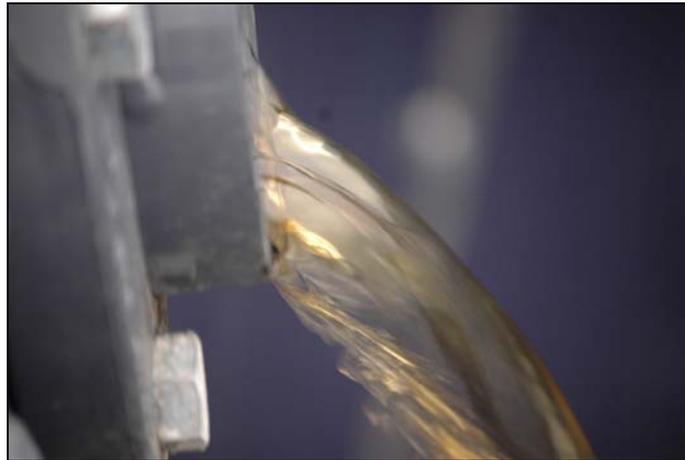


**Evaluation of Environmental Superior Technology Contingent  
Determination – Second Generation Super Soil Technology**

**FINAL REPORT**

**For NC Department of Justice – Office of the Attorney General  
Environmental Enhancement Fund Program**



**Prepared by  
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USDA-ARS**

**Project Title:**

**Evaluation of Environmental Superior Technology Contingent Determination – Second Generation**

**Project Reference:**

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## Executive Summary

Disposal of animal wastes from concentrated animal agriculture poses serious challenges. Currently, implemented technologies for animal waste management have drawbacks including: the odor, pathogens and air pollution; the acreage needed for disposal; and the potential water contamination due to rainfall and flooding. This project evaluates and demonstrates the viability of a second generation manure treatment technology. The technology was developed as an alternative to the lagoon/spray field system typically used to treat the wastewater generated by swine farms in North Carolina. This second generation technology was installed and tested full-scale on a 765,000 lb steady state live weight (SSLW) finishing farm in Sampson County, North Carolina. It separates solids and liquids with the aid of polymer flocculants; it biologically removes the ammonia nitrogen with bacteria adapted to high-strength wastewater; it removes phosphorus via alkali precipitation; and it substantially eliminates release into the environment of odors, pathogens, ammonia and heavy metals. In addition to the technical standards of the first generation, the second generation system was designed to substantially reduce cost and meet economical feasibility. These efforts were consistent with recommendations provided in the Phase I Technology Determination Report to evaluate a lower cost version of the system. Objectives of this report were to provide performance verification to determine if the lower cost second generation technology meets the criteria of Environmentally Superior Technology on the installed system at full-scale and steady-state operational conditions. Specifically, evaluation of technical and operational feasibility and performance standards related to the elimination of discharge of animal waste into waters and the substantial elimination of ammonia emissions, odors, pathogens, and nutrient and heavy metal contamination of soil and groundwater by manure. The treatment plant completed design, permitting, construction, startup, and 6.5 months of operation under steady-state conditions. Major goals in the demonstration and performance verification of the second generation alternative treatment system were achieved. These include highly efficient treatment performance with both varying solid and nutrient loads typical in animal production and cold and warm weather conditions. On a mass basis, the treatment system removed 97.7% of the total suspended solids, 99.6% of BOD, 96.1% of TKN, 97.3% of ammonia, 94.0% of total phosphorus, 99.3% of copper, and 99.2% of zinc. The system not only replaced the anaerobic lagoon treatment but also provided lagoon cleanup. In less than six months, ammonia concentration was halved in the liquid of the replaced anaerobic lagoon. The treatment system removed 99.9% of odor compounds in the liquid. Pathogen indicators were reduced 4 logs and Salmonella in the manure was eliminated. Ammonia concentration in air of the barns was reduced due to the recycle of cleaner, sanitized water to refill barn pits. Animal health and productivity of the animals were enhanced; mortality decreased 57%, daily weight gain increased 11%, and feed conversion improved 5.4% compared to the traditional lagoon management. Based on performance results obtained in this evaluation, it was verified that the more economical second generation treatment system also meets the operational and technical standards of an Environmentally Superior Technology. These results overall show that cleaner alternative technologies can have significant positive impacts on livestock production and the environment.

**Technology Name and Description:** 2<sup>nd</sup> Generation Super Soil Technology

The on-farm system uses solid-liquid separation, biological nitrogen removal, and disinfection and phosphorus removal unit processes linked together into a practical system for livestock operations (Figure 1). The system greatly increases the efficiency of solid-liquid separation with flocculation of the suspended solids using polymer. Nitrogen management to eliminate ammonia emissions is accomplished by passing the liquid through a biological module containing nitrification and denitrification bacteria adapted to high-ammonia wastewater. Subsequent alkaline treatment of the liquid in a phosphorus removal module precipitates phosphate and kills pathogens. The system recycles clean water to flush the barns and simultaneously separates the phosphorus precipitate with the manure. The treated water is stored in the former lagoon, which is cleaned up in about one year. The solids are removed from the farm and used for the manufacture of value-added products and energy production.

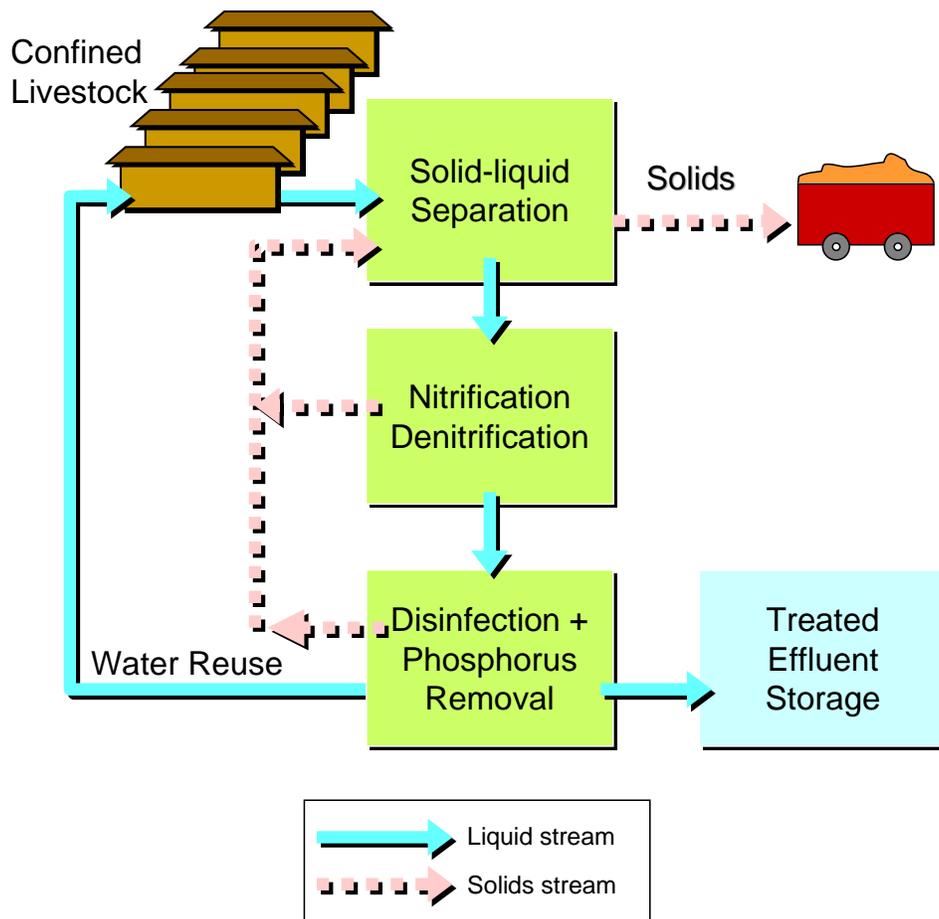


Figure 1. Schematic of the second generation Super Soil technology.

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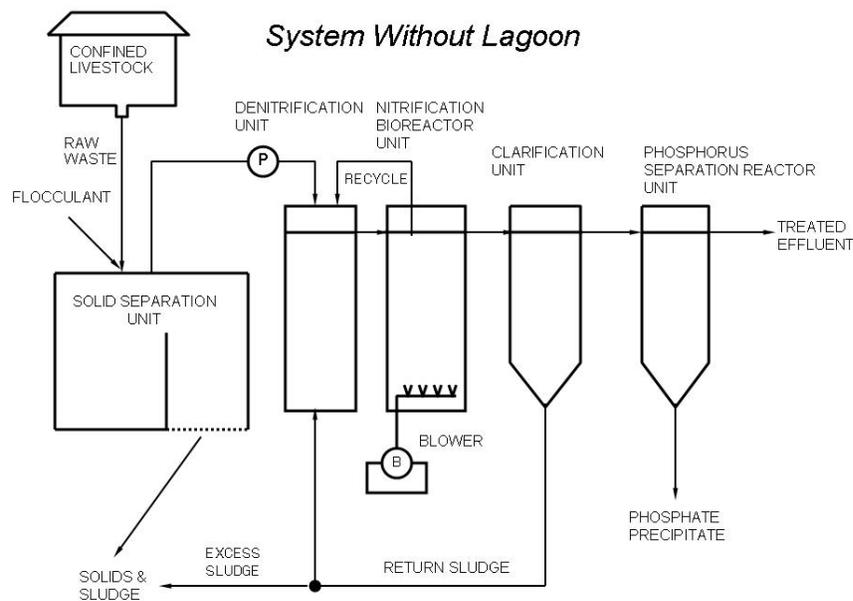
### **Background:**

This project evaluates and demonstrates the viability of a second generation manure treatment technology developed as an alternative to the lagoon/spray field system typically used to treat the wastewater generated by swine farms in North Carolina. It separates solids and liquids with the aid of polymer flocculants; removes the ammonia nitrogen biologically with acclimated bacteria; removes soluble phosphorus; and substantially eliminate release of pathogens, odors, ammonia and heavy metals into the environment. In addition to the technical and operational feasibility standards of the 1<sup>st</sup> generation, the 2<sup>nd</sup> generation system was designed to substantially reduce cost and meet economical feasibility consistent with recommendations provided in the Phase I Technology Determination Report (NC Attorney General/Smithfield Foods) to evaluate a lower cost version of the system (Williams, 2004). The performance verification was done on the installed system at full-scale under steady-state operational conditions.

### **First Generation Technology**

The technology is a swine wastewater treatment system without lagoon (Vanotti et al., 2005b) involving solid-liquid separation, biological N removal and P removal (Figure 2). It is comprised of (1) a solid separation unit, wherein flocculants are used to clump suspended solids and increase solid-liquid separation efficiency, (2) a denitrification unit in direct fluid communication with a clarified effluent from the solid separation unit, (3) a nitrification unit in fluid communication with the denitrification unit, (4) a phosphorus separation reactor unit in fluid communication with the liquid effluent from the nitrification unit, and (5) a clarification unit between the nitrification unit and phosphorus unit. Homogenization and storage tanks were added to the system to integrate discontinuous operations, such as flushing and barn pit recharge, with continuous operation of the treatment system such as

nitrification/denitrification and P treatment. The first generation technology was demonstrated full-scale in Goshen Ridge farm, a 4,400-head finishing farm in Duplin County, NC. The on-farm technology met the environmental performance criteria of an EST (Williams, 2004). It was determined as unconditional Environmental Superior Technology for new farms which are permitted and constructed for the first time after March 2005, and for expansion of existing swine farms (Williams, 2006). Recommendations were also made to evaluate an improved, redesigned second generation version of the wastewater treatment system to meet the contingency described in Section 5.0, page 27 of the referenced July 2004 report.



**Figure 2. First generation wastewater treatment system without lagoon.**

## Second Generation Technology

The new system design is based on experiences gained during first generation demonstration and incorporates new science (Vanotti et al., 2007). It is intended to significantly lower capital, maintenance and operating cost of the system without lagoon. In addition, it was designed to meet the technical feasibility standards of the system previously evaluated. Table 1 describes the improvements made in the 2<sup>nd</sup> generation system to lower cost and also improve system reliability and simplicity.

**Table 1. Improvements made in the 2<sup>nd</sup> generation system to lower cost and improve system reliability.**

System Component	First Generation (Goshen Ridge farm)	Second Generation (Tyndall farm)
Manure Evacuation	Large lift station: 500 gal/min with coarse stationary screen	Smaller lift station: 250 gal/min, coarse screen eliminated (lowered cost)
Solid-Liquid Separation	Coarse rotary screen for flushes on top of homogenization tank Flow rate: 8.8 gal/min Operation: 24h-7d  Separated manure with 18% solids using rotating screen/DAF/belt filter press Permanent construction – 2-floor concrete building Concrete pad with drainage under trailer Three concrete pits and pumps for lifting manure	Eliminated (improved reliability)  Flow rate: 40.0 ± 2.0 gal/min Operation: 2d/week (21h total) (lowered operational cost) Separated manure with 25% solids using rotary press  Mobile unit (more economical)  Not needed, solids in trailer are drier  One concrete pit with one pump for lifting
Separated Water Tank	None – Processing flow-rate of solids separation is limited by constant flow needed by N system	Added – Allows high rate solid-liquid separation and stable N treatment (improved reliability)
Biological N Treatment	Use of nitrification pellets and stainless screen structure for pellets  Air piping for diffuser was built under the concrete floor to allow pellet circulation  Progressive cavity pump for pellet removal and extra tank for storage One concrete pit, 2 electronic valves, and pump for wasting sludge  Two aeration tanks (nitrification and oxic) Blower with inverter for variable air flow Two denitrification tanks and two submersible mixers	Use of high-performance suspended bacteria, no screen structure (saved capital cost)  Diffuser piping network installed above ground level (more economical)  Eliminated – not needed with suspended bacteria Pit, valves and extra pump were eliminated. (Recirculating sludge line was modified for wasting).  Oxic tank eliminated  Direct drive (more economical)  One denitrification tank and one mixer eliminated

	Settling tank with extra weir and electronic valve for floating scum	Eliminated. Floating scum removed in the P module
Phosphorus Treatment	<p>Process pH = 10.5</p> <p>Used prepared liquid lime slurry</p> <p>Used a dedicated solid-liquid separation unit and polymer preparation unit for P sludge dewatering</p> <p>Concrete pad for drying the calcium phosphate</p> <p>Small settling tank and automation to remove the P sludge several times/day</p> <p>Operator handles two solids streams (manure and P)</p>	<p>Process pH = 9.5 (saved lime)</p> <p>Used powder lime (saved in transportation cost)</p> <p>Solid-liquid separation unit eliminated – P sludge dewatered with manure solids (saved capital and polymer operating cost)</p> <p>Not needed and eliminated.</p> <p>Larger settling tank to accumulate P sludge with manual removal (2 days a week/5 min). (improved reliability)</p> <p>Operator handles one solids stream (manure + P)</p>
System Control	Fully automated: two PLC, sensors, two custom software programs	Simpler controls – No automation – Easier to operate
Reliability	Medium	High

### **System Description**

As part of the project to demonstrate EST to replace treatment lagoons, a 5,150-swine finishing farm was retrofitted with the second generation system. The system was designed, constructed and operated by Super Soils Systems USA. It was designed to provide EST treatment to the manure generated by 5,600 finishing pigs with an average weight of 135 lb/pig or a steady state live weight (SSLW) of 756,000 lb. The system made use of three process units (Figure 1). Once the treatment plant was operational, flow of raw manure into the lagoons was discontinued. The liquid manure was diverted into a 100,000 gal homogenization tank. Transfer rate was rather quick using a 250 gpm capacity pump. The manure collected in the homogenization tank was kept well mixed using a submersible mixer (3.5 kW, 12.1 m<sup>3</sup>/min. flow). From there, the raw liquid manure received solid-liquid separation treatment. The process used polymer flocculant to enhance separation of fine suspended particles typical of swine manure (Vanotti and Hunt, 1999). Solids were separated using a rotary press separator that included two polymer preparation tanks (560 gal each), polymer metering pump, sludge feed pump, flocculator, and a dual, 48” rotary press. The prepared polymer solution containing 2.14 g polymer/L (0.2%) was mixed with the manure at a 6% rate. This resulted in a final polymer dosage of 128 mg/L that was used during the evaluation. The separated manure solids were transported off-site to a centralized solids processing facility and converted to organic-based plant fertilizer, soil amendments, and plant growth media as described in Vanotti (2005).

The separated liquid was stored in another tank the same size as the homogenization tank, and further treated in the second process unit. This second process unit treated the separated liquid continuously using nitrification - denitrification processes. Nitrification was performed in an aeration tank (60,000 gal) that used high-performance nitrifying bacteria adapted to swine wastewater. Air was provided continuously with a 10 HP rotary lobe blower and 98 fine-air diffusers. Nitrification transformed  $\text{NH}_4\text{-N}$  into  $\text{NO}_3\text{-N}$ . A pre-denitrification configuration transformed  $\text{NO}_3\text{-N}$  into  $\text{N}_2$  gas where nitrified wastewater was continually recycled to a 73,000 gal anoxic denitrification (DN) tank. In this tank, suspended denitrifying bacteria used soluble manure carbon contained in the separated liquid to remove the  $\text{NO}_3^-$ . A settling tank was used to clarify the N effluent and to return the suspended bacteria into the N tanks. The rates of sludge and nitrified liquid recycle into the DN tank were 3.5 and 0.5 times the inflow rate, respectively. The clarified effluent was stored in a clean water storage tank (73,000 gal) and used to refill the barn pits.

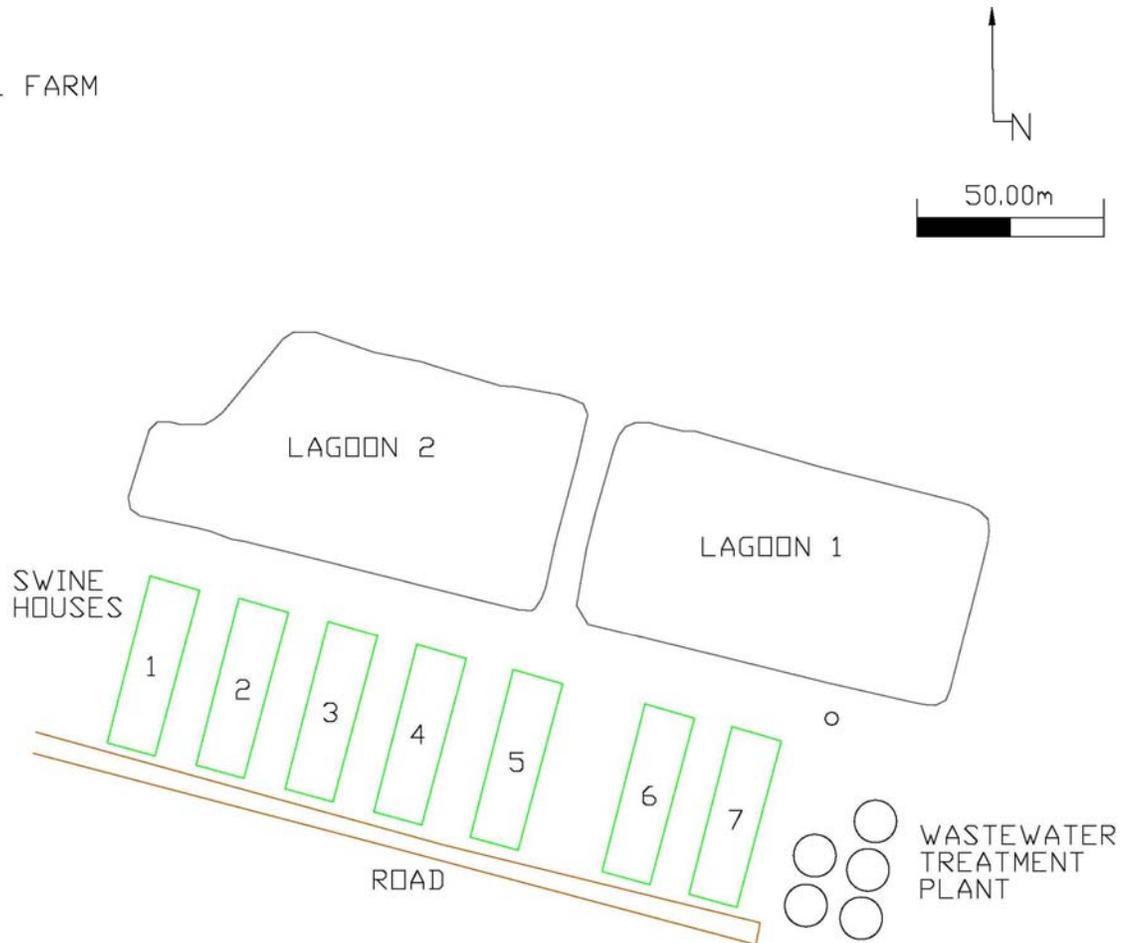
In the third process unit, P was recovered as calcium phosphate solid (Vanotti et al., 2003), and pathogens were reduced by the alkaline environment (Vanotti et al., 2005a). The effluent from the biological N treatment was treated with hydrated lime in a  $0.3 \text{ m}^3$  reaction chamber. The pH of the process was kept at 9.5 by a pH probe and controller linked to the lime injection pump. Lime consumption was  $1.18 \text{ kg/m}^3$ . The reaction produced calcium phosphate precipitate, which was separated in a settling tank. The P precipitate was further dewatered using the solid-liquid separation unit in the front of the plant and combined with the manure solids that left the farm (Figure 1).

### **Swine Farm Characteristics:**

The full-scale demonstration facility was installed on B&B Tyndall farm near Clinton, Sampson Co., NC (Figure 2), and evaluated intensively during half a year under steady-state conditions. The farm contained seven swine barns with a permitted number of pigs of 5,145 and two traditional anaerobic lagoons of equal area (0.58 ha each) for treatment and storage of the manure. Manure was collected under the barns using slotted floors and a pit-recharge system typical of many swine farms in North Carolina (Barker, 1996a) and treated and stored in the anaerobic lagoons. Under this traditional management, lagoon liquid was recycled into the barns to recharge the pits under the slotted floor and facilitate flushing of the newly accumulated manure. Farm records for the previous three growing cycles (2005-2006) showed the farm produced 1,287,613 lb of total live weight (1,073,719 lbs gain) in each growing cycle. The growing cycles started with an average of 5,697 pigs and finished with an average of 5296 pigs. The average weight of a pig was 147.7 lb (range 0 to 253 lb).



TYNDALL FARM



**Figure 2. Wastewater treatment system retrofitted into a 5150-head swine finishing farm.**

### **Objectives:**

Our objective was to provide critical performance evaluation of a lower cost, 2<sup>nd</sup> Generation wastewater treatment technology to determine if the technology is technical and operational feasible and meets the performance criteria of an Environmental Superior Technology defined in Appendix D: Engineering Subcommittee Report (Williams, 2004). Specifically, five environmental variables were considered, including the discharge of animal waste to surface waters and groundwater; emission of ammonia; emission of odor; pathogens; and nutrient and heavy metal contamination of soil and groundwater.

The performance verification of the 2<sup>nd</sup> generation wastewater treatment facility was completed, and it is summarized in this report for the Phase I Environmentally Superior Technology Contingent Determination, sponsored by the NC Department of Justice, Office of the Attorney General through the Smithfield Foods Environmental Enhancement Fund Grant Agreement.

## **Results:**

### **1. Permitting and Agreements**

All necessary agreements and State permits for installation and operation of the new treatment facility at B&B Tyndall farm were completed.

### **2. Construction**

Construction and installation of the wastewater treatment facility started in March 2006 and were completed in Nov. 2006.

### **3. Sample collection, analytical methods, and monitoring**

Liquid samples were collected using four refrigerated automated (Sigma 900max) samplers placed before and after each of the treatment modules as follows: 1) the untreated liquid manure in the mixing tank before solids separation, 2) the effluent from the solid-liquid separation treatment, 3) the effluent after the nitrification-denitrification treatment, and 4) the effluent after the phosphorus removal treatment. Each sample was the composite of four sub-samples taken over a 3.5-day period. Grab samples were also taken weekly at intermediate points of the nitrogen system to check mixed liquor suspended solids. Samples of lagoon supernatant liquid were obtained monthly from each of the two lagoons in the farm; a sample was collected by combining eight sub-samples taken around a lagoon.

For the separated solids, we collected one composite sample from each trailer leaving the farm. Manure was placed in calibrated 5-gal. buckets and weighed at the farm for calculation of the bulk density of the solids (used for solids production determinations). Once a week, liquid and solids samples were transported on ice to the ARS Florence laboratory for analyses.

Wastewater analyses were performed according to Standard Methods for the Examination of Water and Wastewater (APHA, AWWA & WEF, 1998). Solids analyses of the treated and untreated liquid samples included total solids (TS), volatile solids (VS), total suspended solids (TSS), and volatile suspended solids (VSS). Total solids are the solids remaining after evaporation of a sample to constant weight at 105°C. Total suspended solids (TSS) are the solids portion retained on a glass microfiber filter (Whatman grade 934-AH, Whatman, Inc., Clifton, NJ<sup>1</sup>) after filtration and drying to constant weight at 105°C, while VS and VSS are the fractions of TS and VS, respectively, that were lost on ignition in a muffle furnace at 500°C for 15 min. Therefore, the TSS and VSS are measurements of the insoluble total and volatile solids that are removable by solids separation.

Chemical analyses consisted of pH, electrical conductivity (EC), chemical oxygen demand (COD), 5-d biochemical oxygen demand (BOD<sub>5</sub>), ammonia-N (NH<sub>3</sub>-N), total Kjeldahl N

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<sup>1</sup> Mention of trade names or commercial products in this report is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

(TKN), orthophosphate-P ( $\text{PO}_4$ ), and total P (TP). For COD, we used the closed reflux, colorimetric method (Standard Method 5220 D). The orthophosphate ( $\text{PO}_4$ -P or soluble P) fraction was determined by the automated ascorbic acid method (Standard Method 4500-P F) after filtration through a 0.45- $\mu\text{m}$  membrane filter (Gelman type Supor-450, Pall Corp., Ann Arbor, MI). The same filtrate was used to measure  $\text{NH}_4$ -N by the automated phenate method (Standard Method 4500- $\text{NH}_3$  G),  $\text{NO}_3$ -N by the automated cadmium reduction method (Standard Method 4500- $\text{NO}_3^-$  F), and soluble COD. Total P and TKN were determined using the ascorbic acid method and the phenate method, respectively, adapted to digested extracts (Technicon Instruments Corp., 1977). Alkalinity was determined by acid titration to the bromocresol green endpoint ( $\text{pH}=4.5$ ) and expressed as  $\text{mg CaCO}_3 \text{ L}^{-1}$ . Cu, Zn, S, and K were measured in acid digestion extracts using inductively coupled plasma (ICP) analysis. The ICP also measured P that provided values comparable to the block digestion TP method. Solids samples were analyzed for moisture content using a microwave moisture analyzer. Microelements and P in the solids were measured by ICP analysis after acid digestion. Carbon and N contents in the solids were determined using a dry combustion analyzer.

Once a month (Dec. 2006 to June 2007), a composite sample of the separated solids collected in the trailers was sent to a private fuels laboratory (Hazen Research, Inc., Golden, CO) for analyses of its energy content using the fuel industry standard proximate and ultimate analyses.

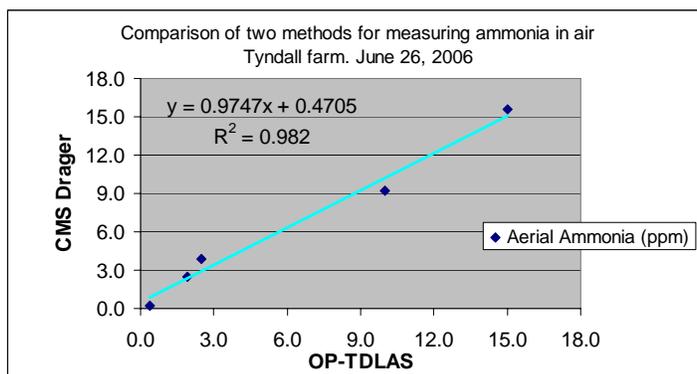
Odor analyses were done in the laboratory of Dr. John Loughrin in Bowling Green, KY. A stir bar extraction and chromatographic method developed by USDA-ARS (Cook et al., 2007) was used to measure concentration of malodorous compounds (Skatole, Phenol, p-Cresol, p-Ethylphenol and Indole) contained in the liquid manure as it passed through the treatment system. Triplicate liquid grab samples were collected monthly and shipped overnight in refrigerated containers to the ARS-Bowling Green laboratory. Twisters<sup>®</sup> stir bars (10 by 3.2 mm; Gerstel, Baltimore, MD) with a 1-mm polydimethylsiloxane (PDMS) coating were preconditioned for 1 h at 250 °C under a stream of high purity  $\text{N}_2$ . Ten-milliliter liquid from the bottles were placed in 2-mL autosampler vials along with the stir bars/extractors; the vials were then closed, and the samples extracted from 1 h at 500 r.p.m. at room temperature. Afterwards, the Twisters<sup>®</sup> were removed from the vials, rinsed with deionized water, blotted dry and placed in 17.8 cm long by 4mm internal diameter thermal desorption tubes (Supelco Inc., Bellefonte, PA) and desorbed in a model TDSA thermal desorption system (Gerstel). The stir bars were desorbed using an initial temperature of 25 °C with a delay time of 0.25 min and then heated at 60 °C  $\text{min}^{-1}$  to 225 °C with a final time of 3 min. Desorbed volatiles were transferred by a heated transfer line maintained at 240 °C to a glass woolpacked injection liner maintained at - 50 °C with liquid  $\text{CO}_2$ . Retained compounds were then transferred with a 20 : 1 split ratio to a 30m by 0.25mm Rtx-35 MS column (35% diphenyl-65% polydimethylsiloxane-Restek Corp., Bellefonte PA) with a film thickness of 0.25 mm by heating the injector at 10 °C  $\text{min}^{-1}$  to 300 °C with a final time of 3 min. GC-MS was performed on a Varian Saturn 200 ion trap interfaced to a Varian model 3800 gas chromatograph (Varian Associates, Palo Alto, CA). GC operating conditions were: He carrier constant flow rate of 1mL  $\text{min}^{-1}$ , column oven 55 °C for 1 min, then programmed at 7 °C  $\text{min}^{-1}$  to 100 °C, and hence at 15 °C  $\text{min}^{-1}$  to 295 °C and held for 10 min, transfer line temperature 300 °C. The mass spectrometer was run in electron ionization mode with an emission current

of 10 m amperes using a scan time of 0.35 s per scan and a scan range of 45–225 atomic mass units. Levels of the odor compounds were quantified relative to external standards of the compounds obtained from commercial sources.

Microbiological analyses of liquid samples were done in the laboratory of Dr. Patricia Millner in Beltsville, MD, using the standard protocols for pathogens and indicator microbes for the examination of wastewater. Duplicate liquid grab samples were collected monthly and shipped overnight in refrigerated containers to the ARS-Beltsville laboratory. Samples were analyzed for Total Coliforms, Fecal Coliforms, Enterococci and Salmonella.

Ammonia concentrations in the air inside the barns were measured using a Dräger CMS Analyzer and Remote System (Dräger Safety AG & Co. KGaA, Luebeck, Germany). The accuracy of the method is  $\pm 4\text{-}7\%$ . The analyzer uses capillary chips, a mass flow controller and pump system that pulls the same mass of air through the capillary, and a photo-optical controller for analyzing the chemical reaction. All measurements were started with capillary chips having a 0.20 – 5.0 ppm ammonia scale. When the ammonia concentration was  $> 5.0$  ppm, the measurement was repeated on the spot using chips with a 2.0 – 50.0 ppm range. Thus, the detection limit of the procedure was 0.20 ppm ammonia. Monthly measurements were done in the same two barns (barns # 2 and 6) at the following points inside the barn: 1) at 5 ft height (operator nose), 2) at 1 ft height (pig nose), and 3) at 6 in. below the concrete slotted floor (inside the manure pit atmosphere). A telescopic probe and remote system (Dräger CMS) was added to the analyzer to measure ammonia in the pit atmosphere. We also measured the ammonia in the air blown out by the large exhaust fans that provide ventilation to the buildings. Measurements were done during a 4-month period in 2006 using the lagoon system, and repeated in 2007 using the new treatment system.

Air ammonia concentrations obtained with the Dräger CMS Analyzer were compared with those obtained with an open-path tunable diode laser absorption spectroscopy system (OP-TDLAS, GasFinder 2.0, Boreal Laser Inc., Spruce Grove, Canada). Measurements were done at Tyndall farm simultaneously at the following points: inside two barns (#2 and #6) at 5 ft height, at the exhaust fans of the same barns, and at an adjacent field approximately 150 m from the barns as a background measurement. Results showed a good agreement between measurement methods ( $R^2 = 0.98$ ). However, the CMS analyzer was used in this evaluation because measurements were easier and faster to perform, and allowed measurements in the pit atmosphere below the slatted floor that was not possible with the laser system.



A system of five liquid-level probes connected to a data logger (CR800, Campbell Scientific Inc., Logan, UT) and nine flowmeters were used to monitor liquid volumes in different parts of the treatment system. The liquid level indicator system was used primarily for this report. It used ultrasonic probes (SR50 Sonic Ranging Sensor, Campbell Scientific Inc., Logan, UT) placed on top of the homogenization tank, separated water tank, clean water tank, and settling tanks. Actual volume dynamics were calculated using recorded measurements of liquid height and area of the tank. This allowed precise calculations of manure flushes, separation activity and flows, feed rate into the N system, water recycle, and wasting of the sludges. We also monitored air and water temperatures, precipitation, DO, ORP and pH of the liquid. Process data and sampler information were retrieved daily from the Florence, SC laboratory using cell phones connected to the field devices.



## 4. Technology Verification Conditions

### 4.1 Timeframe

Performance verification started December 9, 2006, with both the solids separation unit and biological N removal unit fully operational. The phosphorus module was checked in batches during December 2007 and brought in-line on January 11, 2007. The system was evaluated for approximately 6.5 months (ending 7/2/2007), with the results summarized in this report.

In order to start the evaluation in winter with a fully functional biological nitrogen removal system, the acclimation of the nitrification bacteria to swine wastewater was conducted during October and November 2006 right after the nitrogen tanks, air supply system, and corresponding pump and mixers were installed, while construction details of other parts of the system were being completed. Acclimation consisted of inoculating the nitrification tanks with 1-L nitrification bacteria adapted to high-ammonia swine wastewater and conducting a fill-and-draw batch method using the lagoon wastewater that was rich in ammonia. Batch cycles lasted about 10 days at the beginning and were progressively shortened, as the nitrification biomass increased, to about 2-day cycles by December when the N system was brought in-line continuously.

### 4.2 Weather

Performance evaluation of the wastewater treatment technology included cold and warm weather conditions with monthly averages of max and min temperatures ranging from 0.4 to 32.8°C (32.8 to 90.1°F) (Figure 3).

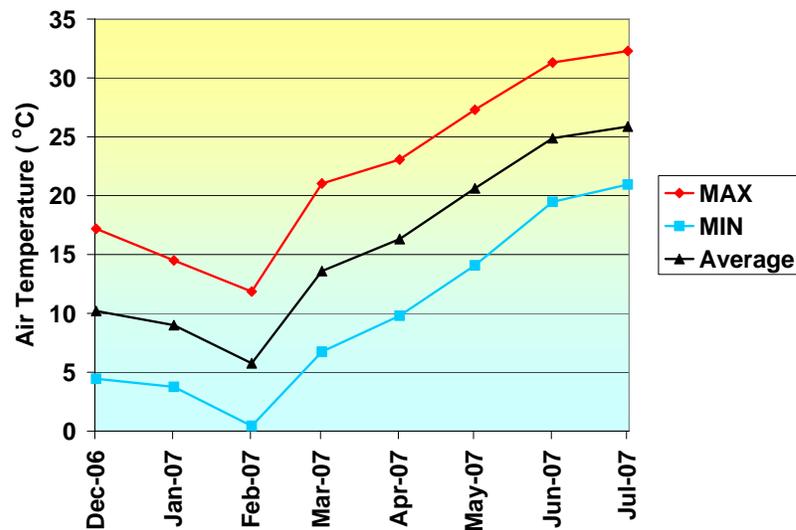


Figure 3. Air temperature during Dec. 1, 2006-July 15, 2007. Data are monthly averages of daily maximum, average, and minimum temperatures.

### 4.3 Livestock and Manure Inventory

New batches of pigs were received Dec. 12, 2006-Jan. 2007, and May 14-June 4, 2007. The first batch was finished April 14-May 6, 2007, and the second is projected to be completed Sept. 25-Oct. 8, 2007. With the first batch of pigs that was evaluated using the new wastewater treatment system, the production cycle started with 5,312 pigs distributed in seven barns that had a total weight of 209,495 lbs (39.4 lb/pig). The cycle finished 126 days later with 5,148 pigs weighing a total of 1,320,497 lbs (256.5 lb/pig). The average gain per day was 1.718 lb/pig/day and the average weight of a pig during the growing cycle was 148 lb/pig. The steady state live weight (SSLW) that tested the second generation system was 764,996 lb [(209,495 + 1,320,497)/2]. It is consistent with the 756,000 lb SSLW (5,600 pigs @ 135 lb each) used to design the second generation system for Tyndall farm. Since the average pig weight (148 lb) in this farm was heavier than the 135 lb standard, the actual 764,996 lb SSLW is equivalent to 5,667 standard pigs (135 lb average). Therefore, a 765,000 lb SSLW (5667 pigs @ 135 lb each) reflects the actual conditions under which the second generation treatment system was evaluated, and the treatment capacity of the system when extrapolated to other standard farms.

**Table 2. Total pig weight and liquid volumes of raw manure and treated water at B&B Tyndall farm during the evaluation period December-June 2007. Monthly total pig weights (Barns 1 to 7) were calculated from farmer records. Volumes were measured by evaluation team using ultrasonic liquid-level indicators and flowmeters. Flushed manure is the raw waste collected in the homogenization tank. Barn refill is the volume of treated liquid recycled to the barn pits.**

Month/Year	Days	Total Pig Weight lb×1000	Flushed Manure	Barn Refill	New Manure <sup>[a]</sup>	To N Module	System Effluent
----- Total gallons -----							
December 06	23 <sup>[b]</sup>	194	226,320	57,729	168,591	235,684	177,955
January 07	31	423	175,686	95,462	80,224	180,575	85,113
February 07	28	685	155,724	41,020	114,704	157,220	116,201
March 07	31	946	260,093	68,360	191,733	264,907	196,547
April 07	30	1,024	309,975	45,555	264,420	311,973	266,418
May 07	31	156 <sup>[c]</sup>	126,833	56,939	69,894	123,220	66,281
June 07	30	414 <sup>[c]</sup>	245,959	43,297	202,662	249,938	206,642
Total Dec-Jun.	204		1,500,590	408,362	1,092,228	1,523,517	1,115,155
----- Gallons/day -----							
December 06	23	194	9,840	2,510	7,330	10,247	7,737
January 07	31	423	5,667	3,079	2,588	5,825	2,746
February 07	28	685	5,562	1,465	4,097	5,615	4,150
March 07	31	946	8,390	2,205	6,185	8,545	6,340
April 07	30	1024	10,333	1,519	8,814	10,399	8,881
May 07	31	156	4,091	1,837	2,255	3,975	2,138
June 07	30	414	8,199	1,443	6,755	8,331	6,888
Average Dec-Jun.	204		7,356	2,002	5,354	7,468	5,466

<sup>[a]</sup> New manure = Flushed manure – Barn pit refill. This is the manure and wasted water production (urine, feces, water wasted by pigs) generated in the barn.

<sup>[b]</sup> 23 days = Treatment plant started operation Dec. 9, 2006.

<sup>[c]</sup> Total pig weight for second batch of pigs are estimates.

Monthly average total pig weight varied greatly within production cycles from a low of about 156 Animal Units (1 AU=1000 lb) to a high of about 1,024 AU (Table 2); the amount of manure that went through the treatment system varied accordingly, from 4,091 gallons per day to 10,333 gallons per day. A total of 1.50 million gallons of flushed manure was processed from Dec. 9, 2006, to June 30, 2007, or an average of 7,356 gallons per day. On the average, the flushed manure contained 27.27% recycle treated water (used to refill the pits) and 72.8% manure and wasted water (urine, feces, water wasted by pigs). The manure and wasted water production (“new manure” = flushed manure – pit recharge, Table 2) averaged 5,354 gal/day or 13.6 gal/1000 lb/d. This average is consistent with the table value of 12.1 gal/1000 lb/d for manure and wasted water production in feeder-to-finish operations provided by Chastain et al. (1999). It is also consistent with the value of 13.9 gal/1000 lb/d obtained during the one-year evaluation of the 1<sup>st</sup> generation system at Goshen Ridge. This “new manure” volume generation was generally higher in warmer months. For example, it varied from 5.98 to 6.54 gal/1000 lb/d in Jan-March and from 13.46 to 16.29 gal/1000 lb/d in May-July. The average volume that was used to refill each barn was 3,718 gal.

#### 4.4 Loading Rates of Solids and Nutrients

Loading rates of solids and nutrients into the system were well correlated with changes in total pig weight (Figures 4 and 5). Nitrogen production averaged 0.26 lb N/1000 lb/day but varied from 0.18 to 0.52 lb N/1000 lb/day. These rates are consistent with the N production rates obtained during 1<sup>st</sup> generation project (average = 0.29 lb N/1000 lb/day; range = 0.18-0.42). For comparison, SCS National Engineering Waste Management Handbook value is 0.42 lb N/1000 lb/day. The relationship between suspended solids load and pig weight was 1.41lb TSS/1000 lb/day (range 1.1-2.1). These are consistent with the TSS production rates obtained during 1<sup>st</sup> generation project (average = 1.93 lb TSS/1000 lb/day; range = 1.1-3.4). However, they are significantly lower than the value of 5.05 lb TSS/1000 lb/day provided by the SCS reference.

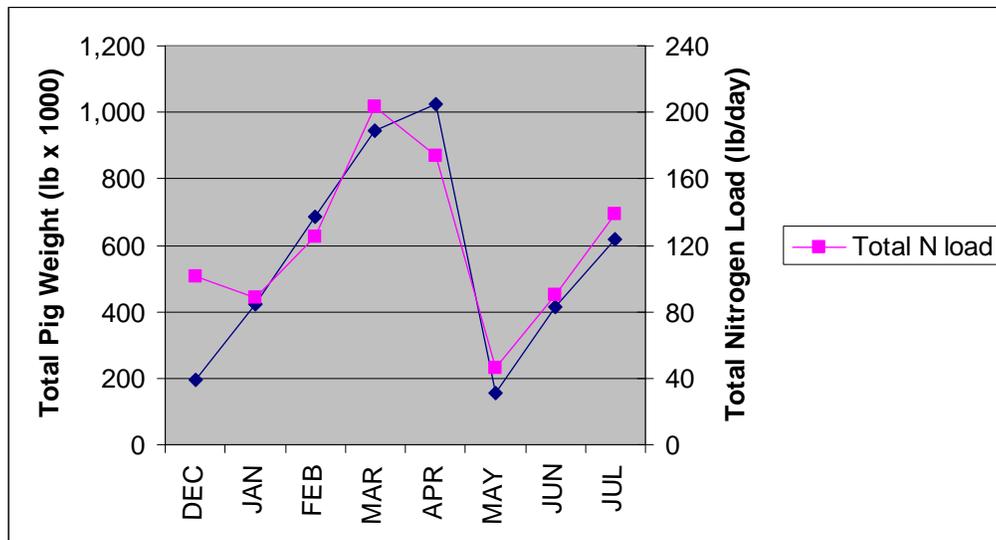


Figure 4. Changes in the loading rates of nitrogen into the treatment system as affected by changes in total pig weight in the barns (shown in blue color) during the period Dec. 9, 2006-July 15, 2007.

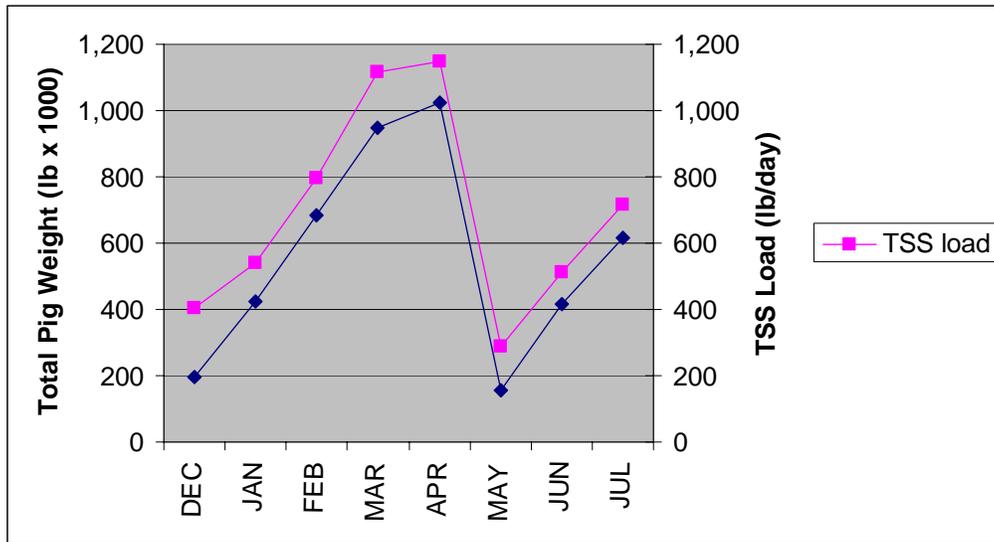


Figure 5. Changes in the loading rates of suspended solids into the treatment system as affected by changes in total pig weight in the barns (shown in blue color) during the period Dec. 9, 2006-July 15, 2007.

The amount of nitrogen that went into the biological N removal module (after solid-liquid separation treatment) varied greatly during evaluation. The fluctuating N loads were well predicted by the changes in total pig weight (Figure 6). The TKN load into the N removal module varied from 35 to 160 lb N/day. The ammonia load varied from 28 to 134 lb N/day. The higher than predicted N load observed in December was due to additional initial flushings to remove manure solids settled in the barn pits from previous production cycles.

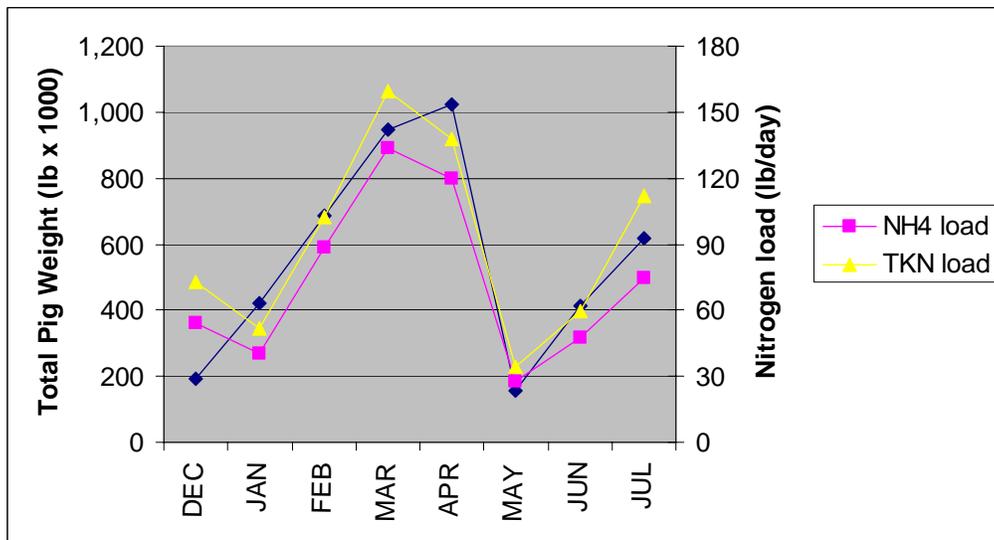


Figure 6. Changes in the loading rates of total Kjeldahl N (TKN) and ammonia (NH<sub>4</sub>-N) into the nitrification/denitrification process unit as affected by changes in total pig weight in the barns (shown in blue color) during the period Dec. 9, 2006-July 15, 2007.

## 5. Total Wastewater Treatment System

### 5.1 System Performance – Water Quality Improvement

The wastewater treatment performance data obtained during full-scale operation are summarized in Table 3 showing the values of various water quality indicators as the liquid passed through each treatment module and the overall efficiency of concentration reduction for these parameters. Individual sampling data are presented in graphics in the appendix section. The on-farm system lowered concentration of constituents in wastewater as follow: 97.1% of TSS, 98.3% of VSS, 89.9% of VS, 96.5% of COD, 99.4% of BOD<sub>5</sub>, 95.5% of TKN, 96.9% of NH<sub>4</sub>-N, 92.2% of TP, 99.0% of Cu, 98.8% of Zn, 73.0% of alkalinity, and 56.4% of EC. Concentration reduction of other elements were: 73.2% of S, 12.8% of K, 82.2% of Al, 99.8% of Mn, and 98.8% of Fe.

**Table 3. Reduction in concentration of solids, COD, BOD, nutrients, and heavy metals in the wastewater by the new treatment system evaluated at B&B Tyndall farm. System efficiency is the % reduction in concentration between the flushed manure and the effluent after P treatment. Data are means ± standard deviation of samples collected during the period of Dec. 9, 2006 – July 2, 2007 (n=60).**

Water Quality Parameter	Raw Flushed Manure (mg/L)	After Solids Separation Treatment (mg/L)	After Biological N Treatment (mg/L)	After Phosphorus Treatment (mg/L)	System Efficiency (Concentration Basis) (%)
TSS	11,230 ± 5,171	1,320 ± 1,136	270 ± 246	325 ± 204	97.1
VSS	8,506 ± 4,135	937 ± 853	174 ± 144	148 ± 100	98.3
VS	17,136 ± 7,118	5,940 ± 3,223	1,724 ± 916	1,732 ± 1,243	89.9
COD	22,708 ± 11,936	8,906 ± 4,933	1,016 ± 529	798 ± 396	96.5
BOD <sub>5</sub>	7,725 ± 4,969	3,548 ± 2,165	67 ± 59	43 ± 49	99.4
TKN	1,910 ± 712	1,428 ± 597	101 ± 145	85 ± 127	95.5
Ammonia-N	1,180 ± 597	1,182 ± 483	59 ± 124	37 ± 88	96.9
Oxidized N <sup>[a]</sup>	1 ± 5	0	127 ± 114	84 ± 56	--
Total N <sup>[b]</sup>	1,911	1,428	228	169	91.2
Total P	461 ± 179	184 ± 90	73 ± 33	36 ± 22	92.2
Copper	14.0 ± 10	2.57 ± 3.22	0.16 ± 0.10	0.14 ± 0.07	99.0
Zinc	20.5 ± 8	3.33 ± 3.16	0.36 ± 0.56	0.25 ± 0.27	98.8
pH	7.81 ± 0.31	7.75 ± 0.19	8.23 ± 0.30	9.76 ± 0.68	--
Alkalinity	6,854 ± 2,398	5,249 ± 1,695	1,658 ± 694	1,851 ± 708	73.0
EC (mS/cm)	14.31 ± 4.39	13.37 ± 4.06	6.72 ± 1.73	6.24 ± 1.50	56.4

[a] Oxidized N = nitrate + nitrite-N;

[b] Total N = TKN + Oxidized N

These high treatment concentration reduction efficiencies were obtained during a 6.5-month period with average daily air temperatures ranging from -1.5 to 28.2°C and large variations in the strength of the manure due to typical livestock growth cycles. These results are consistent with the efficiency of concentration reduction obtained with the more expensive first generation treatment system (97.0% of TSS, 99.0% of VSS, 97.4% of COD, 99.7% of BOD<sub>5</sub>, 98.5% of TKN, 98.7 of NH<sub>4</sub>-N, 95.0% of TP, 94.1% of Cu, and 99.0% of Zn; Vanotti, 2004).

Removal of N, P, Cu, and Zn by the treatment system was also determined using a mass approach. This mass approach utilized the element concentration as well as water flows throughout the plant and also water reuse in the barns. The removal obtained on a mass basis by the treatment system at B&B Tyndall farm is presented in Table 4 for solids, COD, BOD, nutrients, and heavy metals. The calculations correspond to the period Dec. 9, 2006 – June 30, 2007 (204 days total). Total mass values are the sum of monthly mass calculations. On a mass basis, the treatment system removed 97.7% of the suspended solids, 99.6% of BOD, 96.1% of TKN, 97.3% of NH<sub>4</sub>-N, 94.0% of TP, 99.3% of Cu and 99.2% of Zn. Therefore the second generation treatment system met the standards for ammonia, nitrogen, phosphorus, copper, and zinc removal that define an Environmentally Superior Technology.

**Table 4. Mass removal of solids, COD, BOD, nutrients, and heavy metals by the treatment system at B & B Tyndall farm during the period Dec. 9, 2006 – June 30, 2007 (204 days total).**

Water Quality Parameter	System Influent (Raw Flushed Manure) [A] (kg)	Water Reuse in Barns [B] (kg)	System Effluent (After Phosphorus Treatment) [C] (kg)	System Efficiency <sup>[a]</sup> (Mass Basis) (%)
TSS	64,256	397	1,464	97.7
VSS	48,772	260	709	98.5
VS	98,552	2,612	7,606	92.1
COD	130,495	1,529	3,863	97.0
BOD <sub>5</sub>	43,429	97	187	99.6
TKN	10,987	148	427	96.1
Ammonia-N	6,804	86	179	97.3
Total N <sup>[b]</sup>	10,993	342	875	91.9
Total P	2,637	109	153	94.0
Copper	78.7	0.2	0.5	99.3
Zinc	117.4	0.5	0.9	99.2

[a] System efficiency removal = { 1- [C / (A – B)] } \* 100

[b] Total N = TKN + Oxidized N; the oxidized N (nitrate and nitrite) contained in the water reuse (194 kg) was fully denitrified in the pits under the barn; thus, it was subtracted from B in the system efficiency calculation for Total N.

## 5.2 Solids Production

A total of 90 trailers containing 274 m<sup>3</sup> of separated solids was produced and left Goshen Ridge farm in about 6 months from Dec. 9, 2006, to June 2, 2007. This amount of manure weighed 214,580 kg (473,070 lb or 237 tons) and contained 24.9% ± 3.1% of solids (75.1 ± 3.1% moisture), 21,984 kg of carbon, 2,709 kg of nitrogen, 1,663 kg of phosphorus, 60 kg of copper, and 92 kg of zinc (Table 5) that left the farm in the same period. To accomplish this task, the separator unit used 610 kg of dry polymer for flocculation of the solids and separation enhancement.

**Table 5. Amount and composition of the solids produced from the separation process at B&B Tyndall farm. Concentration values are provided on a dry manure basis. Data are means (± standard deviation) and total mass separated during Dec. 9, 2006 - June 2, 2007, n=90.**

Element	Average Concentration % (± s.d.)	Min-Max Concentration %	Total Mass that Left Farm with the Solids (kg)
Total Nitrogen	5.18 (0.47)	4.12-6.46	2,709
Total Phosphorus	3.17 (0.45)	2.30-4.19	1,663
Copper	0.12 (0.04)	0.05-0.18	60
Zinc	0.17 (0.06)	0.08-0.30	92
Total Carbon	42.08 (2.02)	36.22-46.47	21,984
Potassium	0.82 (0.21)	0.41-1.28	74
Calcium	2.79 (0.94)	1.57-5.61	251
Magnesium	1.40 (0.44)	0.65-2.22	126
Sulfur	0.76 (0.09)	0.59-0.97	68

The solids separated with the rotary press were drier than the 1<sup>st</sup> generation system that used a rotating screen and filter press, 24.9% solids and 18.2%, respectively. This drier material is more amenable for the composting process used by Super Soil Systems USA that mixes the separated manure solids with cotton gin waste (Vanotti, 2005). It is also a better situation for use in energy production using gasification and combustion processes. The energy analyses composition of the separated solids is provided in Table 6. Results showed that the heat content of separated solids averaged 2,195 ± 622 Btu/lb on the as-produced basis and 8,729 ± 458 Btu/lb on a dry basis. For comparison, the heat content of coal consumed in the USA averages 6,500 Btu/lb for brown coal (lignite), 8,500 Btu/lb for subbituminous coal and 12,000 Btu/lb for bituminous.

As part of the verification process, we conducted independent mass calculations based on 1) the liquid manure volume and concentration before and after separation and 2) the solids measured in the trailers that left the farm. Results of these mass calculations are shown in Table 7 and indicate a quantitative recovery of solids, N, P, Cu, and Zn by the solid-liquid separation step as predicted by the corresponding removal from the liquid fraction.

**Table 6. Energy composition analysis of the separated solids.**

Energy Composition	Separated Solids in the Trailers <sup>[a]</sup>	Separated Solids on a Dry Basis
% Moisture	75.01 ± 5.97 <sup>[b]</sup>	0 ± 0
Btu/lb (HHV) <sup>[c]</sup>	2,195 ± 622	8,729 ± 458
Btu/lb (MMF) <sup>[d]</sup>	2,937 ± 776	11,704 ± 320
% Ash	5.81 ± 1.43	23.41 ± 3.73
% Volatile	17.16 ± 4.43	68.53 ± 2.76
% Fixed C	2.02 ± 0.55	8.06 ± 1.17
% Hydrogen	1.54 ± 0.40	6.17 ± 0.51
% Carbon	11.89 ± 3.21	47.42 ± 3.10
% Oxygen	4.06 ± 1.04	16.20 ± 0.99
% Sulfur	0.21 ± 0.06	0.85 ± 0.08
% Nitrogen	1.47 ± 0.29	5.95 ± 0.65

Other Characteristics	
lb Ash/MM Btu	25.06 ± 5.75
lb SO <sub>2</sub> /MM Btu	1.96 ± 0.25
DSCF/MM Btu	10,178 ± 379

[a] Solids as they leave the farm (with about 25% dry matter).

[b] Means ± s.d. of samples collected monthly from Dec. 2006 to June 2007 (n=7).

[c] HHV = Higher Heated Value (gross calorific value)

[d] MMF = Mineral Matter Free (used for coal classification)

**Table 7. Percent recovery of solids, N, P, Cu and Zn by the solid-liquid separation step. Data compare the mass measured in the trailers (column 5) during Dec 9, 2006 to June 30, 2007 vs. the mass that was expected based on liquid volume and concentrations before and after the separation process (columns 2-4).**

Solids Element	Liquid manure passing through the solid-liquid separation process			Mass measured in the trailers that left the farm (kg)	Recovery [a] (%)
	Mass In (kg)	Mass Out (kg)	Mass Removal (In-Out) (kg)		
Dry Solids [b]	64,256	7,551	56,705	54,779	96.6
Total Nitrogen	10,993	8,213	2,780	2,838	102.1
Total Phosphorus	2,637	924	1,713	1,741	101.6
Copper	78.7	11.8	66.9	63.0	94.2
Zinc	117.4	16.4	101.0	96.2	95.2

[a] Recovery = (Mass that left farm from trailer measurements/ Mass removal from liquid measurements) \* 100.

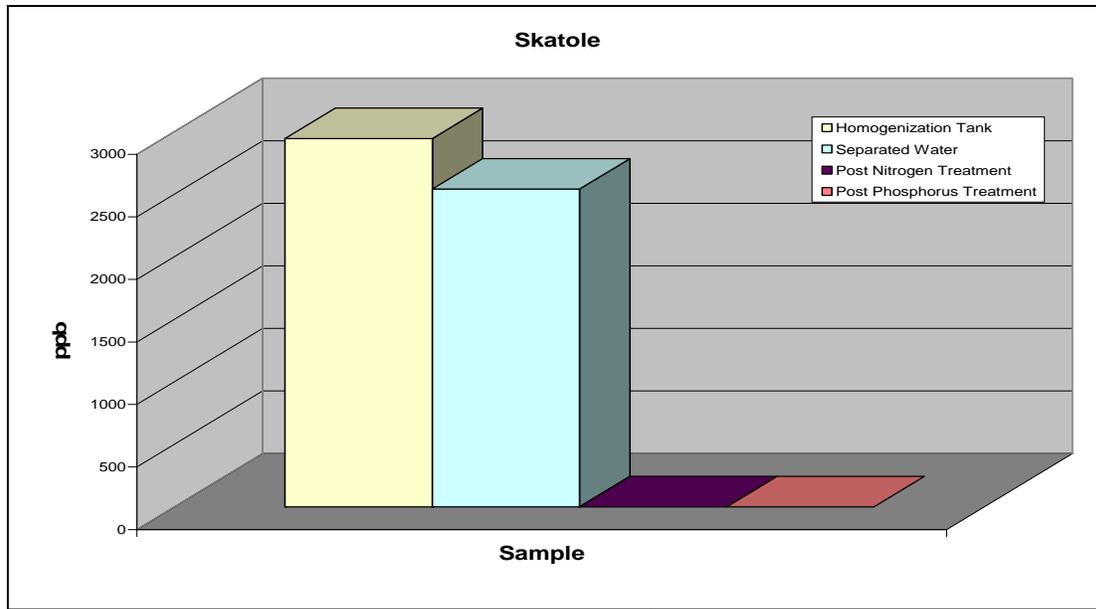
[b] Dry solids = adjusted to 0% moisture.

### 5.3 Reduction of Odors

The treatment system was very effective in reducing odor-generating compounds contained in the liquid (Table 8). The potential of effluent to produce offensive odors was quantified by measuring in the liquid the concentration of compounds typically associated with malodors in animal waste according to the published method of Cook et al. (2007). The largest reduction was observed after the liquid passed through aeration in the biological nitrogen treatment. Removal efficiencies were particularly high for major malodor compound contributors such as p-cresol and skatole (Figure 7). The treatment system eliminated 99.9% of the selected odor compounds evaluated.

**Table 8. Reduction of odor compounds contained in the liquid by the new treatment system installed at B&B Tyndall farm. Data are means ( $\pm$  standard error) of liquid samples taken monthly Dec. 2006 – May 2007 (n=6). System efficiency compares reduction of odor compound concentrations in the treated liquid (after phosphorus treatment) with concentration in raw flushed manure.**

Odor Compound	Raw Flushed Manure ppb ( $\pm$ s.e.)	After Solids Separation Treatment ppb ( $\pm$ s.e.)	After Biological N Treatment ppb ( $\pm$ s.e.)	After Phosphorus Treatment ppb ( $\pm$ s.e.)	System Efficiency (%)
Phenol	6,880 (917)	4,458 (802)	5 (5.33)	5 (3.06)	99.9
p-Cresol	43,191 (6305)	38,588 (7951)	46 (36)	32 (20.28)	99.9
p-Ethylphenol	7,313 (1620)	6,686 (1348)	0 (0)	0 (0)	100
Indole	745 (184)	636 (166)	0.21 (0.21)	0.38 (0.38)	99.9
Skatole	2,943 (496)	2,540 (420)	0 (0)	0 (0)	100
Total	61,072	52,908	51.21	37.38	99.9



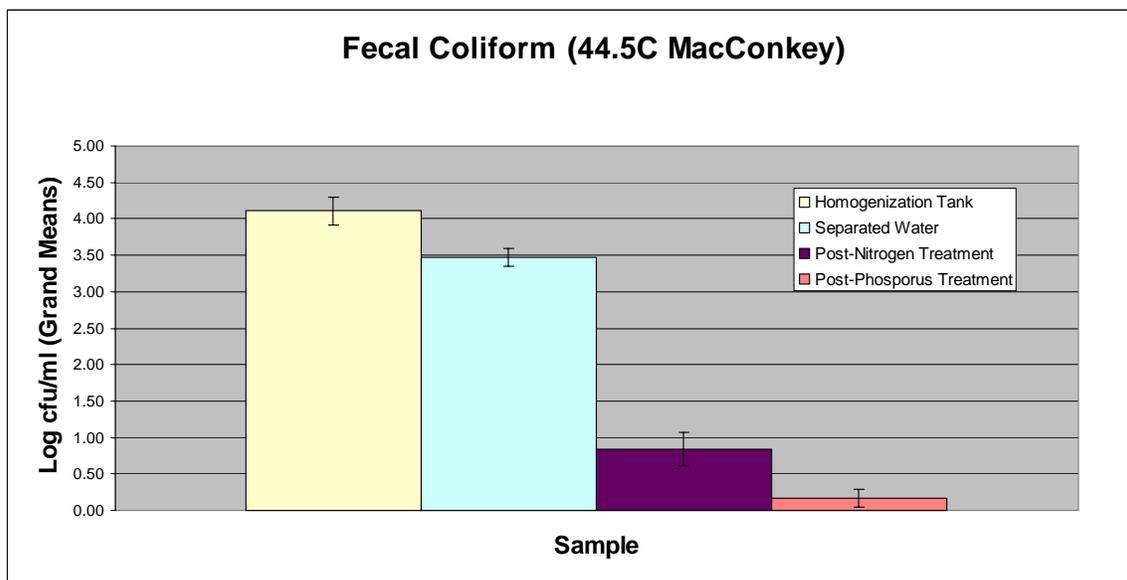
**Figure 7. Reduction of skatole in liquid samples of the 2<sup>nd</sup> generation wastewater treatment system.**

## 5.4 Reduction of Pathogens

The treatment system was very effective in reducing pathogens in liquid swine manure (Table 9 and Figures 8, 9, 10). Results showed a consistent trend in reduction of microbial indicators as a result of each step in the treatment system. The largest reduction overall was obtained in the biological N treatment. The reductions in pathogens in the treated liquid (post P-treatment) relative to that present in raw manure were: Total coliforms = 99.97%, Fecal coliforms = 99.99%, Enterococci = 99.99%, and Salmonella = 100%. Therefore, the 2<sup>nd</sup> generation system met the 4 log pathogen reduction standard of an EST.

**Table 9. Microbiological analyses of liquid manure effluent before treatment and at each step of the treatment system. Values are means (standard error) of log<sub>10</sub> colony forming units (cfu) per mL for duplicate samples for six sampling dates in 2007 (Jan, Feb., Mar., Apr., May, and Jun.). Enrichments were done for Salmonella on all samples. Only the raw flushed manure and the separated wastewater showed positive results (Post-N and Post-P treatment were negative). The raw flushed manure and the separated wastewater were further quantified using XLT4 agar plates.**

Indicator Microorganism	Raw Flushed Manure log <sub>10</sub> cfu/mL (± s.e.)	After Solids Separation Treatment log <sub>10</sub> cfu/mL (± s.e.)	After Biological N Treatment log <sub>10</sub> cfu/mL (± s.e.)	After Phosphorus Treatment log <sub>10</sub> cfu/mL (± s.e.)
Total Coliforms	4.30 (0.136)	3.60 (0.094)	1.03 (0.201)	0.76 (0.179)
Fecal Coliforms	4.11 (0.186)	3.47 (0.115)	0.84 (0.230)	0.17 (0.117)
Enterococci	5.11 (0.134)	3.62 (0.175)	1.53 (0.343)	1.14 (0.350)
Salmonella present	+	+	-	-
Salmonella (XLT4)	1.79 (0.109)	1.14 (0.299)	--	--



**Figure 8. Reduction of fecal coliforms in manure with the 2<sup>nd</sup> generation wastewater treatment system.**

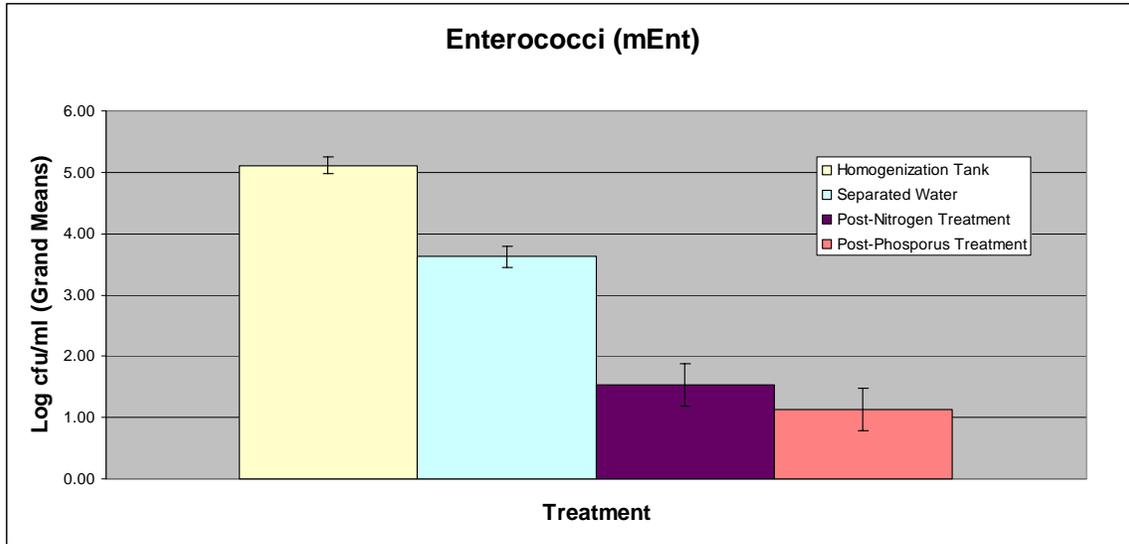


Figure 9. Reduction of Enterococci in manure with the 2<sup>nd</sup> generation wastewater treatment system.

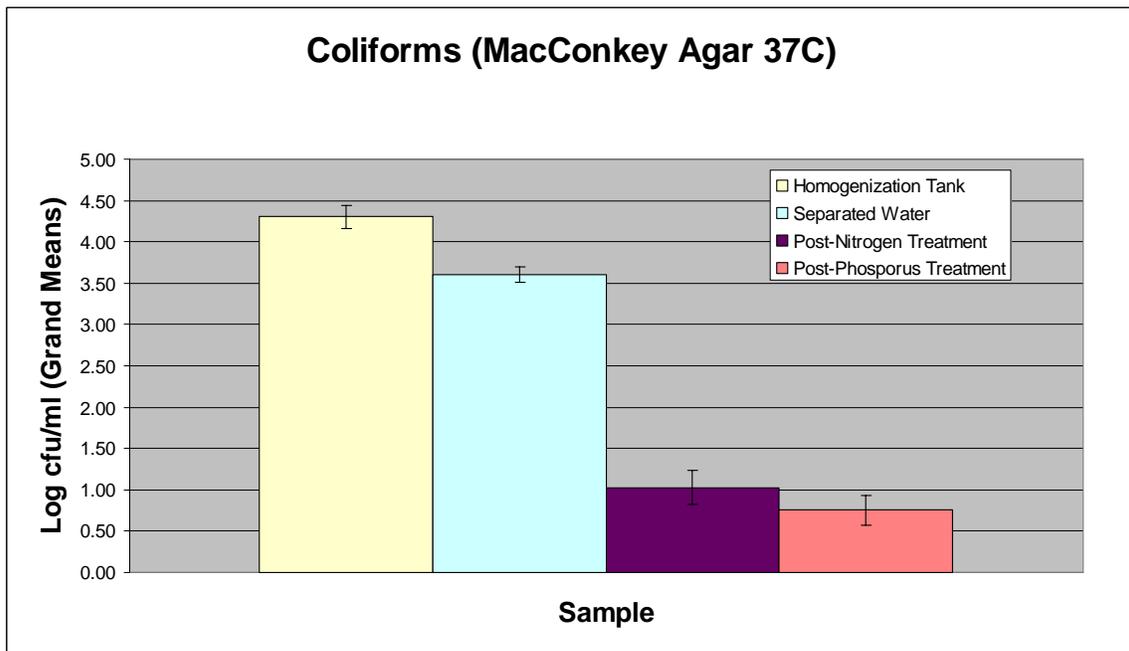


Figure 10. Reduction of Total Coliforms in manure with the 2<sup>nd</sup> generation wastewater treatment system.

## 5.5. Reduction of Ammonia in the Pig Houses

Ammonia concentration in the air inside the barns was measured during traditional lagoon treatment in 2006 and again with the new treatment system in 2007. Measurements were done in the same barns (barns # 2 and 6) during the same time of the year (May-September) at the following points inside the barn: 1) at 5 ft height (operator nose), 2) at 1 ft height (pig nose), and 3) at 6 in. below the slotted floor (inside the manure pit atmosphere). We also measured the ammonia in the air blown out by the large exhaust fans that provide ventilation to the buildings. Each of the four-month measurement periods included pig sizes representative of a full production cycle; the average pig weight per barn was 113,134 lb during 2006 measurements and 112,943 lb during 2007 measurements. Results of the air measurements showed a vertical gradient of ammonia inside the barns with higher concentrations close to the liquid manure in the pit (Table 11). However, the new system had significantly lower ammonia concentrations in the air than the lagoon management system at all depths, and the differences between management systems were more pronounced at the lower depths (Table 11). Compared to the lagoon system, the new system lowered ammonia concentrations in the air inside the barns by an average of 40.3% at the operator nose level, 44.5% at the pig nose level, and 58.1% in the manure pit atmosphere below the slotted floor. We also found pronounced differences in the quality of the air blown to the outside by the barn's ventilation fans; the average ammonia concentration reduction in the exhaust air was 75.1% with the use of the new treatment system (Table 11 and Figure 11).

**Table 11. Ammonia concentrations in the air inside the swine barns and in the ventilation air exiting the barns. Measurements were done on the same farm before (2006) and after (2007) conversion to the alternative manure treatment system. Measurements in 2006 were done May 30-Sept 25, and measurements in 2007 were done May 14-Sept 11. Aerial ammonia values are averages ( $\pm$  s.d.) of monthly measurements done in barns #2 and #6. Each four-month measurement period included pig sizes representative of a full production cycle. Exhaust fan data are also shown in Figure 11.**

Manure Management System	Average total pig weight per barn during measurement period	Ammonia Concentration in the Air Inside the Barns			Ammonia in the Air Outside the Barns
		Operator Nose Level (5 ft height)	Pig Nose Level (1 ft height)	Manure Pit Below Floor (- 6 in. height)	Air Blown Out by the Barn's Ventilation Fan
	lb x 1000	-----ppm NH <sub>3</sub> -----			
<b>Lagoon system</b> May-Sept 2006	113.2 $\pm$ 52.0	3.05 $\pm$ 1.93	3.73 $\pm$ 2.18	12.09 $\pm$ 9.99	11.30 $\pm$ 3.68
<b>New system</b> May-Sept 2007	112.9 $\pm$ 55.1	1.82 $\pm$ 0.99	2.07 $\pm$ 1.21	5.06 $\pm$ 4.50	2.81 $\pm$ 1.07
% Change	- 0.2%NS	- 40%*	- 45%*	- 58%*	- 75%***

NS = non-significant.

\*, \*\*\* significant at 0.05 and 0.001 level, respectively.

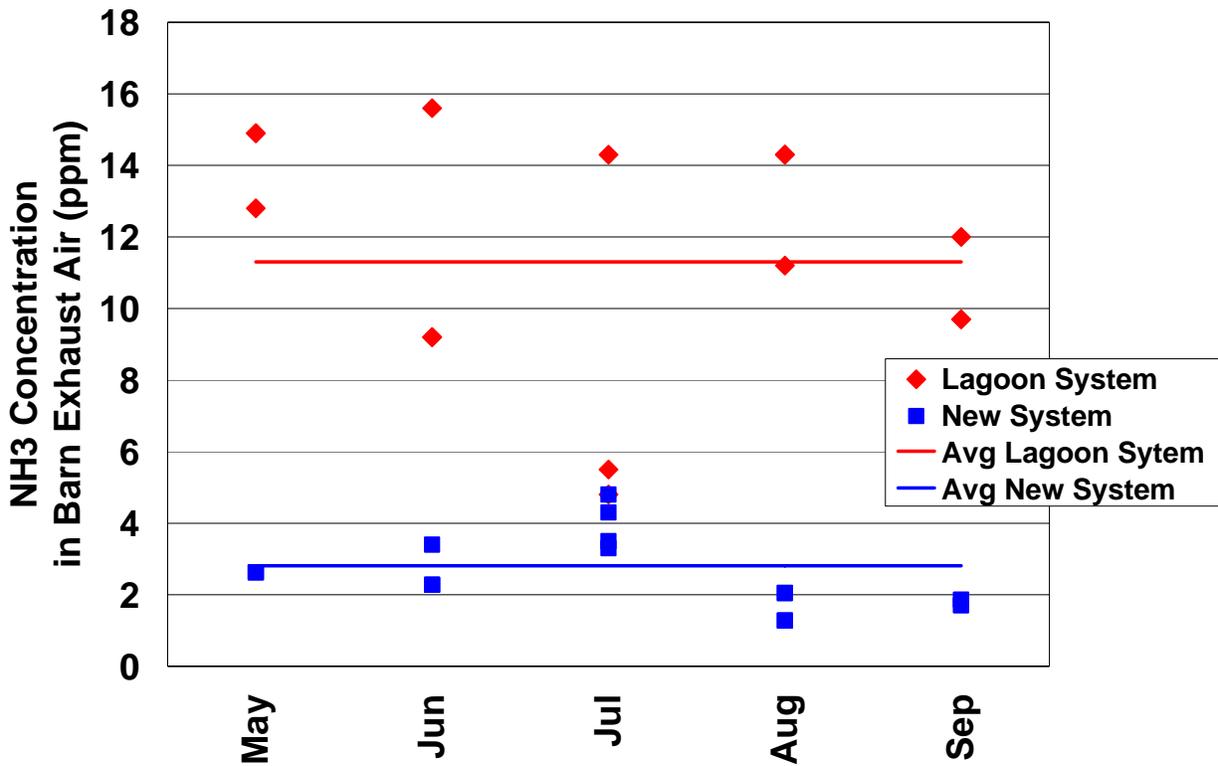


Figure 11. Ammonia concentrations in fan exhaust air with the traditional lagoon system (2006 measurements in red) and the new treatment system (2007 measurements in blue). Measurements were done on the same farm (barns #2 and #6) in 2006 and 2007. The operation used the same production practices in 2006 and 2007, except pit recharge management. The old system used dirty lagoon liquid to recharge the pits, and the new system used to refill the barn the cleaner, sanitized liquid that was treated in the plant. Additional ammonia measurements inside the house are shown in Table 11.

## 5.6. Improvement in Animal Production Performance and Health Indicators

The reuse of cleaner, sanitized water to refill barn pits reduced ammonia concentration in the air (Table 11) and improved the growing environment. As shown in Figure 1, part of the treated water was reused on the farm to flush the pits under the barns. It replaced the dirtier lagoon liquid charged with ammonia used for the same task under the traditional lagoon management. As a result, animal health and productivity were enhanced (Table 12). These data show that, compared to lagoon management, significantly fewer pigs died as a result of the cleaner environment (mortality decreased 57%). In addition, the rate of feed conversion into meat improved 5.4%. The pigs also grew faster with the cleaner environment. The average daily weight gain (lb/pig/day) increased 11%. This is even higher than the 4.8% increase in daily gain obtained with the 1<sup>st</sup> generation version of the system at Goshen Ridge.

**Table 12. Improvement of animal productivity and health indicators obtained with the new waste treatment system compared with the previous lagoon system. Data are means  $\pm$  s.e. of production records in seven barns (n=7).**

	Preceding growing cycles using the old lagoon system			Pig growing cycle with new system	% Change <sup>[a]</sup>
	Oct. 2005- Feb 2006	Feb. 2006 – July 2006	July 2006- Dec.2006	Dec. 2006 – May 2007	
Mortality (%)	10.01 $\pm$ 0.98	7.60 $\pm$ 0.84	3.58 $\pm$ 1.05	3.06 $\pm$ 0.80	- 56.7%
Daily Gain <sup>[b]</sup> (lb/pig/day)	1.529 $\pm$ 0.02	1.485 $\pm$ 0.02	1.644 $\pm$ 0.02	1.718 $\pm$ 0.02	+ 10.5%
Feed Conversion <sup>[c]</sup> (lb feed/lb meat)	2.78 $\pm$ 0.05	2.48 $\pm$ 0.03	2.59 $\pm$ 0.05	2.47 $\pm$ 0.03	-5.4%
Condemnation <sup>[d]</sup> (%)	0.26 $\pm$ 0.19	0.17 $\pm$ 0.05	0.21 $\pm$ 0.15	0.13 $\pm$ 0.07	-38.1%

[a] % Change compares performance obtained with the new waste management system with the average performance obtained in the three previous cycles using the lagoon system. Production records were provided by Prestage Farms (integrator). Least significant differences (LSD<sub>0.05</sub>) to compare values among any pig growing cycle are: Mortality=2.70, Daily gain=0.062, Feed Conversion=0.11, and Condemnation=NS.

[b] Daily gain = Finished weight minus start weight divided by number of days on feed.

[c] Actual feed conversion after condemnation.

[d] Entire hogs that did not pass USDA inspection.

Results obtained in the second pig growing cycle with the new system (May-Sept. 2007) provide further evidence that animal performance is enhanced with the new manure management system. Farmer records (Mr. Bill Tyndall, Sept. 25, 2007) showed that, at the end of the second production cycle with the new system, the animal mortality was reduced again. Averaged over the seven barns, mortality was 2.56% ( $\pm 0.81$ ), which was 63.8% lower than previous farm records using traditional lagoon management and consistent with results obtained during the first growing cycle using the new system shown in Table 12.

Results obtained in this demonstration project are consistent with the observations of Dr. James Barker (Barker, 1996b) on the substantial animal production advantages that can be realized by improvements in manure management in swine production buildings. Barker (1996b) documented with many examples the direct linkage between improved manure management and improved air quality in the barn -especially lower ammonia concentrations- and their effect on animal productivity and health such as healthier pigs, reduced mortality, increased daily gain, improved feed conversion, and substantial economic benefits to the producer.



***Economic Benefits from Improvements in Animal Productivity and Health***

Data in Table 13 shows the economic benefits of the improvement in animal productivity and health observed in this project after implementation of the new system. Weight gain, feed consumption and days on feed are actual values measured at the site before and after conversion. On an annual basis, the productivity improvements with the new system resulted in an additional 207,538 lb of live animal weight produced at the facility with an additional consumption of 136,102 lbs of feed. The economic benefits associated with the productivity improvements amount to an additional \$91,920 per year. This amount translates into \$120.15/1000 lbs SSLW/year. Therefore, the economic advantages from enhanced productivity and health using the new technology are substantial and have the potential to pay for most of the cost of the treatment. These results are consistent with observations of Barker (1996b) that improvements in manure management are associated with improvements in animal health and productivity, and these improvements can result in substantial economic benefits to the farmer.

**Table 13. Potential economic benefits of the improvements in animal productivity due to implementation of the new system. Weight gain, feed consumption and cycle duration are actual records obtained at B&B Tyndall farm with the lagoon system before conversion and new system.**

Manure Management System <sup>[a]</sup>	Days On Feed	Growing Cycles Per Year <sup>[b]</sup>	Pig Production		Feed Consumption		Economic Benefit with New System
			Per Cycle (lbs live weight gain)	Per Year (lbs live weight gain) <sup>[c]</sup>	Per Cycle (total lbs)	Per Year <sup>[c]</sup> (total lbs)	
Lagoon System	131.0	2.552	1,073,719	2,740,130	2,799,449	7,144,194	
New System	125.6	2.653	1,111,002	<u>2,947,488</u>	2,744,175	<u>7,280,296</u>	
Annual change (lbs)				207,358		136,102	
Annual change (\$/year) <sup>[d]</sup>				\$103,679		\$11,759	\$91,920/yr
Annual change <sup>[e]</sup> (\$/1000 lbs SSLW/year)							\$120.15 /1000 lbs/yr

[a] Lagoon system values are means of production, feed consumption and cycle duration obtained during three cycles in seven barns (Oct. 2005 – Dec.2006); New system values are means of one cycle and seven barns (Dec. 2006- May 2007).

[b] Total cycle duration = days on feed + average 12 days used for barn cleanup and disinfection.

[c] Amount per year = amount per cycle x cycles/year.

[d] Calculation uses hog prices of \$50 per live hundredweight (100 lbs), and feed cost of \$8.64 per 100 lbs (Hurt, 2007; Lawrence, 2006). The cost of feed is estimated based on a typical grow-finish hog diet average over five diets (Lawrence, 2006) containing 79.4% corn (\$4/bu), 15.6% SBM (\$175/T), and 2.3% SBO (0.28 \$/lb). Annual benefit = \$103,679 - \$11,759.

[e] Calculation uses actual SSLW of 765,000 lb (section 4.3).

## 6. Cleanup of the Lagoon

We monitored water quality of the two lagoons on the same farm starting about 10 months before the new treatment operation started operation on Dec. 9, 2006, and continued until July 2007. Results obtained showed that the lagoon liquid was progressively cleaner once the new system started operation (Table 14 and Figure 12). After about 4-6 months of operation, the ammonia and TKN were halved relative to the levels during the same time the previous year. COD, VSS, and salinity (EC) content in the water were reduced about 20-30%. These results are consistent with the rate of NH<sub>4</sub>-N concentration reductions obtained from the lagoon at Goshen Ridge (first generation system) during the first six months of EST operation (initial and after 6-month of operation NH<sub>4</sub>-N concentrations in lagoon liquid were 464 and 186 mg/L, respectively, denoting a change of -60%). After one year, in the same study, NH<sub>4</sub>-N declined 90%. These differences in water quality characteristics between lagoons produced remarkable differences in atmospheric ammonia (NH<sub>3</sub>) emissions. Szogi et al. (2006) found a reduction of 90% annual NH<sub>3</sub> in the converted lagoon at Goshen Ridge with respect to those in a traditionally anaerobic lagoon at the same farm.

**Table 14. Water quality changes in Tyndall farm lagoons with the new treatment system. Before installation of the new system, lagoon 1 received the flushed manure from 3 barns, and lagoon 2 received flushed manure from 4 barns. After Dec. 9, 2006, flushing into the lagoon was discontinued and all the liquid manure was diverted into a collection tank where it was mixed (homogenized) and pumped into the new wastewater treatment system. Data are averages of duplicate composite samples collected from eight points around each lagoon.**

Year	Lagoon	pH	TKN (mg/L)	NH <sub>4</sub> -N (mg/L)	COD (g/L)	VSS (mg/L)	EC (mS/cm)
2006 (March-July)	1	8.16	635	480	2.6	477	9.1
	2	8.07	742	576	2.3	386	10.0
2007 (March-July)	1	8.11	333	218	1.8	374	6.8
	2	8.08	410	297	1.8	283	7.5
% Change <sup>[a]</sup>	1	-0.6	-47.6	-54.6	-30.8	-21.6	-25.3
	2	0.1	-44.7	-48.4	-21.7	-26.7	-25.0

[a] Negative values indicate % reductions in 2007.

Changes in ammonia concentration in Tyndall farm lagoons

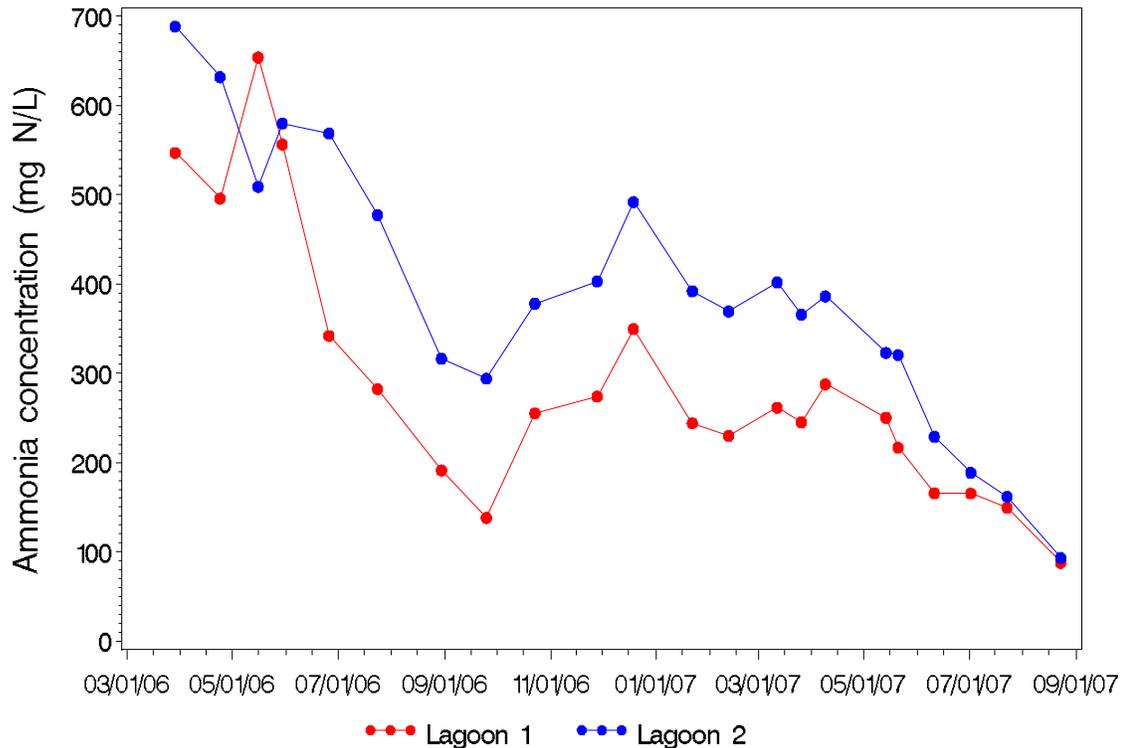


Figure 12. Changes in ammonia nitrogen concentration with time in Tyndall farm lagoons. Before the new system started operation, both lagoons performed traditional anaerobic treatment. After Dec. 9, 2006, flushing into the lagoon was discontinued and all the liquid manure was diverted into a collection tank where it was mixed (homogenized) and pumped into the new wastewater treatment system. Data are averages of duplicate composite samples collected from eight points around each lagoon.

## 7. Operational Problems Experienced and Solutions

There were no project delays but several challenges to bringing the 2<sup>nd</sup> generation technology to its full potential:

### *Polymer Preparation*

Very cold well water (3-4°C) in winter affected preparation of polymer solutions in the mobile solids separation unit; the polymer was not fully activated. This problem was solved by installation of a small water-heater that warmed the water (10-12°C) used to prepare the stock polymer solutions.

### *Electrical Connection of Blower*

Electrical connections and circuit serving the air blower were redesigned after reoccurring air supply interruptions experienced in late February affected biological N conversion efficiency. The aeration system worked fine after this correcting work.

### *Adaptation of Separation Process to Very-High Strength Wastewater*

Polymer formulation and mixing strategies of the solid-liquid separation equipment had to be adapted to the very high strength wastewater in this project in order to bring separation treatment capacity to target design values of 25 gpm. The original polymer used in the 1<sup>st</sup> generation project at Goshen Ridge did not produce good flocculation with the very high strength wastewater at Tyndall project. This affected separation efficiency and system performance during March, 2007. The problem was solved by April with the use of a new polymer formulation. In addition, simple modifications in the mixing components of the separator increased the treatment capacity of the separator to 40 ±2 gpm (60% more than the target design value).

## **8. Operator Training**

The 2<sup>nd</sup> generation system is much easier to operate than the previous version. An operator with 8<sup>th</sup> grade education can successfully operate the system. The operator needs to receive 2 weeks training by the company that includes detailed information on plant equipment, operation and maintenance, safety and health aspects, identification and reporting of problems, and simple troubleshooting. A trained operator can safely operate three farms within a 20-mile radius, each farm providing treatment to about 6,000 pigs.

In addition to the plant operator, successful operation of the technology also requires support from an engineering technician having a 2- to 4-year engineering technology degree and mechanical/electrical skills. This person can provide support to about 10 farms; each plant is visited about twice a month to help with specialized issues such as parts replacement and system checkup.

## **Conclusions**

Major goals in the demonstration and verification of a second-generation, lower-cost wastewater treatment system for swine manure were achieved. These goals included replacement of anaerobic lagoon treatment, and highly efficient treatment performance of an EST with varying weight of animals typical of confined production, and cold and warm weather conditions. The treatment plant completed design, permitting, construction, startup, and half-year operation under steady-state conditions at full-scale on a 765,000 lb steady state live weight finishing farm. It was verified that the lower cost second generation technology is technically and operationally feasible and meets the high standards of an Environmentally Superior Technology. In addition, animal productivity was improved. These results overall show that cleaner alternative technologies can have significant positive impacts on livestock production and the environment.

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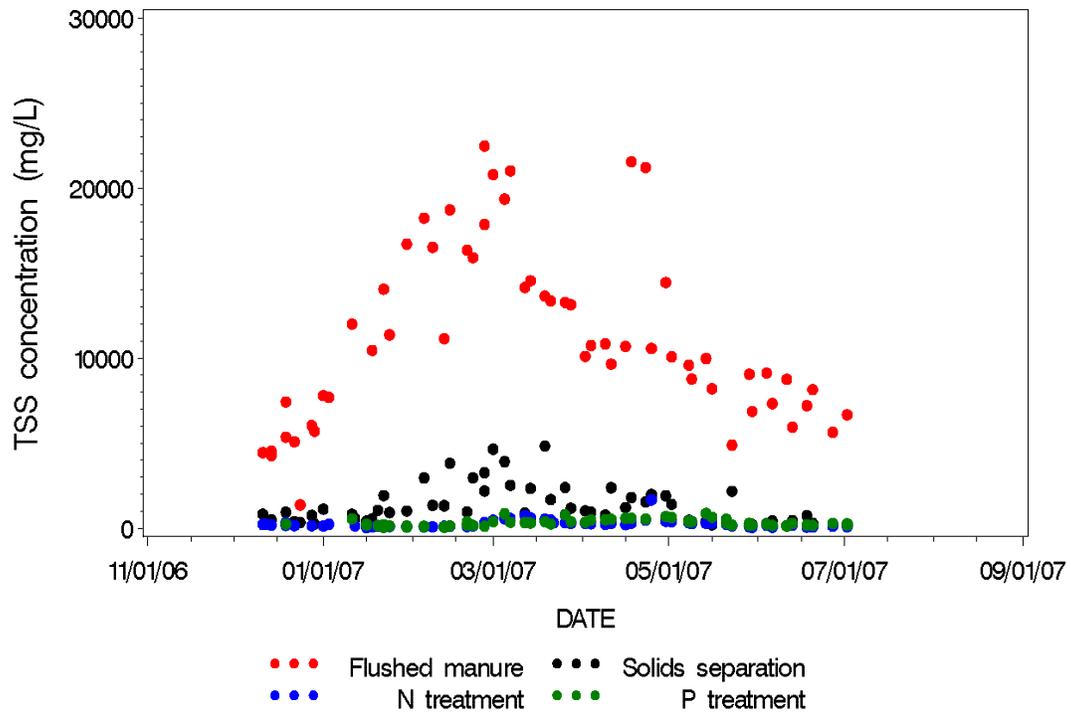
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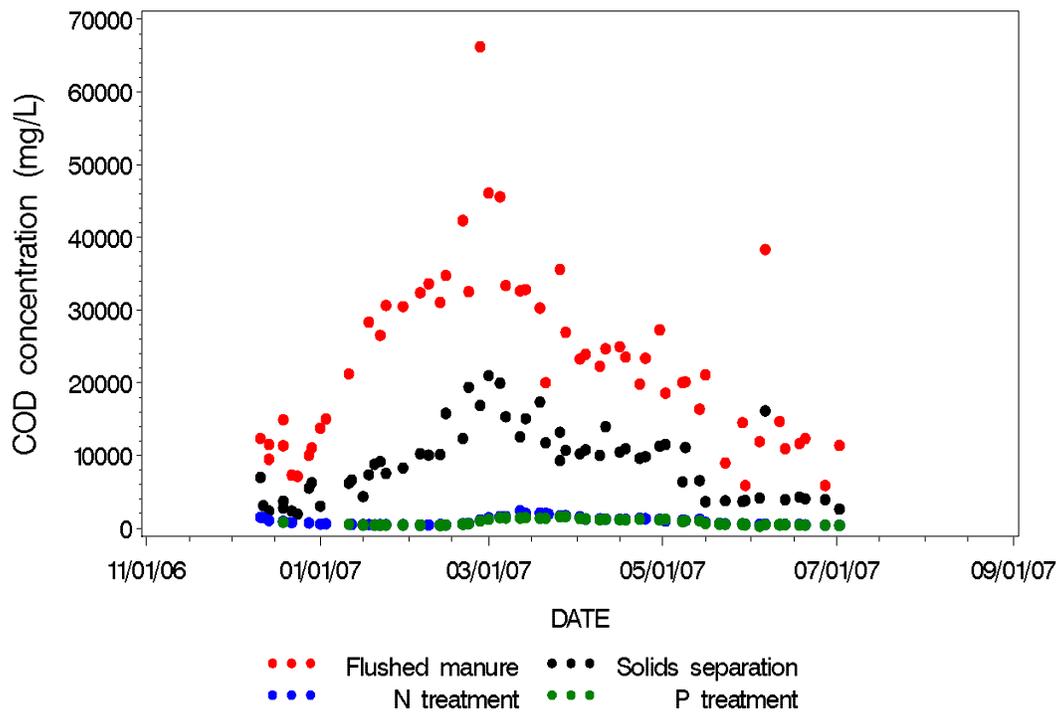
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## Appendix A: Graphs of Water Quality Improvements with Treatment System

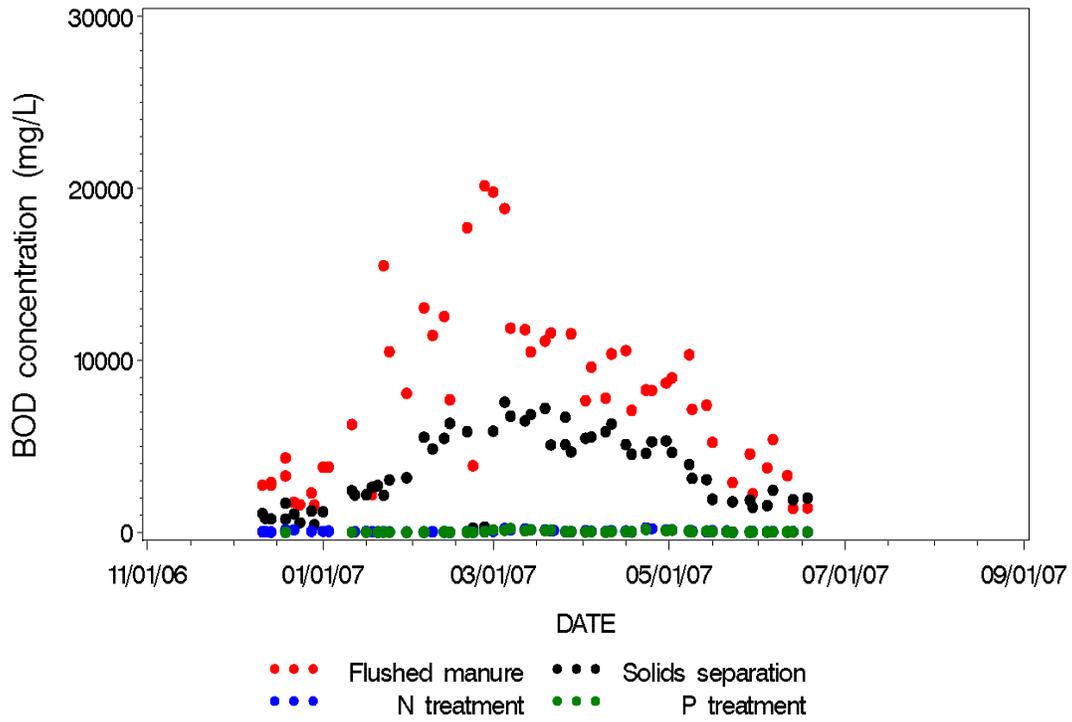
### Removal of Total Suspended Solids by treatment system



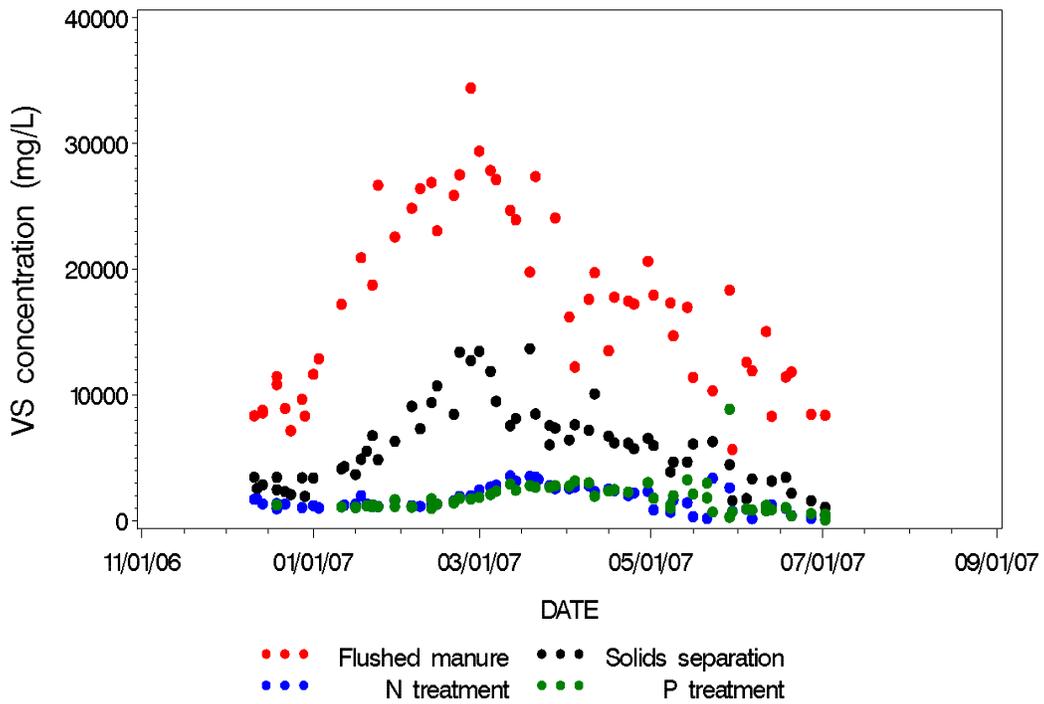
### Removal of COD by treatment system



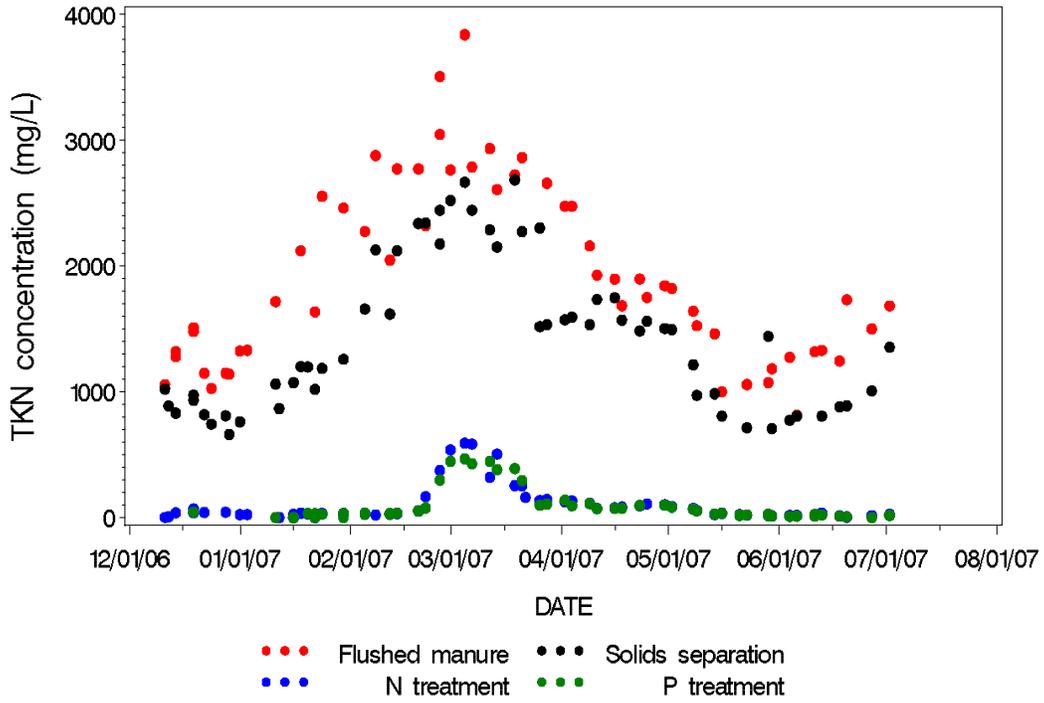
Removal of BOD by treatment system



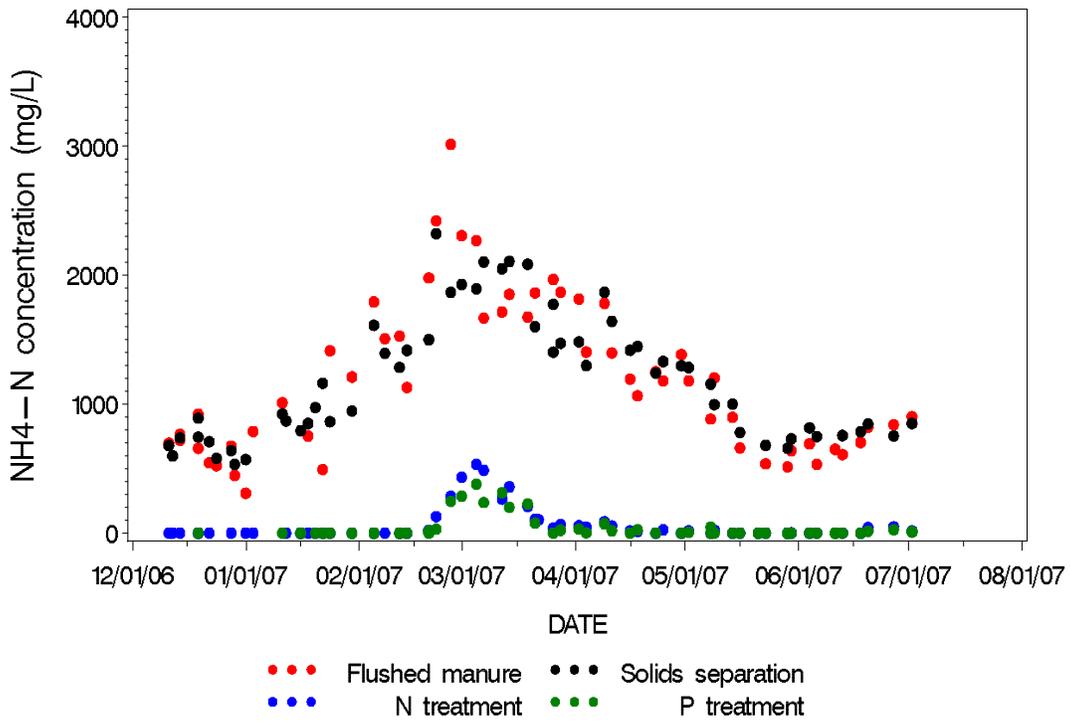
Removal of Volatile Solids by treatment system



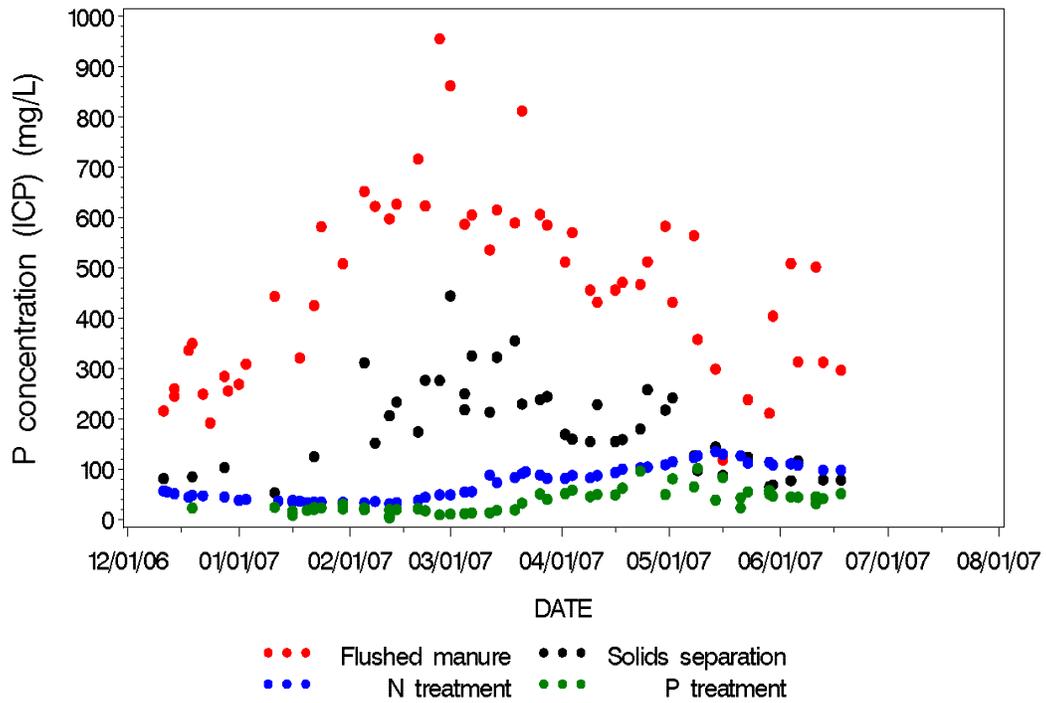
Removal of TKN by treatment system



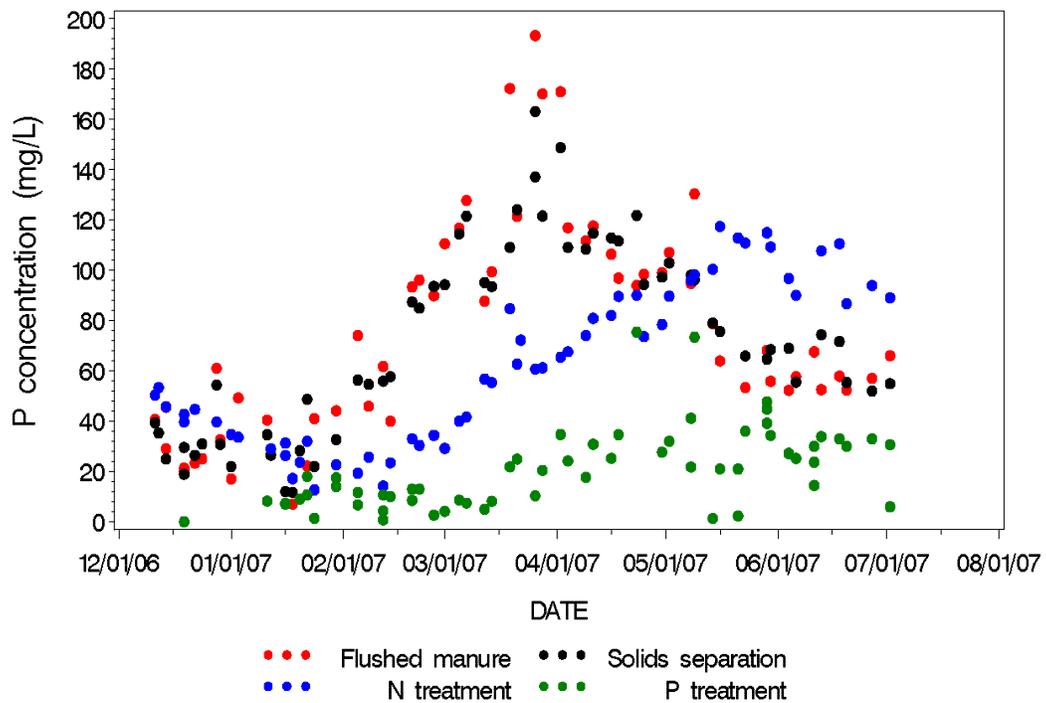
Removal of Ammonia by treatment system



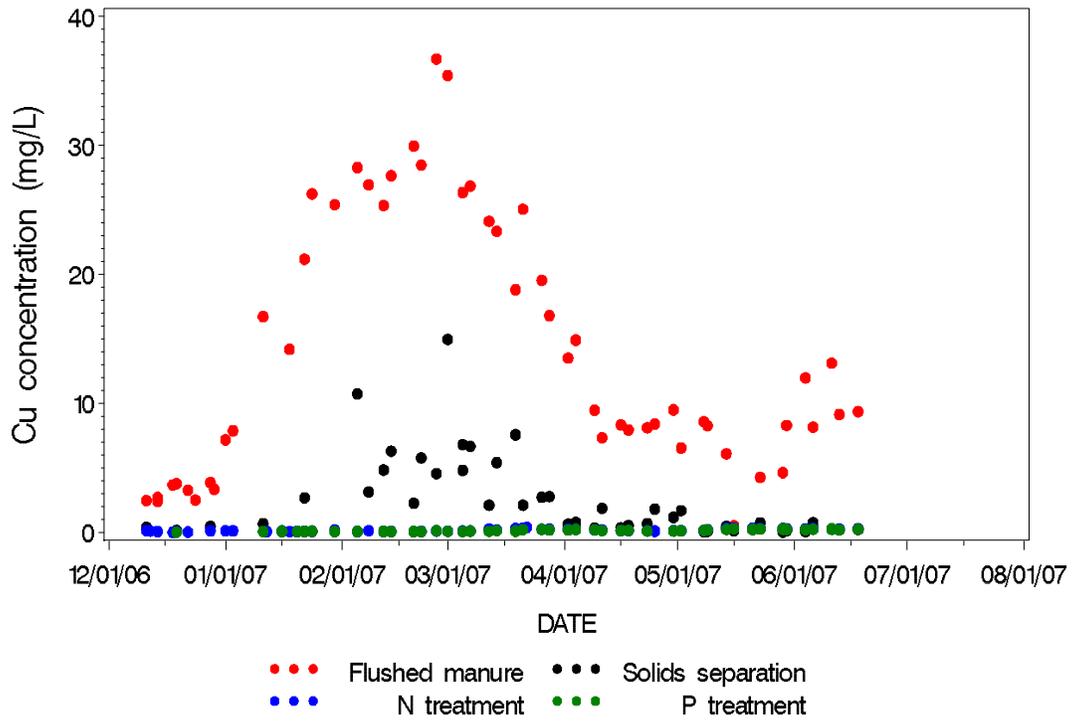
Removal of P by treatment system



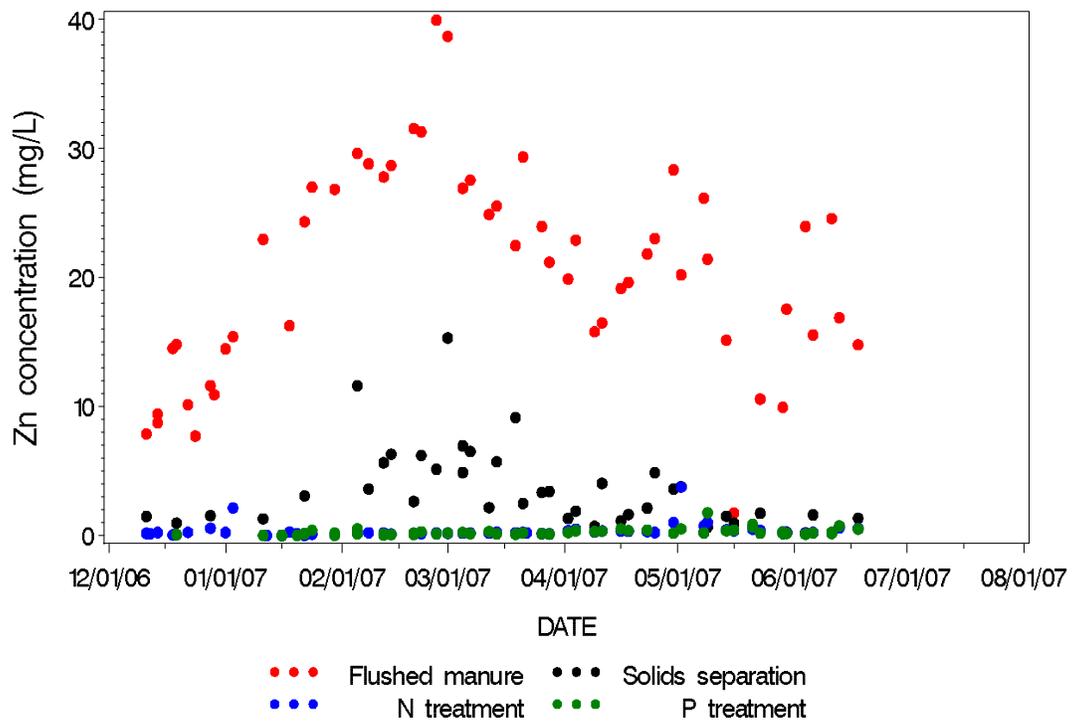
Removal of soluble phosphorus by treatment system



Removal of Copper by treatment system



Removal of Zinc by treatment system



## Appendix B: Project Pictures



**Figure B.1:** Treatment system (left), swine barns, and discontinued anaerobic lagoon at Tyndall Farm near Clinton, NC.



**Figure B.1:** Tanks comprising the 2<sup>nd</sup> generation Super Soil treatment system installed at Tyndall Farm near Clinton, NC.



**Figure B.2:** Mobile liquid-solids separation unit using PAM flocculation and rotary press dewatering.



**Figure B.3: Flushed manure diverted into the homogenization tank to undergo depuration treatment.**



**Figure B.5: Manure solids that are separated during liquid-solids separation treatment.**



**Figure B.6: Nitrification tank using suspended, acclimated bacterial biomass.**



**Figure B.7: Observation and evaluation platform connecting process tanks in the system.**



**Figure B.8: Phosphorus removal module at Tyndall farm.**



**Figure B.9: Depurated effluent from the 2nd generation treatment system.**



**Figure B.10: USDA-ARS staff monitoring the process conditions at 2nd generation Super Soil System.**



**Figure B.11: Tour of treatment system at Tyndall farm by NC Div. Soil and Water Conservation, USDA-NRCS, NC Dept. of Justice, NCSU A&PVMC, NC DNR, and industry, January 2007.**



**Figure B.12: View of nitrification tank (right) and phosphorus module (left).**



**Figure B.13: Field Day organized by Super Soil Systems USA, June 2007.**

**(A)**



**(B)**



**Figure B.14: (A) Lagoon 1 in Dec. 2006 before new treatment system started operation; and (B) same lagoon in July 2007 showing green algae, which is an intermediate stage in its transformation into an aerobic pond.**