatment.

These findings showed that the combination of solid-liquid separation and biological N treatments can be very effective for rapidly improving water quality and significantly reducing lagoon sludge mass in anaerobic lagoons during the lagoon conversion to storage pond.

Acknowledgements

Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture. This research was part of USDA-ARS National Program 206: Manure and By-Product Utilization; ARS Project 6657-13630-001-00D "Innovative animal manure treatment technologies for enhanced environmental quality." The authors thank Mr. and Mrs. Billy Tyndall for providing their farm for this study. The authors acknowledge Ms. Aprel Ellison and Mr. William Brigman for their assistance in collection of wastewater samples and water quality analyses.

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