Title: On-farm Evaluation of the Good Neighbor System for Manure Treatment for Reducing Emissions from Swine Facilities - **NPB #04-164**

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Industry Summary: The objective of this study was to investigate the effectiveness of the Good Neighbor System (GNS) at reducing gaseous emissions from swine facilities under full-scale production conditions. Also, the impacts of the GNS on manure composition and animal performance and on the costs associated with adopting the system on typical swine facilities were evaluated.

The GNS, a commercially available program, consists of three processes, as follows:

1. Treatment of the stored manure with a neutralizing agent to increase the pH of the slurry to reduce the release of hydrogen sulfide and volatile fatty acids (major components of "swine odor") from the manure.
2. Covering the surface of the manure in the pit with a liquid oil "lid" to reduce gaseous emissions.
3. Spraying the building air space with an atomized oil-based liquid acidifier to reduce ammonia and dust levels within the building.

The GNS is fully automated and, after installation, requires limited labor input.

The study was carried out in four identical 1,000 head wean-to-finish barns located at a site in central Illinois. The barns had fully-slotted floors, with deep pits, and were tunnel ventilated with side curtains. There were five room-exhaust fans located at one end of each building (4 x 122 cm diameter fixed speed fans and 1 x 91 cm diameter variable speed fan); there were 4 x 46 cm diameter pit fans, two located on each side of the building. The GNS was installed in two of the barns with the other two being left untreated to act as controls. The GNS was operated in accordance with the supplier's recommendations. Each barn was fitted with equipment to automatically sample and measure gas concentrations (ammonia, hydrogen sulfide, and carbon dioxide) in the inlet air into the barn and at three of the exhaust fans (two room-exhaust and one pit fan). In addition, odor levels were periodically measured at one room-exhaust fan and one pit fan, and manure composition, bacterial levels in the exhaust air stream, and animal performance were also measured. The time of operation and speed of all of the fans on the building (five room-exhaust and four pit fans) were monitored continuously to calculate total ventilation rates. Monitoring of the barns was carried out over a 12 month period to test the GNS in the range of weather conditions typically experienced in the Midwest of the U.S. The barns treated with the GNS compared to the controls had lower ammonia emission rates (about 15%) but this treatment difference was not statistically significant and this result requires validation. Odor concentrations were lower (approximately 33%) for the GNS compared to the control, however, hydrogen sulfide emission rates were actually higher for GNS compared to the

ontrol. There was no effect of the GNS relative to controls on manure pH; the concentrations of sulfur and copper were lower in the manure from the GNS barns compared to the control barns, however, these treatment differences were small. There was no effect of the GNS compared to the control on pig growth rate, number of treatments given to pigs for health problems, or mortality levels. Costs associated with the purchase and installation of the GNS for a typical 1000 head wean-to-finish barn were approximately $14 per pig place and material costs (for the liquid oil lid, atomization solution, and pit neutralizer solution) equated to around $3.50/pig produced. Assuming the 10 year depreciation time claimed by the supplier for this system resulted in a total cost for installing and operating the system of approximately $4.19/pig produced.

The results of this study suggest that the GNS was effective at reducing odor concentrations in the fan exhaust air and could possibly reduce ammonia emissions, although this requires validation. There was no positive impact of the GNS on manure nutrient composition or animal performance and, consequently, no economic gains to offset against the cost of adopting this system which was around $4.19/pig produced.

Scientific Abstract: This study was carried out to evaluate the effectiveness of a commercially-available program, the Good Neighbor System (GNS), at reducing gaseous emissions from swine facilities. In addition, the impact of the GNS on manure composition and animal performance was also evaluated. The Good Neighbor System is a fully-automated, three-part process that consists of the following:

1. Treatment of the stored manure with a neutralizing agent to increase the pH of the slurry to reduce the release of hydrogen sulfide and volatile fatty acids (major components of "swine" odor) from the manure.
2. Covering the surface of the manure in the pit with a liquid oil "lid" to reduce gaseous emissions.
3. Spraying the building air space with an atomized oil-based liquid acidifier to reduce ammonia and dust levels within the building.

The study was carried out in four identical commercial wean-to-finish barns as a completely andomized design with two treatments: 1. Good Neighbor System (barns treated with the full system) 2. Control treatment (barns left untreated). There were two replicates (barns) per treatment with the four barns being randomly allotted to either the GNS or the control treatments.

The barns had totally-slatted floors with deep pits and were tunnel ventilated with curtain sides. Five room-exhaust fans were located at one end of the buildings and there were four pit fans, two on each side of the buildings. The study was carried out over a 12-month period that involved two complete cycles of pigs (from filling of the barn with newly-weaned piglets to emptying of the barn and shipping of the pigs for harvest). The manure pits were not emptied during the study period. Gas levels (ammonia, hydrogen sulfide, and carbon dioxide) were automatically measured at the air inlet into the barn, and at two of the room-exhaust fans and one of the pit fans. The time of operation and the speed of all of the fans were continuously measured to calculate ventilation rates. Calculation of emission rates was based on the difference in concentration of the gases between the air inlet and the exhaust fans and the ventilation rate. Samples of exhaust air were taken periodically during the study from one of the room-exhaust fans and one of the pit fans and odor levels were measured using olfactometry. The pH of the manure was measured every two weeks during the study and a sample of manure was taken at the end of the study to measure nutrient composition. A subsample of 10% of the pigs (104 pigs from each barn in each cycle) was weighed at entry into the barn at weaning and at 10 and 20 weeks postweaning to measure growth rates, and the number of treatments that were given to the animals for health problems and all deaths were recorded for the first cycle of the barn only.

Total emission rates for ammonia, averaged across the 12-month period of the study were not different ($P = 0.34$) between barns treated with the GNS and untreated control barns (440 and 520 g/day, for the GNS and control respectively; SEM = 33.7). Total emission rates for hydrogen sulfide were higher ($P = 0.03$) for the GNS compared to the control (81.8 and 63.2 g/day, respectively; SEM = 0.54). There was no effect of barn treatment on total emission rates for carbon dioxide. Average odor concentrations measured at one of the room-exhaust and one of the pit-exhaust fans were lower ($P = 0.07$) for the GNS than the control (1463 and 2198 threshold units, respectively; SEM = 331.1). There was no effect of the GNS on either total bacterial counts in the barn exhaust air or on manure pH. The concentrations of sulfur and copper were lower ($P < 0.05$) in the manure from the GNS than the control, however, treatment differences were small. Also, the growth rate of the pigs from weaning to

week 20 postweaning, the number of treatments administered to the animals for health problems, and mortality levels were similar ($P > 0.05$) for the GNS and control treatments.

Overall, results of this study suggest that the Good Neighbor System was effective in reducing odor concentrations at the room-exhaust and pit-exhaust fans. However, the system was not effective at reducing ammonia and hydrogen sulfide emissions and had no effect on any other parameter measured, including manure composition and animal performance.

Introduction:

The issue of emissions of odors and gases from swine facilities is of critical importance to the US agricultural industry. Public complaints and concerns about proposed siting of new facilities and expansion of existing operations are focused largely on the potential impact of emissions on neighbors and continue to be the major limitation to the long-term public acceptance and future prosperity of the industry. Despite considerable research effort, very few approaches for emission reduction have been fully evaluated for commercial application and there is still a dearth of proven practical solutions to these problems available to producers.

The Good Neighbor System (GNS) is a commercially available program that involves three processes that, in theory, could reduce gaseous emissions from swine buildings. The three processes involved in the GNS are:

1. Treatment of the stored liquid manure in the pit with a neutralizing agent to maintain the slurry pH at around 7.5. This, in theory, will neutralize the acids thereby reducing odor production from the manure (volatile fatty acids are major components of swine manure odor), as well as reducing hydrogen sulfide emissions.
2. Covering the surface of the liquid manure in the pit with a layer of oil (the so-called "lid") which should limit gaseous emissions (Portejoie et al., 2003).
3. Treatment of the air space in the building with an atomized, acidified, oil-based spray that is claimed to neutralize gaseous ammonia and could also reduce dust levels in the building (Stevens et al., 1989; Riskowski, 2003).

Thus, from a theoretical standpoint and based on previous research, the manufacturers' claim for the GNS for reducing gaseous and dust emissions from swine buildings can be supported by data in the literature. However, before producers can be confident that the GNS is effective, these claims require validation in full-scale field evaluations and this was the overall objective of this project.

Objectives:

I. Evaluate the effectiveness of the Good Neighbor System at reducing dust and gaseous emissions from typical swine facilities.

II. Establish the impact of the GNS on animal performance (mortality, morbidity, and growth rate).

III. Carry out a cost-benefit analysis to establish the economics of adopting the GNS on typical Illinois swine operations.

Materials & Methods:

Study Location:

The project was carried out at a commercial site belonging to the Maschhoffs Inc. located at McLean, Illinois (Diagram 1). This site had 9 similar wean-to-finish barns that were identical in design with the exception that 4 of the barns were designed for ~1,000 pigs and the other 5 barns were designed for ~1100 pigs and were, therefore, longer. The four barns used in this study were those for 1,000 head. All barns had tunnel ventilation and deep pits that were pumped once per year in the Fall (October).

Study Design:

This study was carried out as a randomized design with two treatments (barn treated with GNS vs. untreated control barn) and two replicates (barns) per treatment. Four identical barns were used; two were chosen at random to be treated with the GNS (i.e., slurry neutralizer, oil lid, and atomized spray in combination); the other two barns were left untreated. The GNS was operated according to the supplier's recommendations (Note: The system supplier installed all of the equipment for the study, supplied all of the treatment materials used during the study, and was closely involved in supervising the operation of the system to ensure that it was functioning properly). The study was carried out between November 2005 and October 2006 during which there were two cycles (from entry of the newly-weaned piglets to emptying of the barns and shipping of pigs for harvest) of the wean-to-finish barns (Cycle 1: November 2005 to April 2006; Cycle 2: May 2006 to October 2006) to evaluate the program over the range of weather conditions and with all the possible amounts of manure that were likely to be stored in the deep pit beneath the building.

Facilities:

The four identical wean-to-finish buildings used in the study were 64.5 meters long and 12.2 meters wide giving a total building floor space of 787 m^2. The floors were of total slats; pens held ~26 pigs at a floor space of ~0.65 m^2/pig. Pigs were placed in the building at weaning at ~18 days of age and 5 kg live weight and the building was emptied when pigs reached an average weight of ~130 kg. Pigs had ad libitum access to feed from an Aquatube Wet/Dry Feeder and water from two nipple-type drinkers in each pen. The building air space was tunnel ventilated by 5 room-exhaust fans (four 122 cm diameter fans and one 91 cm diameter fan). The fans were thermostatically controlled with the 91 cm diameter fan operating at variable speed for minimum ventilation, and with the four 122 cm diameter fans being fixed speed. The pit was 2.4 meters deep and was ventilated by four 46 cm diameter pit fans that ran continuously, with two on either side of the building. The facilities used in this study are illustrated in Diagram 2.

Diagram 1. Barn layout at the McLean Site.

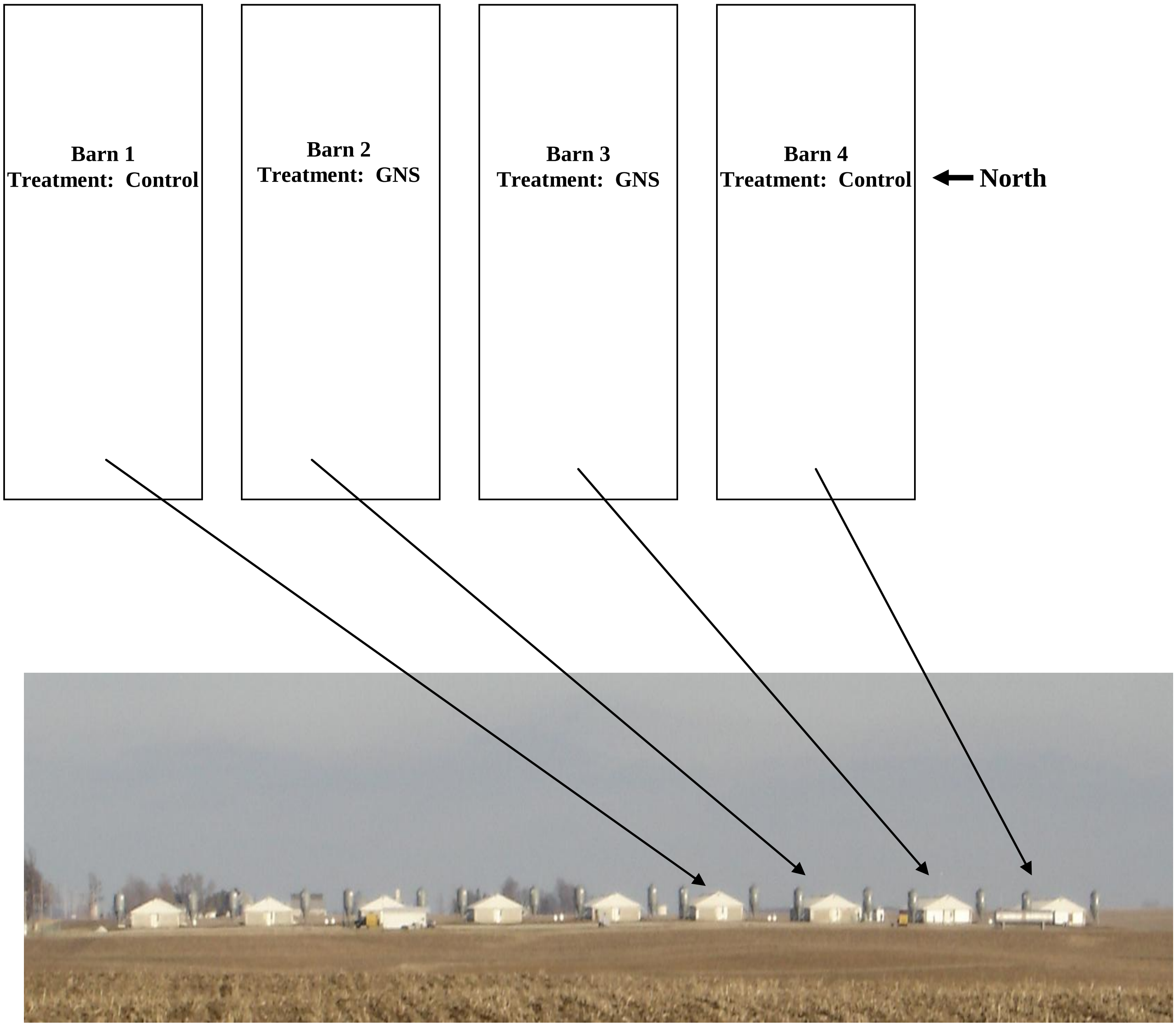
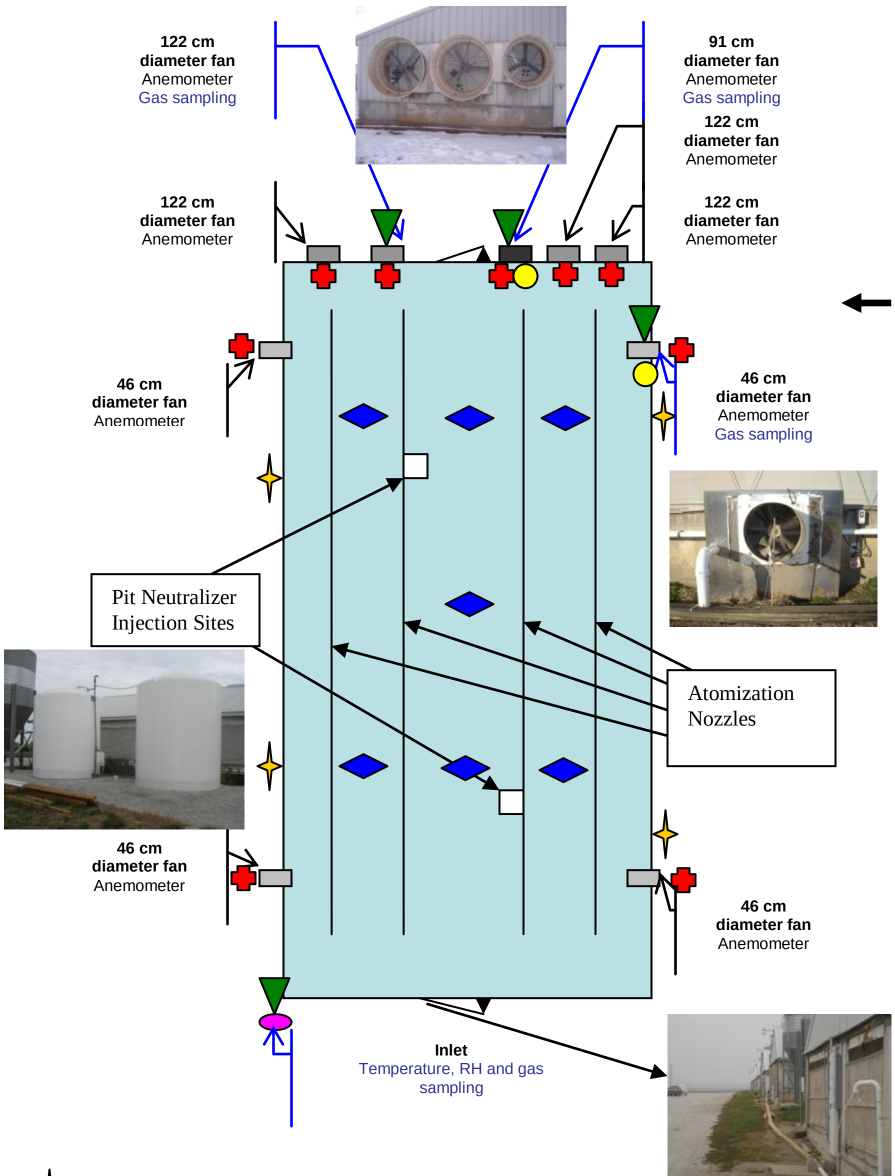


Diagram 2. Locations of monitoring equipment and GNS equipment.



- Sites of manure sampling
- Sites of measurement of manure pH
- Sampling locations for ammonia, hydrogen sulfide, and carbon dioxide
- Sampling locations for odor
- Location of anemometers to measure fan speed and operating time

Operation of the Good Neighbor System: The oil lid was applied at the beginning of the study, and was left intact until the end of testing. No oil was added or removed during the course of the study. Oil was added to the manure pit in each treated barn so that the oil depth was approximately 1.9 cm. The oil used was petroleum based, similar to some crop oil surfactants.

The neutralizer was injected into the pit at a depth of approximately 200 cm in two separate locations (see Diagram 2). Probes were fixed to the neutralizer injectors to monitor slurry pH; when the pH dropped below 7.4, neutralizer solution was added to bring the pH up to the target level of 7.5. The atomization nozzles were installed in four rows running the length of the ceiling of the barn. Each row had 11 nozzles that were placed 6.1 m apart for a total of 88 nozzles per barn. Atomization occurred once per day at 3 am, and a total of 1.85 gallons of the atomization solution was applied to each barn at the daily application. The atomization and pit neutralizer systems were both fully automated.

Gas Sampling System: A gas sampling system, linked to automatic gas analyzers, was installed in each of the four barns to sample air from inlet and exhaust air locations. The system had the capacity to sample at up to 16 different locations (4 locations per barn). It consisted of Teflon tubing and a pump that brought the air from the location being sampled to a three-way solenoid valve, a mass flow meter, and a sampling manifold. Concentrations of gases (ammonia, hydrogen sulfide, and carbon dioxide) in the manifold were measured using gas analyzers as described below.

Four points were sampled in each building, namely at the air inlet and at two room-exhaust fans and one pit fan (Diagram 2). Since the buildings were tunnel ventilated, two room fan exhaust points were used to represent the concentration of air exhausting from each tunnel fan. The two sampling points were located on the east side of the building (Diagram 2) at the intake of the 91cm diameter fan (variable speed) and one of the 122 cm diameter fans (fixed speed). One of the 46 cm diameter pit fans was monitored per building. In addition to the exhaust and pit fan locations, gas concentrations were measured at the air inlet at the west end of the building bringing the gas sampling and measurement points to four per building, and 16 for the four buildings involved in the study. Air from each sampling location was sampled and measured continuously for 10 min before switching to another sampling location. Thus, for the 16 sampling locations, a 160-minute sampling cycle allowed each location to be sampled nine times per day.

Gas Sampling Instrumentation:

Ammonia: Ammonia (NH_3) was measured with a Chemiluminescence NH_3 analyzer (Model 17C, TEI, Franklin, MA) which is a combination of an NH_3 converter and an NO-NO_2-NO_x analyzer. The analyzers scale range was set at 0 to 200 ppm.

Hydrogen Sulfide: Hydrogen sulfide (H_2S) was measured with a pulsed-fluorescence SO_2 detector (TEI Model 45C) after the H_2S was converted to SO_2 with an SO_2 converter (TEI Model 340). The equipment had a range of 0.05 to 100 ppm.

Carbon Dioxide: Carbon dioxide (CO_2) concentrations were measured with 2,000 ppm and 10,000 ppm photo acoustic infrared CO_2 analyzers (Model 3600, MSA).

For a detailed explanation of the operation of the gas analyzers see Heber et al. (2001).

All gas analyzers were calibrated (zero, span, and multipoint) prior to use and at regular intervals during sampling (every two weeks or whenever the offset was greater than ±5%). Gas calibration was done using a dilution chamber and calibration gases.

***Sampling and Measurement of Odor*:** Odor samples were collected at the intake of the 91 cm diameter exhaust fan and at the intake of one of the 46 cm diameter pit fans (Diagram 2) once per week over a five-week period in September and October 2006. Samples of air for measuring odor concentration were pumped into 10 L Tedlar air sampling bags fitted with a polypropylene valve (Cat. No. 231-939, SKC, Eighty four, PA) using a sealed Vac-U-Chamber (SKC Vac-U-Chamber, Eighty four, PA) and a sampling pump (Model No. PCXR4, SKC, Eighty four, PA). The bags were then shipped to the Iowa State University Olfactometry Laboratory for analysis which was carried out on the day following sample collection. Odor threshold levels were measured using dilution olfactometry as described below.

Odor concentrations were assessed by a group of 8 trained panelists using an olfactometer (AC'SCENT Olfactometer, St. Croix Sensory, Inc., Lake Elmo, MN) and the triangular forced-choice method. Each panelist was presented with six to eight dilutions of each sample, with each dilution differing by a factor of two. Dilutions were made using odor-free air supplied by a compressor fitted with activated carbon filters and an air dryer. Each panelist sniffed each of the three sample presentations, one of which contained the odor, the other two of which were 'blanks'. The panelist then selected the one of the three that was 'different' from the other two. For each dilution, panelists indicated, by pushing a button, which sample presentation was the odorous air and if the selection was a 'guess', 'detection', or 'recognition', as defined by ASTM E679-91. Dilution threshold was determined by the geometric mean of the last concentration at which the odor was not detected and the next higher concentration that the panelist could correctly detect.

Airborne Bacteria Concentration: Total airborne bacteria concentration in the exhaust air was measured in colony formation units/m^3 of air (Hurst et al., 1997). A Total Suspended Particle sampling device, developed at the University of Illinois (UIUC-TSP), was used to collect dust from the exhaust air at the inlet of the 91 cm diameter variable speed fan in each barn. The air was pumped across a paper filter (2 ft^3/min) for 24 hours. The paper filters were then mixed in 10 ml of sterilized phosphate buffer solution. After a series of dilutions with phosphate buffer (10^1 to 10^3) 20 µl from the 10^3 dilution was spread on a sterilized culture plate using the Dropler method. After 48 h of incubation, the number of colony formation units were counted on the culture plates and used to calculate the concentration of airborne bacteria in the exhaust air. All samples were measured in triplicate.

Ventilation Fan Monitoring: The ventilation rates in each building were measured with propeller anemometers which were installed downstream of all of the fans (room-exhaust and pit fans). The anemometers measured the total air flow rate through a fan by measuring the airspeed at a representative location. The propeller anemometer consisted of an 18-cm diameter vane attached to a sealed bearing direct current (DC) generator that produced a 0-1 voltage DC output proportional to the rotational speed. The exact location of the anemometer downstream of the fan was determined during calibration of the fans in the fan test chamber in the BESS laboratory at the University of Illinois. The ventilation rate of all exhaust and pit fans was measured to calculate the total building ventilation rate. All data were recorded continuously using Fieldpoint data acquisition (DAQ) modules (National Instruments, Austin, TX), the operation of which was controlled by a labVIEW computer program.

Environmental Parameter Measurements: The environmental conditions were monitored continuously within the building and in the exhaust air at the fans. Ambient air temperature at the gas sampling locations was logged to allow corrections to the volumetric flow rate to be made. Three copper-constantan thermocouples (Type T) were used to sense temperature and they were located inside the barn, at the inlet, and in the airspace of the enclosure surrounding the pit fan that was being monitored for gaseous emissions in each of the four barns (Diagram 2).

An electronic relative humidity and temperature transmitter (Model HMW61, Vaisala, Woburn, MA) housed in a NEMA-4 enclosure monitored temperature and relative humidity at the exhaust fan sampling locations in each building. Ambient weather data were obtained from a weather station located at Bloomington, IL, about 10 miles from the trial site.

Manure composition: The pH of the manure was measured every 2 weeks during the study with measurements being made at 7 locations in each pit (Diagram 2). Core samples of the manure were taken at each of the sampling locations and placed in sealed plastic containers. The pH of each sample was recorded immediately after the samples were taken using an Oyster-16 pH meter (Extech Instruments, Waltham, MA). The pH meter was calibrated before each sampling event using standard buffer solutions of pH 4.01, 7.01, and 10.0. Samples of the manure in the pit were taken from each of the four pump-out ports of each barn (Diagram 2) one week prior to manure pumping. Samples were composited by barn and were analyzed for pH, chemical composition (TKN, NH_3-N, P, and K), and total solids using standard analytical procedures (AOAC, 1998).

***Animal Environment, Health, and Performance*:** During the first and second cycles of the barn (November 2005 to April 2006 and May 2006 to October 2006, respectively), a sub-sample of 104 pigs (10% of animals) were randomly selected in each building and weighed individually at the start, 10 wks post-placement, and 20 wks post-placement to measure growth rates. During the first cycle of the barn only, all treatments given because of health problems, and all mortalities were recorded.

Calculation of Emission Rates: The emission rate for each fan was calculated using the following formula:

$$\mathbf{E = (Ce - Ci) \times M \times \left(\frac{Pa}{R \times (Ta + 273.15)} \right) \times Qa}$$

Where:

E = Emission rate, mg/sec
Ce = Exhaust gas concentration, ppm
Ci = Inlet gas concentration, ppm
M = Molecular weight
= 17.03 for ammonia
= 34.08 for hydrogen sulfide

= 44 for carbon dioxide
R = 0.08206 L-atm/(mol-K)
Ta = Temperature measured at each fan, ^{o}C
Pa = Atmospheric pressure, atm
Qa = Ventilation rate for each fan, m^3/s

The temperature and ventilation rates were measured for each of the 9 fans on each building (5 room-exhaust fans and 4 pit fans). Exhaust gas concentrations were measured at the 91 cm diameter room-exhaust fans, at one of the 122 cm diameter room-exhaust fans, and at one of the 46 cm pit-exhaust fans. It was assumed that the exhaust gas concentrations were the same for all four of the pit-exhaust fans and all four of the 122 cm diameter room-exhaust fans.

Statistical Analysis

Daily means were computed for gas concentrations, and ventilation and emission rates and were analyzed as a randomized complete block design with two treatments using the GLM procedures of SAS (SAS Inst., Cary, NC). The model used included the effect of barn treatment (GNS vs. control).

Economics

All costs incurred during the study associated with the installation and application of the technology were collected and these were used to calculate the cost of the GNS per finished pig produced.

Results:

Conditions During the Study: The outside weather conditions, measured at a weather station located at Bloomington, IL, about 10 miles north of the McLean site where this study was carried out, together with the average temperature and relative humidity levels in the barns during the study period are summarized in Table 1 and the monthly values for temperature and relative humidity are illustrated in Figure 1; equivalent monthly data for external weather conditions, and internal barn temperature and relative humidity are presented in Appendix 1 and 2, respectively.

Table 1. Descriptive statistics for average environmental conditions during the study (external weather conditions and internal temperature and relative humidity levels in the barn).

	Mean	Standard deviation	Maximum	Minimum
Outside weather condition				
Temperature, ^{o}C	11.1	10.3	33.9	-18.3
Relative humidity, %	76.8	14.6	100.0	19.0
Atmospheric pressure, in. Hg	30.0	0.2	30.8	29.2
Wind speed, km/hour	16.9	3.2	42.0	2.0
Conditions inside the barns				
Temperature, ^{o}C	21.4	2.8	25.8	16.2
Relative humidity, %	51.9	8.5	68.0	36.9

Average monthly internal barn temperature and relative humidity during the study, summarized by barn and treatment, are presented in Figures 2 and 3, respectively. The monthly treatment means and statistics for internal barn temperature and relative humidity are presented in Appendix 3 and 4, respectively. In general, temperature and relative humidity levels were similar for the GNS and control treatments (Figure 3).

Figure 1. Average external and internal barn temperature and relative humidity by month of study.

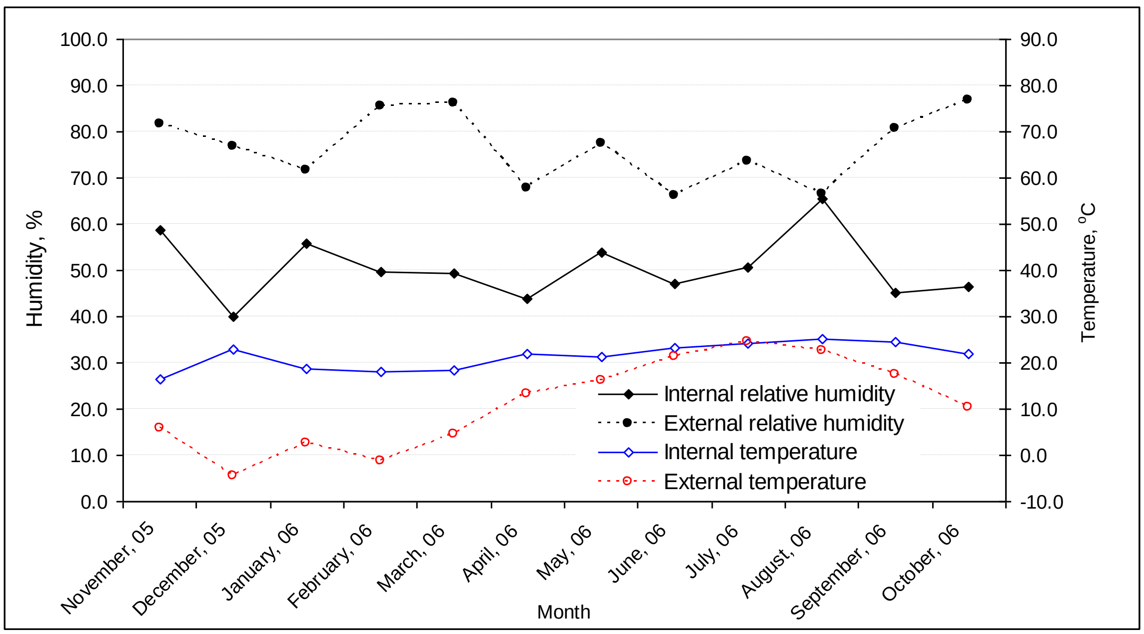


Figure 2. Average monthly internal barn temperature and relative humidity for the four barns.

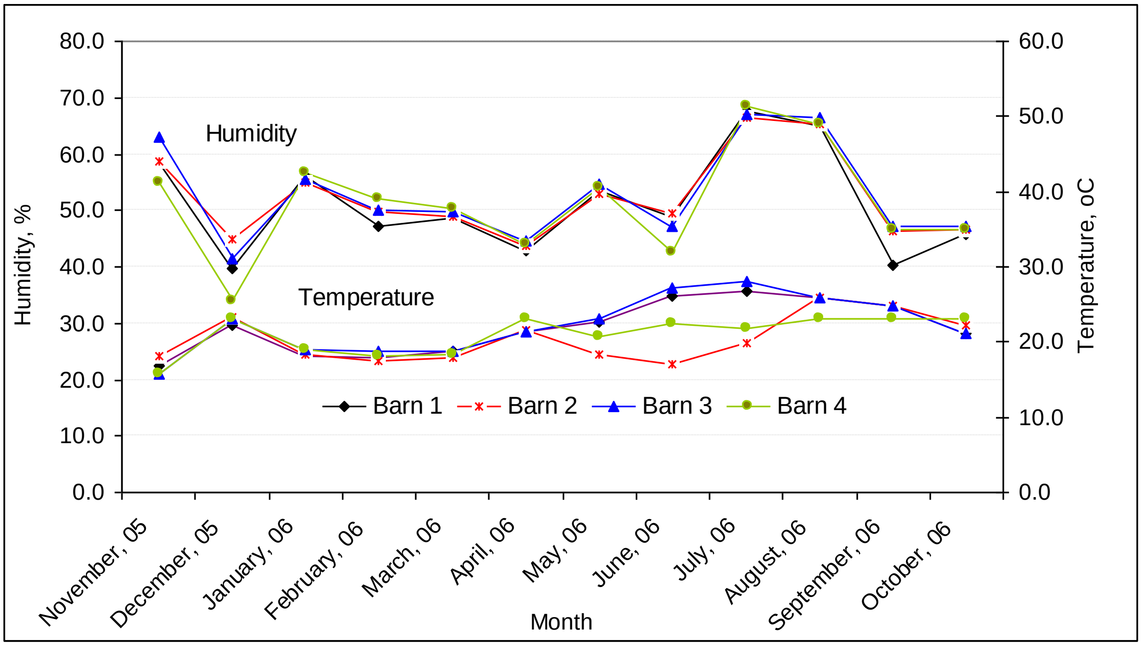
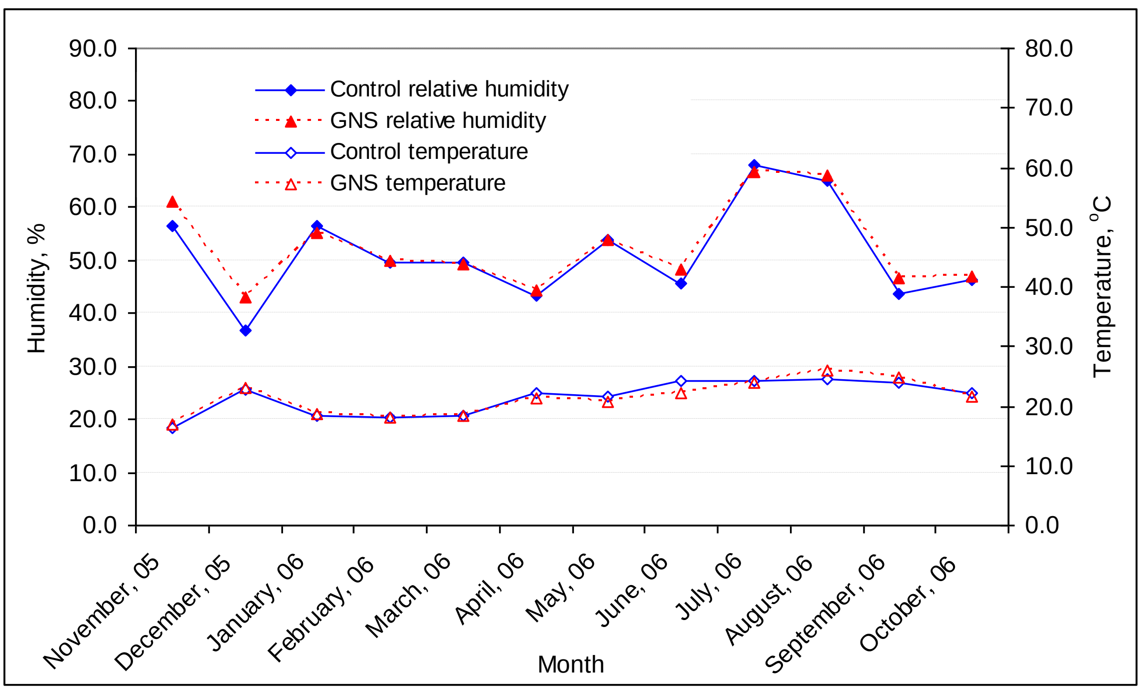


Figure 3. Average monthly internal barn temperature and relative humidity for GNS and control treatments.



Objective I. Evaluate the effectiveness of the Good Neighbor System at reducing gaseous emissions from typical swine facilities.

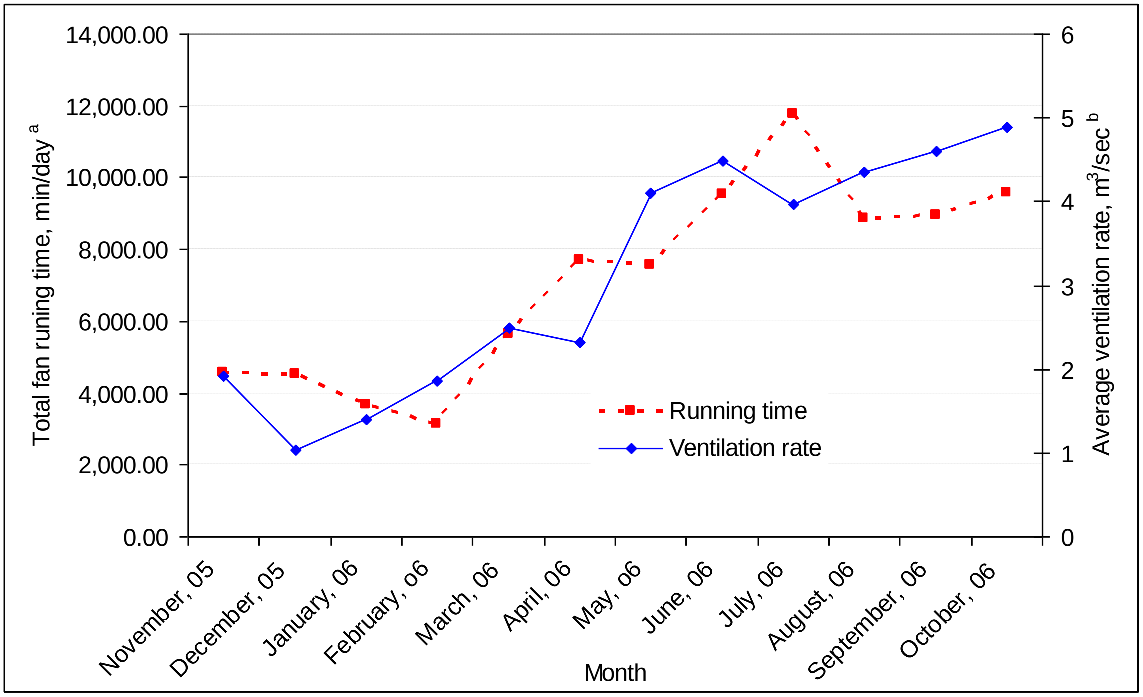
Descriptive Statistics: Descriptive statistics for overall gas concentrations and emission rates, bacteria levels in the barn exhaust air, and fan performance parameters (running time and ventilation rate) are presented in Table 2. The monthly average concentrations at the air inlet and exhaust fans for ammonia, hydrogen sulfide, and carbon dioxide are presented in Appendices 5, 6, and 7, respectively. Fan total running time and total ventilation rate for each month of the study are illustrated in Figure 4 with means and statistics being presented in Appendix 8. Monthly average gaseous emission rates are illustrated in Figure 5 and presented in Appendix 9. Emission rates for ammonia, hydrogen sulfide, and carbon dioxide were generally higher from March to June 2006 than either before or after this period (Figure 5).

Table 2. Descriptive statistics for overall mean gas concentrations and emissions rates, bacteria levels in the barn exhaust air, fan running times, and ventilation rates.

	Mean	Standard deviation	Maximum	Minimum
Inlet gas concentrations, ppm				
Ammonia	2.72	0.15	2.95	2.62
Hydrogen sulfide	0.08	0.01	0.09	0.07
Carbon dioxide	803	8.4	815	795
Exhaust fan gas concentrations, ppm[a]				
Ammonia	3.56	0.10	3.67	3.42
Hydrogen sulfide	0.14	0.02	0.16	0.11
Carbon dioxide	950	21.5	967	922
Emission rates, g/day				
Ammonia	480	58.2	563	435
Hydrogen sulfide	72.5	10.7	82.0	62.2
Carbon dioxide	181,810	23,796	199,700	146,740
Odor levels, threshold units[b]	1,821	617.1	2767	1304
Bacteria levels in exhaust air, CFU/m^3 x10^3[c]	7.24	0.13	7.58	7.00
Fan measurements				
Total fan running time, minutes/day[d]	7,120	156	7,255	6,967
Average ventilation rate, m^3/second[c]	3.12	0.13	3.30	3.02

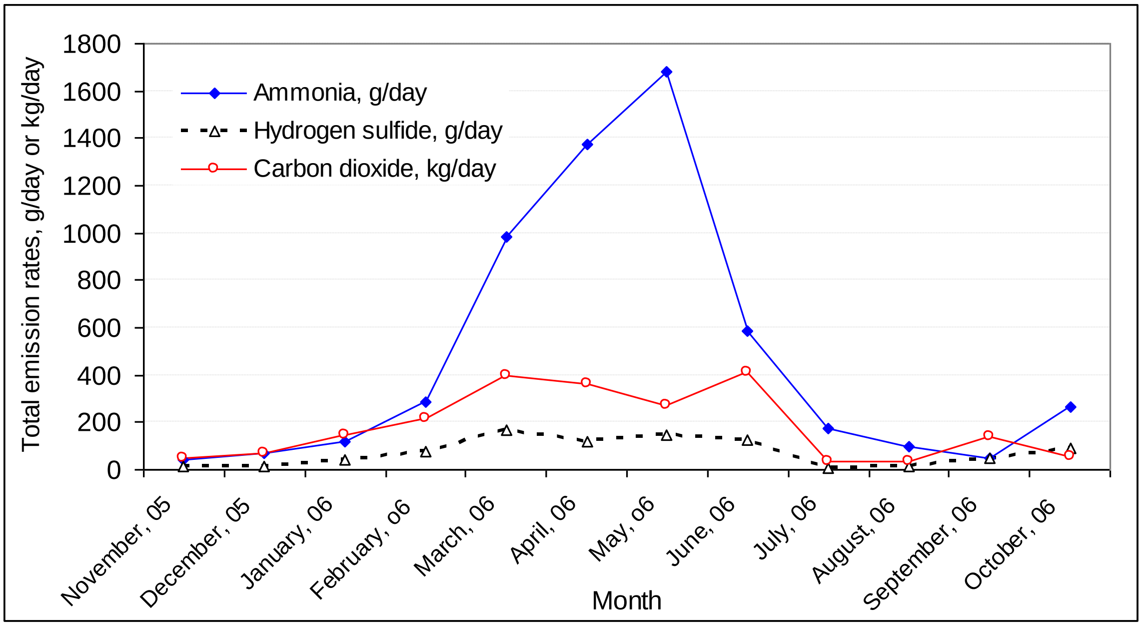
[a]Average concentration at three exhaust fans (two room-exhaust fans and one pit fan).
[b]Average concentration at two exhaust fans (one room-exhaust fan and one pit fan).
[c]CFU= Colony Formation Units.
[d]Total time that all fans (five room-exhaust fans and four pit fans) were running.
[e]Average ventilation rate of all nine fans

Figure 4. Total fan running times and ventilation rates by month of study.



[a]Total time that all nine fans (five room-exhaust fans and four pit fans) were running.
[b]Average ventilation rate of all nine fans.

Figure 5. Monthly average total emission rates for ammonia, hydrogen sulfide, and carbon dioxide.



Barn Treatment Effects: Overall means for the effect of barn treatment on gas levels and emission rates and odor levels are presented in Table 3; monthly means for gas levels at the inlet and exhaust fans and emission rates are given in Appendices 10 to 18; monthly means for emission rates are illustrated in Figures 6, 7, and 8.

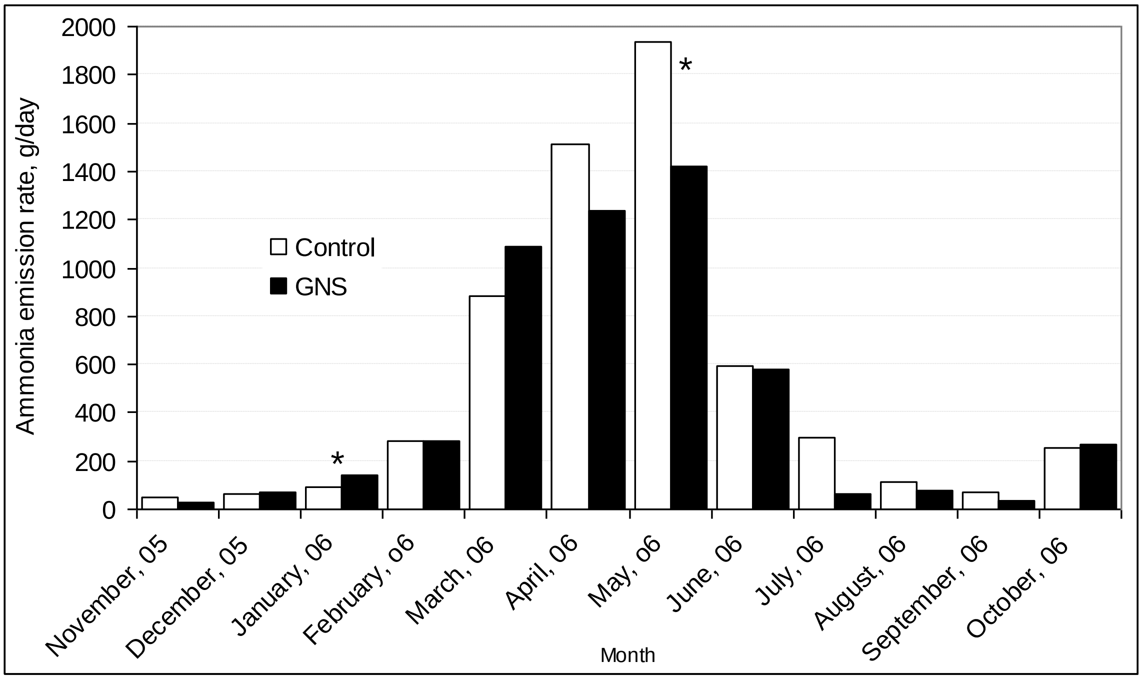
There were no barn treatment effects on inlet or exhaust fan concentrations for any of the gases monitored (Table 3). Ammonia emission rates were approximately 15% lower for the barns treated with the GNS, however, this treatment difference was not statistically significant ($P = 0.34$). Monthly ammonia emission rates were significantly lower ($P < 0.05$) for the GNS compared to controls in the month of May and higher ($P < 0.05$) in January (Figure 6). Overall hydrogen sulfide emission rates were greater ($P < 0.05$) for the GNS compared to controls, however, there was no treatment effect on overall carbon dioxide emission rates (Table 3). Monthly means for hydrogen sulfide emissions were greater ($P < 0.05$) for the GNS than the control for the month of June only (Figure 7). Monthly means for carbon dioxide emissions were higher ($P < 0.05$) for the GNS than the control in March, but there was no effect ($P > 0.05$) of barn treatment on carbon dioxide emission rates in any other month (Figure 8). Average odor levels at the room-exhaust and pit fan that were sampled were around 33% lower ($P = 0.07$) for the GNS compared to the control. Total bacteria counts were similar ($P > 0.05$) for the GNS and control treatments (Table 3).

Table 3. Barn treatment means for overall gas concentrations and emission rates and odor and bacterial levels.

	Treatment			
	Control	Good Neighbor System	SEM	*P* Value
Inlet gas concentrations, ppm				
Ammonia	2.78	2.66	0.094	0.52
Hydrogen sulfide	0.08	0.08	0.0041	0.79
Carbon dioxide	805	801	6.6	0.78
Exhaust fan gas concentrations, ppm[a]				
Ammonia	3.61	3.51	0.023	0.20
Hydrogen sulfide	0.126	0.155	0.0067	0.21
Carbon dioxide	944	956	7.9	0.50
Emission rates, g/day				
Ammonia	520	440	33.7	0.34
Hydrogen sulfide	63.2	81.8	0.54	0.03
Carbon dioxide	173,220	190,400	18,159	0.62
Odor levels, threshold units[b]	2,198	1,443	331.1	0.07
Bacteria levels in exhaust air, CFU/m^3 x10^3	7.24	7.25	0.039	0.87

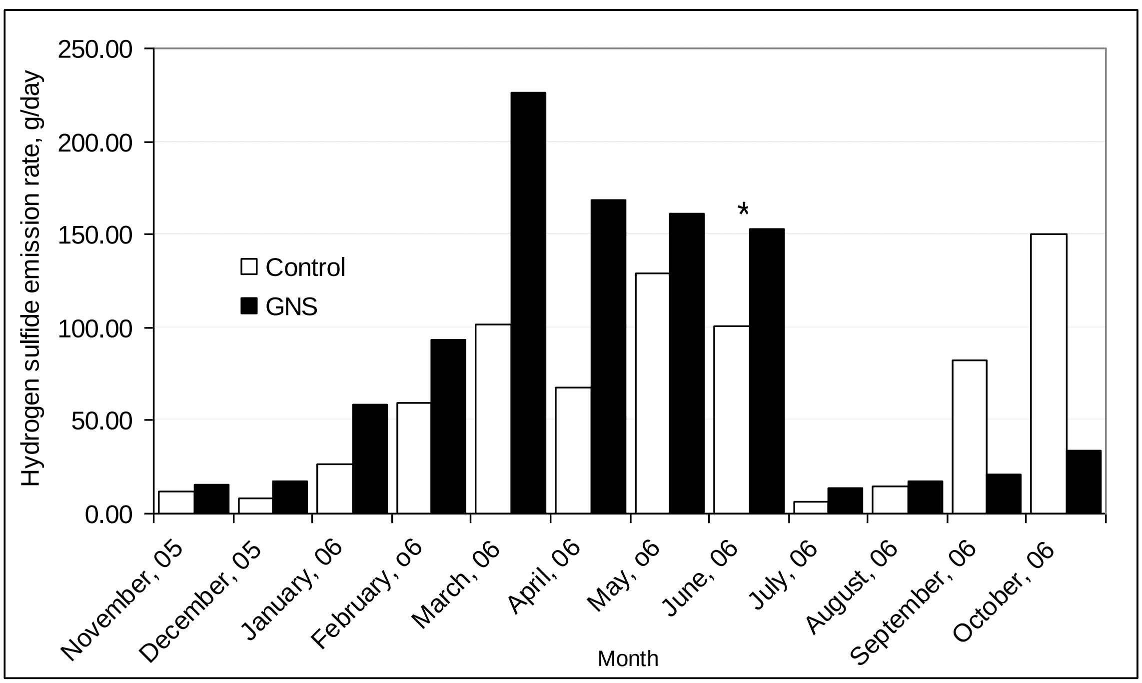
[a]Average concentration at three exhaust fans (two room-exhaust fans and one pit fan).
[b]Average concentration at two exhaust fans (one room-exhaust fan and one pit fan).

Figure 6. Barn treatment means for monthly average ammonia emission rate[a].



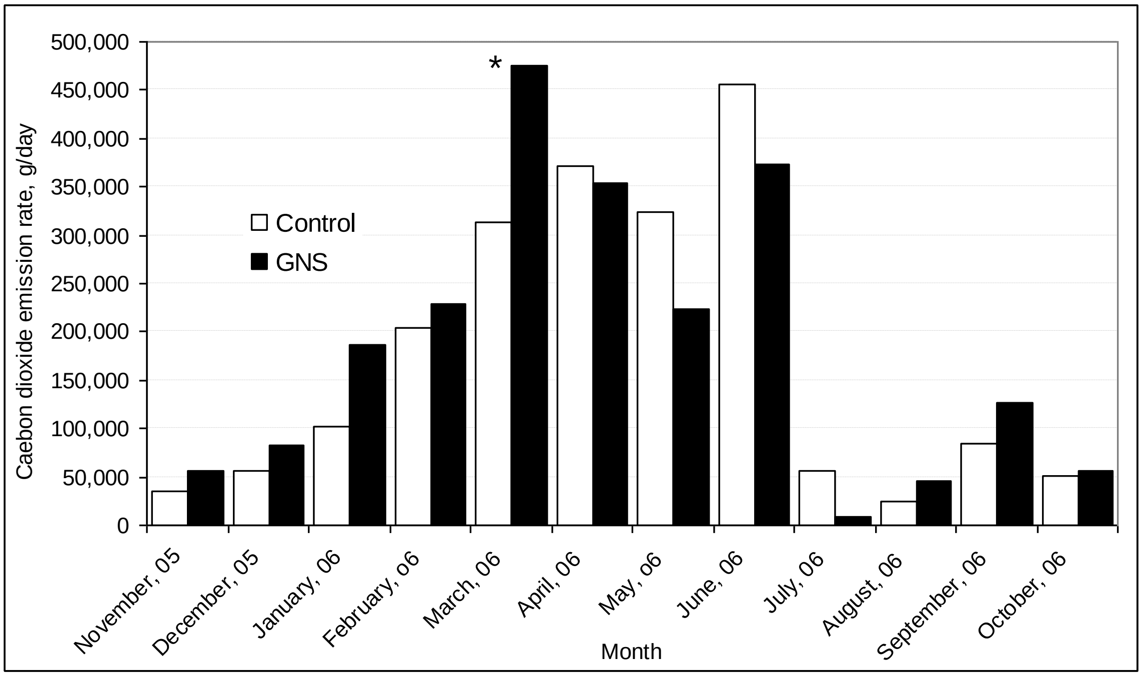
[a] Total emissions from all room-exhaust and pit fans.
*Barn treatment means differ (P < 0.05).

Figure 7. Barn treatment means for monthly average hydrogen sulfide emission rate[a].



[a] Total emissions from all room-exhaust and pit fans.
*Barn treatment means differ (P < 0.05).

Figure 8. Barn treatment means for monthly average carbon dioxide emission rate[a].



[a] Total emissions from all room-exhaust and pit fans.
*Barn treatment means differ ($P < 0.05$).

Manure Composition: Descriptive statistics for manure pH and manure composition are presented in Table 4 with barn treatment means being given in Table 5. The pH data is based on measurements taken every two weeks throughout the study period and the manure composition is based on samples taken in September 2006 when the manure storage pit was full, just before the end of the study and before pits were emptied. Manure samples were taken at four locations in each barn and combined into one composite sample per barn for analysis. Manure pH was similar ($P > 0.05$) for the control and GNS (7.58 vs. 7.65, respectively; Table 5). Manure concentrations for sulfur and copper were lower for the GNS compared to controls (Table 5), however, the treatment differences were relatively small.

Table 4. Descriptive statistics for manure composition[a].

	Average	Standard deviation	Maximum	Minimum
Manure pH[b]	7.62	0.08	7.67	7.50
Moisture, %	95.09	1.19	96.46	93.67
Solids, %	4.91	1.19	6.33	3.54
Nitrogen (total), %	0.64	0.03	0.68	0.61
Nitrogen (ammonium), %	0.45	0.03	0.48	0.42
Nitrogen (organic), %	0.19	0.05	0.26	0.15
Phosphorus, %	0.11	0.03	0.14	0.08
Potassium, %	0.28	0.03	0.30	0.23
Sulfur, %	0.05	0.01	0.06	0.04
Magnesium, %	0.06	0.01	0.07	0.04
Calcium, %	0.08	0.02	0.10	0.05
Sodium, %	0.07	0.01	0.08	0.06
Aluminum, ppm	34.50	7.05	42.00	25.00
Boron, ppm	4.00	0.00	4.00	4.00
Copper, ppm	40.00	9.13	50.00	30.00
Iron, ppm	129.75	26.17	159.00	96.00
Manganese, ppm	21.50	5.51	28.00	16.00
Zinc, ppm	160.25	37.57	208.00	123.00

[a]Based on one composite sample per barn taken in September 2006.
[b]Measured every two weeks throughout the study period.

Table 5. Barn treatment means for manure composition[a].

	Control	GNS	SEM	P Value
Manure pH[b]	7.58	7.66	0.064	0.54
Moisture, %	95.11	95.07	1.032	0.98
Solids, %	4.89	4.94	1.032	0.98
Nitrogen, total N %	0.65	0.64	0.027	0.82
Nitrogen, ammonium (NH4-N), %	0.44	0.47	0.018	0.42
Nitrogen, organic, (N), %	0.21	0.18	0.039	0.64
Phosphorus (P), %	0.13	0.09	0.010	0.11
Potassium (Na), %	0.29	0.26	0.022	0.44
Sulfur (S), %	0.06	0.04	0.000	0.001
Magnesium (Mg), %	0.07	0.05	0.005	0.11
Calcium (Ca), %	0.10	0.07	0.011	0.20
Sodium (Na), %	0.08	0.07	0.008	0.70
Aluminum (Al), ppm	35.50	33.50	6.021	0.84
Boron (B), ppm	4.00	4.00	0.000	0.99
Copper (Cu), ppm	47.50	32.50	2.500	0.05
Iron (Fe), ppm	148.00	111.50	13.440	0.19
Manganese (Mn), ppm	26.00	17.00	1.581	0.06
Zinc (Zn), ppm	189.50	131.00	14.252	0.10

SEM = Standard error of the mean
[a]Based on one composite sample per barn taken in September 2006.
[b]Measured every two weeks throughout the study period.

Objective II. Establish the impact of the GNS on animal performance.

The treatment means for animal performance are presented in Table 6; the growth data are based on a subsample of 10% of animals from the two cycles of the barn (208 pigs per treatment in each cycle). The number of treatments administered for health problems and mortality levels were recorded in the first cycle of the barn only. There was no effect of barn treatment on growth rates, the number of treatments administered for health problems, or mortality levels (Table 6).

Table 6. Barn treatment means for pig growth, number of health treatments, and mortality levels.

	Treatment			
Item	Control	GNS	SEM	*P* value
Number of animals[a]	416	416	-	-
Body weight, kg[a]				
Start (weaning)	11.09	10.45	3.960	0.31
Week 10 post-weaning	51.68	52.48	2.039	0.78
Week 20 post-weaning	114.83	113.85	2.201	0.77
Average daily gain, kg[a]				
Start to week 10	0.570	0.589	0.0500	0.63
Week 10 to week 20	0.974	0.944	0.0306	0.13
Start to week 20	0.762	0.758	0.0387	0.87
Number of treatment[b,c]	1,682	1,763	6.5	0.07
Mortality, %[c]	4.10	3.85	-	0.66

[a]Growth performance was measured during two cycles of the barn (Cycle 1: November 2005 to April 2006; Cycle 2: May 2006 to October 2006).
[b]Number of times animals were treated for health problems.
[c]Measured in Cycle 1 of the barn (November 2005 to April 2006).

Objective III. Carry out a cost-benefit analysis to establish the economics of adapting the GNS on a typical Illinois swine operation.

The economic analysis of the GNS, together with the assumptions used in this analysis, are presented in Table 7. The equipment purchase and installation costs and the costs of purchasing materials (oil lid, atomization solution, and pit neutralizer solution) are the actual charges that were incurred in setting up and running the system during the one-year period in which the study was carried out. The cost calculations assume a depreciation time for the GNS equipment of 10 years, as claimed by the supplier, and, also, that the oil lid would need to be replaced every three years.

Total purchase and installation cost for two barns with 1,000 head capacity each, such as used in this study, were $28,100 or approximately $14 per pig place (Table 7). Total material costs over the 10 year period would be $139,440 or approximately $3.49/pig produced. Thus, the total cost of the GNS would be approximately $4.19 per pig produced (Table 7).

Table 7. Economic analysis of the Good Neighbor System.

Item	Cost ($)[a]
Installation and running costs for the first year of operation	
Equipment purchase and installation	28,100
Materials	
Oil lid	22,000
Atomization solution	4,700
Pit neutralizer solution	2,500
Installation and running costs for a 10-year period[1]	
Equipment purchase and installation	28,100
Oil lid	66,000
Atomization solution	47,940
Pit neutralizer solution	25,500
Total costs	167,540
Cost per pig	***4.19***

[a]Costs for 2 x 1000 head barns.

Assumptions:

1. The GNS has an expected depreciation time of 10 years.
2. The oil lid would be replaced every 3 years.
3. The total cost of atomization and pit neutralizer solution would be $73,440 over the 10 year period assuming a 2% increase in cost every year.
4. Over the ten year period, there would be 20 groups of pigs finished through each barn for a total of 40,000 pigs.
5. No treatment differences in pig growth rate, mortality, or the number of treatments administered were observed. Also, there was no improvement in the nutrient composition of the manure for the GNS. Therefore, there were no economic gains to offset any of the costs of the GNS.

Discussion:

The evaluation of the Good Neighbor System was carried out in conventional, commercial wean-to-finish barns over a 12-month period from November 2005 to October 2006. Consequently, the evaluation was carried out under weather and production conditions typical of the Midwest of the US. The GNS performed reliably throughout and was regularly checked by the supplier to ensure that it was functioning properly.

There was no effect of the GNS on carbon dioxide emissions which was to be expected since no component of the system was designed to reduce carbon dioxide production or release from the buildings. Carbon dioxide results mainly from animal respiration and is of concern because it is one of the greenhouse gases.

Ammonia emission rates were considerably lower (~15%) for the barns treated with the GNS compared to the control barns, however, this treatment difference was not statistically significant. In some situations, a 15% reduction in ammonia emissions could be practically relevant and, therefore, establishing the effect of the GNS on ammonia emissions is important. The current study was a relatively large experiment from the standpoint of the investment of money and time into the four barns used to enable all of the data to be collected; it is interesting to note that over 23 million individual observations were taken during the 12 month study period. However, from a statistical standpoint it was a small experiment with only two replications per treatment. Obviously, more replications (barns) would be needed to detect a difference of 15% in ammonia emission rates between GNS and control treatments as statistically significant.

The increase in hydrogen sulfide emission for the GNS compared to the control is surprising, given that the GNS is, in theory at least, designed to reduce hydrogen sulfide levels. The principle used by the GNS to reduce hydrogen sulfide emissions is neutralizer additions to increase the pH of the manure and there is evidence in the literature that such an approach should be effective (Arogo et al., 1999). However, the relationship between the pH of the manure and gaseous emissions is complex (Derikx et al., 1994) and, although increasing the pH of liquid manure has been associated with reductions in hydrogen sulfide emissions, it has also been shown to increase the release of ammonia (Stevens et al., 1989). More importantly, in the current study manure pH measured at multiple locations in the manure pits showed that the GNS treated and control barns were not statistically different (Table 5). The pH of the manure in the barns treated with the GNS was numerically higher than that in the control barns (7.65 vs. 7.58), and it needs to be borne in mind that measurement of pH is based on a logarithmic scale and that a difference of 0.07 between the two barn treatments is a substantial difference, however, it was not statistically different. Interestingly, the pH of the manure averaged for both GNS and control barns across the entire study period was above the target pH of 7.5. The pH of swine manure can vary widely and is influenced by a number of factors including the diet fed to the pigs. For example, Kerr et al. (2006) found that feeding a low protein (12.5% crude protein), synthetic amino acid supplemented diet compared to feeding a higher protein diet (14.5% crude protein) with soybean meal as the major protein source resulted in a reduction in the pH of the manure from 8.00 to 7.19. No information was available on the formulations of the diets used in the present study. On this basis of manure pH in treated and untreated barns, it is perhaps not surprising that the GNS did not reduce hydrogen sulfide emissions. However, higher hydrogen sulfide emission rates for the GNS, as found here, are unexpected and difficult to explain and may be the result of chance effects.

It is encouraging that the GNS resulted in substantial reductions in odor concentrations at both the room-exhaust and pit-exhaust fans. This is particularly the case as there are a limited number of proven practically applicable approaches to reducing odor emissions from commercial swine facilities. It is not possible to determine which component of the GNS was responsible for the reduction in odor as all three processes (pit neutralizer, oil lid, and aerosol spray) could, in theory, result in reduced odor levels. Further research is warranted to test the three components of the GNS separately to determine the relative contributions of each to reducing odor emissions.

The effect of the GNS system on manure composition was small and of limited practical significance. In addition, there was no effect of the GNS on bacterial levels in the room exhaust air or on animal performance (growth rates, number of health treatments administered, and mortality levels). These results are not surprising given the relatively modest effects of the GNS on the concentrations of the various gases in the buildings.

In summary, the GNS showed some promise in reducing odor levels, however, further research is required to understand the lack of effectiveness at reducing hydrogen sulfide emissions, and to validate any effect on ammonia emissions.

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APPENDICES

Appendix 1. Descriptive statistics for external weather conditions by month of study.

	Mean	Standard deviation	Maximum	Minimum
Temperature, EC				
November 2005	5.9	6.2	21.1	-10.0
December 2005	-4.5	5.6	8.9	-17.0
January 2006	2.5	3.2	13.9	-6.1
February 2006	-1.3	5.4	16.7	-18.3
March 2006	4.6	4.7	21.1	-7.8
April 2006	13.2	4.3	27.8	-1.1
May 2006	16.1	5.6	32.8	5.0
June 2006	21.3	3.1	33.3	8.9
July 2006	24.6	2.5	33.9	12.2
August 2006	22.7	2.3	33.3	13.3
September 2006	17.4	3.5	30.0	5.0
October 2006	10.2	6.0	32.2	-1.7
Relative humidity, %				
November 2005	71.5	14.8	100.0	26.0
December 2005	85.4	9.1	100.0	59.0
January 2006	86.1	9.7	100.0	41.0
February 2006	67.9	15.8	100.0	19.0
March 2006	77.3	14.8	100.0	29.0
April 2006	66.0	16.5	100.0	21.0
May 2006	73.6	14.9	100.0	23.0
June 2006	66.5	11.2	100.0	31.0
July 2006	80.8	11.6	100.0	36.0
August 2006	86.7	8.9	100.0	45.0
September 2006	81.6	10.2	100.0	38.0
October 2006	76.7	13.3	100.0	28.0
Atmospheric pressure, inches of Mg				
November 2005	30.0	0.2	30.7	29.3
December 2005	30.1	0.3	30.8	29.5
January 2006	30.0	0.3	30.6	29.4
February 2006	30.1	0.3	30.8	29.6
March 2006	30.1	0.3	30.6	29.2
April 2006	29.9	0.2	30.4	29.4
May 2006	29.9	0.2	30.3	29.5
June 2006	30.0	0.1	30.2	29.8
July 2006	30.0	0.1	30.3	29.7
August 2006	30.0	0.1	30.2	29.8
September 2006	30.0	0.1	30.2	29.5
October 2006	30.0	0.2	30.5	29.4

Appendix 2. Descriptive statistics for temperature and relative humidity levels in the barns by month of study.

	Mean	Standard deviation	Maximum	Minimum
Temperature, ºC				
November 2005	16.5	1.1	18.1	15.7
December 2005	22.9	0.4	23.3	22.3
January 2006	18.6	0.4	19.0	18.1
February 2006	18.1	0.5	18.7	17.5
March 2006	18.4	0.4	18.8	17.8
April 2006	21.8	0.8	23.1	21.3
May 2006	21.2	2.1	23.0	18.4
June 2006	23.2	4.5	27.2	17.1
July 2006	24.1	4.0	28.1	19.9
August 2006	25.2	1.4	25.9	23.1
September 2006	24.4	0.8	24.8	23.1
October 2006	21.9	1.0	23.1	21.1
Relative humidity, %				
November 2005	58.8	3.4	63.1	54.8
December 2005	40.0	4.5	44.9	33.9
January 2006	55.8	0.7	56.7	55.1
February 2006	49.8	2.0	52.2	47.3
March 2006	49.4	0.8	50.4	48.6
April 2006	43.9	0.7	44.6	42.9
May 2006	53.8	0.8	54.7	52.9
June 2006	47.0	3.0	49.4	42.7
July 2006	67.3	0.9	68.4	66.3
August 2006	65.5	0.6	66.4	64.9
September 2006	45.1	3.2	47.2	40.3
October 2006	46.6	0.6	47.2	45.7

Appendix 3. Monthly treatment means for internal barn temperature (^oC).

	Treatment			
	Control	GNS	SEM	P Value
November 2005	16.21	16.88	0.470	0.50
December 2005	22.66	23.14	0.334	0.50
January 2006	18.52	18.71	1.133	0.50
February 2006	17.98	18.14	0.372	0.82
March 2006	18.47	18.30	0.482	0.84
April 2006	22.27	21.42	0.682	0.54
May 2006	21.72	20.67	2.317	0.80
June 2006	24.18	22.13	4.864	0.82
July 2006	24.26	24.00	4.719	0.98
August 2006	24.47	25.84	0.956	0.50
September 2006	23.97	24.75	0.593	0.52
October 2006	22.14	21.61	1.067	0.78

SEM = Standard error of the mean.

Appendix 4. Monthly treatment means for internal barn relative humidity (%).

	Treatment			
	Control	GNS	SEM	P Value
November 2005	56.63	60.94	2.810	0.47
December 2005	36.90	43.08	0.836	0.12
January 2006	56.42	55.25	0.933	0.07
February 2006	49.73	49.82	1.645	0.97
March 2006	49.51	49.32	0.336	0.75
April 2006	43.51	44.23	0.146	0.18
May 2006	53.88	53.76	0.421	0.87
June 2006	45.76	48.31	1.379	0.42
July 2006	68.04	66.63	0.078	0.05
August 2006	65.16	65.92	0.182	0.21
September 2006	43.53	46.74	1.932	0.45
October 2006	46.18	46.92	0.115	0.14

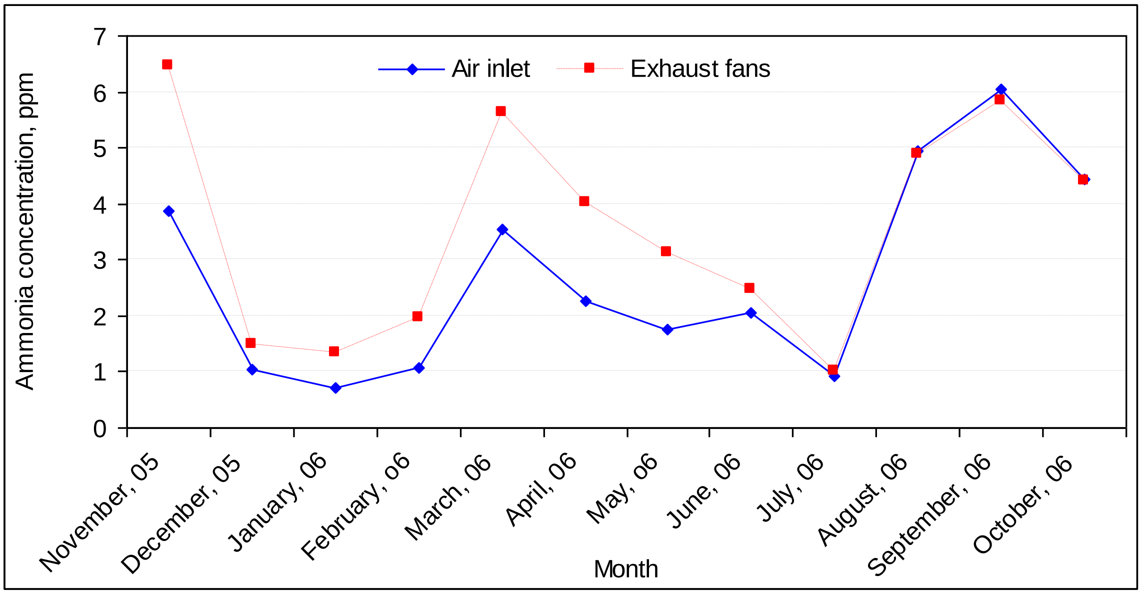
SEM = Standard error of the mean.

Appendix 5. Descriptive statistics for ammonia concentrations at the air an exhaust fans[a] by month of study.

	Mean	Standard deviation	Maximum	Minimum
Inlet gas concentrations, ppm				
November 2005	3.88	0.30	4.29	3.56
December 2005	1.04	0.07	1.14	0.99
January 2006	0.73	0.15	0.95	0.60
February 2006	1.08	0.12	1.24	0.97
March 2006	3.54	0.18	3.79	3.36
April 2006	2.25	0.12	2.42	2.16
May 2006	1.76	0.07	1.86	1.71
June 2006	2.07	0.16	2.31	1.99
July 2006	0.93	0.19	1.16	0.71
August 2006	4.93	0.08	5.03	4.86
September 2006	6.04	0.15	6.22	5.88
October 2006	4.43	0.39	4.95	4.06
Exhaust fan concentrations, ppm[1]				
November 2005	6.46	0.36	6.93	6.05
December 2005	1.48	0.21	1.68	1.29
January 2006	1.34	0.14	1.48	1.19
February 2006	1.97	0.15	2.14	1.78
March 2006	5.64	0.20	5.86	5.38
April 2006	4.03	0.31	4.32	3.70
May 2006	3.14	0.23	3.47	2.94
June 2006	2.48	0.11	2.58	2.35
July 2006	1.02	0.18	1.28	0.88
August 2006	4.88	0.06	4.97	4.83
September 2006	5.84	0.05	5.89	5.79
October 2006	4.42	0.03	4.45	4.38

[a]Average concentration at the three exhaust fans (two room-exhaust fans and one pit fan).

Appendix 5 (continued). Monthly average ammonia concentrations at the air inlet and the exhaust fans[a].



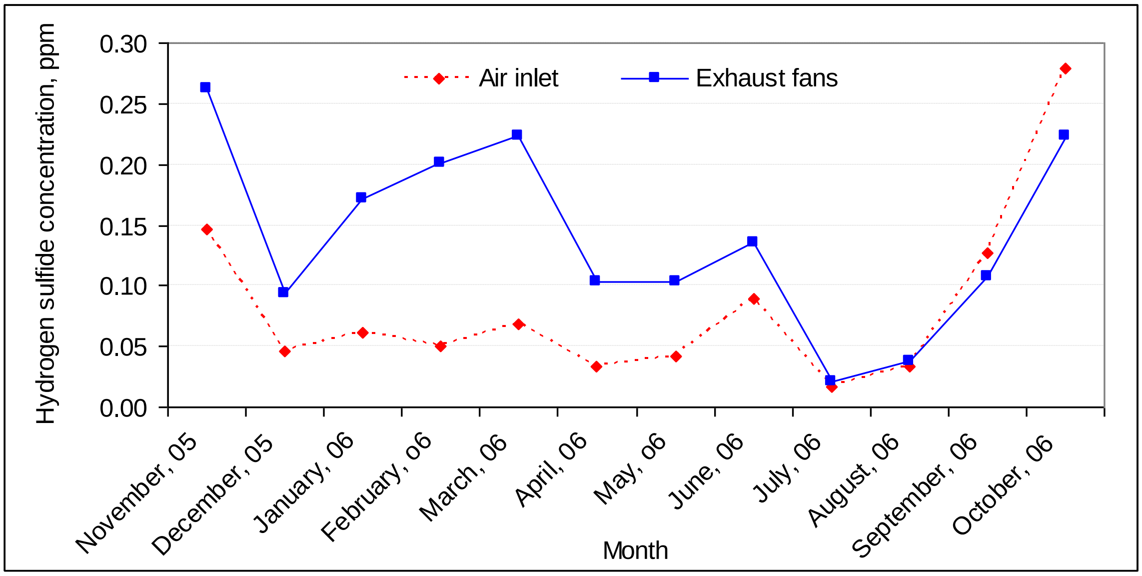
[a] Average concentration at three exhaust fans (two room-exhaust fans and one pit fan).

Appendix 6. Descriptive statistics for hydrogen sulfide concentrations at the air inlet and exhaust fans[a] by month of study.

	Mean	Standard deviation	Maximum	Minimum
Inlet gas concentrations, ppm				
November 2005	0.147	0.014	0.167	0.134
December 2005	0.046	0.006	0.055	0.042
January 2006	0.061	0.005	0.066	0.055
February 2006	0.050	0.003	0.053	0.047
March 2006	0.068	0.004	0.073	0.064
April 2006	0.033	0.002	0.035	0.031
May 2006	0.042	0.005	0.046	0.036
June 2006	0.090	0.005	0.094	0.082
July 2006	0.017	0.001	0.018	0.016
August 2006	0.034	0.002	0.037	0.032
September 2006	0.127	0.046	0.170	0.072
October 2006	0.279	0.104	0.368	0.152
Exhaust fan concentrations, ppm				
November 2005	0.262	0.018	0.274	0.236
December 2005	0.093	0.023	0.125	0.073
January 2006	0.171	0.039	0.205	0.115
February 2006	0.201	0.065	0.250	0.108
March 2006	0.223	0.077	0.280	0.112
April 2006	0.103	0.039	0.144	0.054
May 2006	0.103	0.026	0.117	0.064
June 2006	0.136	0.011	0.148	0.126
July 2006	0.021	0.002	0.024	0.019
August 2006	0.039	0.004	0.043	0.034
September 2006	0.107	0.019	0.127	0.081
October 2006	0.223	0.300	0.252	0.181

[a]Average concentration at the three exhaust fans (two room-exhaust fans and one pit fan).

Appendix 6 (continued). Monthly average hydrogen sulfide concentrations at the air inlet and the exhaust fans[a].



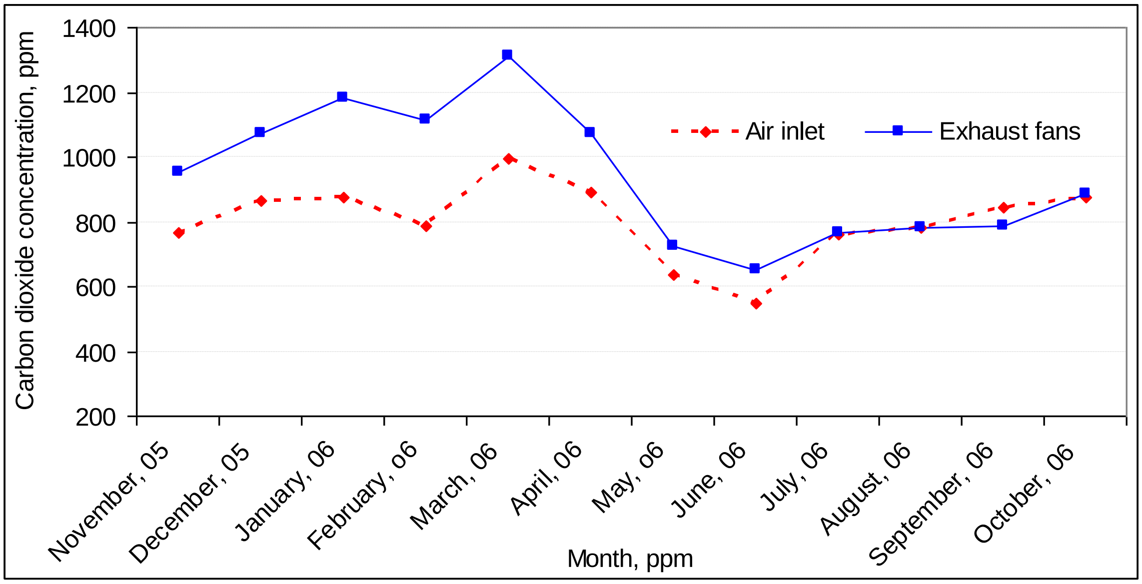
[a] Average concentration at three exhaust fans (two room-exhaust fans and one pit fan).

Appendix 7. Descriptive statistics for carbon dioxide concentrations at the air inlet and exhaust fans[a] by month of study.

	Mean	Standard deviation	Maximum	Minimum
Inlet gas concentrations, ppm				
November 2005	776	7.9	786	767
December 2005	865	18.6	892	851
January 2006	874	22.1	904	854
February 2006	788	42.0	843	753
March 2006	995	33.9	1,024	947
April 2006	890	21.3	906	859
May 2006	635	12.8	643	616
June 2006	547	16.6	561	523
July 2006	763	2.5	766	760
August 2006	780	2.3	782	777
September 2006	845	10.8	860	837
October 2006	877	3.9	883	875
Exhaust fan concentrations, ppm				
November 2005	954	32.0	1,002	933
December 2005	1,075	66.7	1,145	997
January 2006	1,181	43.2	1,208	1117
February 2006	1,113	44.8	1,162	1058
March 2006	1,313	47.2	1,348	1244
April 2006	1,074	21.5	1,096	1050
May 2006	727	12.0	744	717
June 2006	650	6.0	658	645
July 2006	766	6.0	775	761
August 2006	783	3.6	788	780
September 2006	875	6.5	884	869
October 2006	887	1.7	890	886

[a]Average concentration at the three exhaust fans (two room-exhaust fans and one pit fan).

Appendix 7 (continued). Monthly average carbon dioxide concentrations at the air inlet and the exhaust fans[1].



[a] Average concentration at three exhaust fans (two room-exhaust fans and one pit fan).

Appendix 8. Average of monthly ventilation rate and total fan running time by day of the study.

	Mean	Standard deviation	Maximum	Minimum
Average ventilation rates, m^3/s^a				
November 2005	1.91	0.53	2.69	1.50
December 2005	1.04	0.08	1.14	0.96
January 2006	1.40	0.27	1.63	1.05
February 2006	1.86	0.39	2.19	1.52
March 2006	2.49	0.06	2.57	2.42
April 2006	2.31	0.08	2.42	2.22
May 2006	4.11	0.17	4.34	3.96
June 2006	4.48	0.08	4.56	4.39
July 2006	3.97	1.14	5.47	2.98
August 2006	4.35	0.30	4.71	4.04
September 2006	4.61	0.19	4.84	4.44
October 2006	4.89	0.18	5.14	4.70
Total fan running times, minutes/day[b]				
November 2005	4,561	372	5,112	4,292
December 2005	4,536	717	5,047	3,473
January 2006	3,649	1,667	5,334	1,519
February 2006	3,151	1,815	4,722	1,579
March 2006	5,634	1,128	6,444	3,981
April 2006	7,683	1,842	9,213	5,415
May 2006	7,579	732	8,112	6,554
June 2006	9,507	1,177	10,337	7,774
July 2006	11,780	283	11,971	11,370
August 2006	8,868	383	9,366	8,526
September 2006	8,939	365	9,179	8,398
October 2006	9,553	921	10,908	8,890

[a]Average ventilation rate of all nine fans (five room-exhaust and four pit fans).
[b]Total time that all nine fans were running.

Appendix 9. Descriptive statistics for gas emissions rates by month of study.

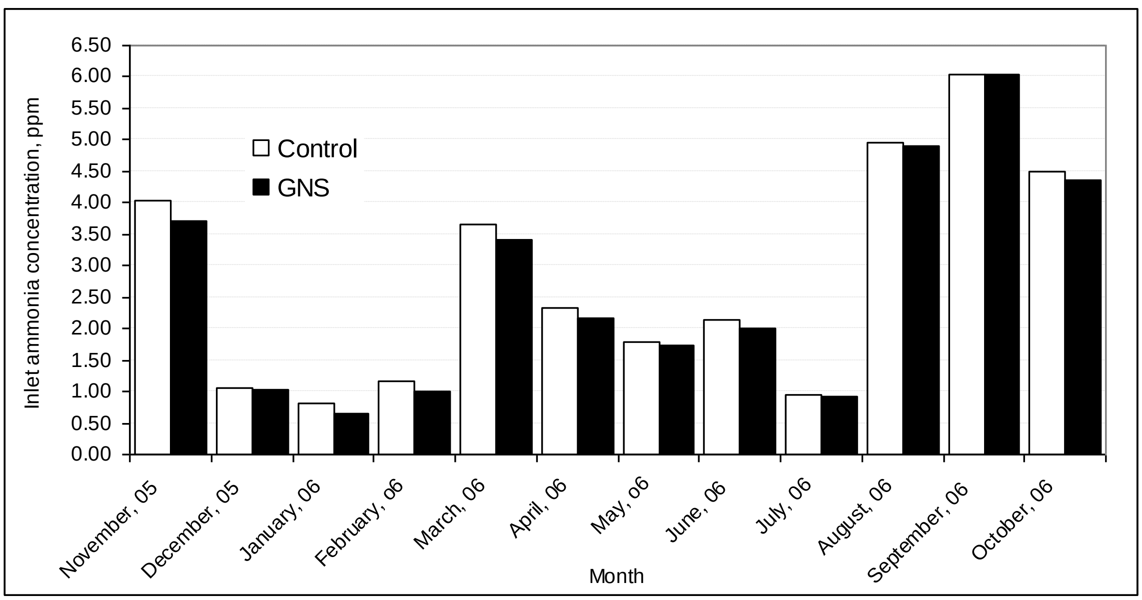
	Mean	Standard deviation	Maximum	Minimum
Ammonia, g/day				
November 2005	39	22	70	23
December 2005	67	19	88	42
January 2006	117	32	153	78
February 2006	284	64	352	219
March 2006	985	175	1212	786
April 2006	1373	169	1578	1210
May 2006	1679	318	2034	1332
June 2006	585	127	726	458
July 2006	178	196	469	59
August 2006	95	24	121	70
September 2006	51	61	134	6
October 2006	262	213	500	16
Hydrogen sulfide, g/day				
November 2005	13.8	8.9	25.8	6.0
December 2005	12.5	5.5	18.3	7.6
January 2006	42.7	20.4	64.9	18.4
February 2006	76.3	26.6	101.0	38.6
March 2006	164.2	94.8	264.4	36.6
April 2006	118.5	65.2	183.5	35.2
May 2006	145.2	66.3	206.3	51.3
June 2006	126.8	35.7	167.8	82.7
July 2006	9.8	8.2	21.3	2.9
August 2006	16.4	10.9	30.9	4.8
September 2006	51.7	78.2	165.2	0.0
October 2006	92.2	142.4	300.9	0.0
Carbon dioxide, g/day				
November 2005	45,508	24,530	80,610	26,340
December 2005	68,733	20,044	91,060	42,480
January 2006	143,880	57,635	223,700	97,790
February 2006	216,378	19,107	243,130	197,870
March 2006	394,498	114,090	524,790	250,520
April 2006	362,145	84,386	470,660	271,030
May 2006	273,185	67,215	364,190	216,400
June 2006	414,918	66,903	513,430	369,010
July 2006	32,985	49,884	106,400	1,880
August 2006	35,755	13,445	50,380	19,870
September 2006	141,030	69,796	227,280	72,840
October 2006	53,725	4,835	60,930	50,690

Appendix 10. Monthly treatment means for ammonia concentrations (ppm) at the barn air inlet.

	Treatment			
	Control	GNS	SEM	P Value
November 2005	4.05	3.71	0.071	0.18
December 2005	1.07	1.02	0.053	0.66
January 2006	0.81	0.64	0.071	0.34
February 2006	1.16	1.00	0.081	0.41
March 2006	3.65	3.43	0.149	0.49
April 2006	2.33	2.18	0.053	0.30
May 2006	1.79	1.73	0.042	0.50
June 2006	2.15	2.00	0.110	0.50
July 2006	0.94	0.93	0.134	0.97
August 2006	4.95	4.90	0.085	0.75
September 2006	6.05	6.04	0.074	0.91
October 2006	4.51	4.36	0.209	0.71

SEM = Standard error of the mean

Appendix 10 (continued). Monthly treatment means for ammonia concentrations (ppm) at the barn air inlet.

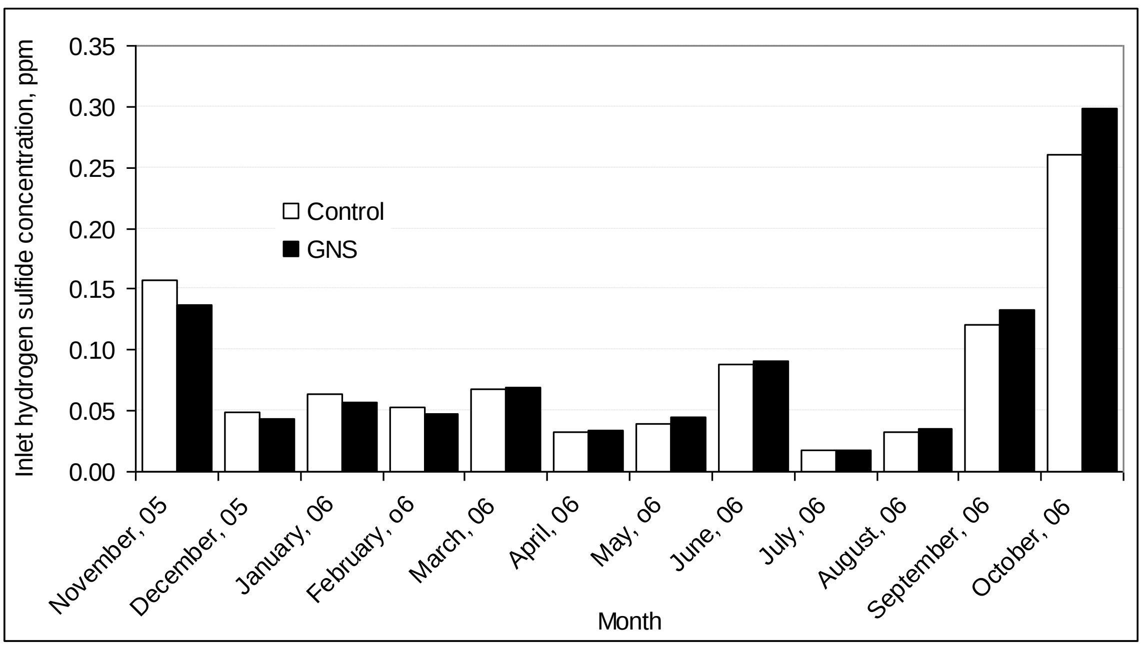


Appendix 11. Monthly treatment means for hydrogen sulfide concentrations (ppm) at the barn air inlet.

	Treatment			
	Control	GNS	SEM	P Value
November 2005	0.157	0.137	0.0055	0.24
December 2005	0.049	0.043	0.0034	0.41
January 2006	0.064	0.057	0.0006	0.07
February 2006	0.053	0.048	0.0008	0.15
March 2006	0.068	0.069	0.0011	0.78
April 2006	0.033	0.034	0.0007	0.61
May 2006	0.040	0.045	0.0016	0.26
June 2006	0.088	0.091	0.0038	0.66
July 2006	0.017	0.018	0.0003	0.44
August 2006	0.033	0.035	0.0003	0.14
September 2006	0.121	0.133	0.0158	0.68
October 2006	0.260	0.298	0.0317	0.55

SEM = Standard error of the mean

Appendix 11 (continued). Monthly treatment means for hydrogen sulfide concentrations (ppm) at the barn air inlet.

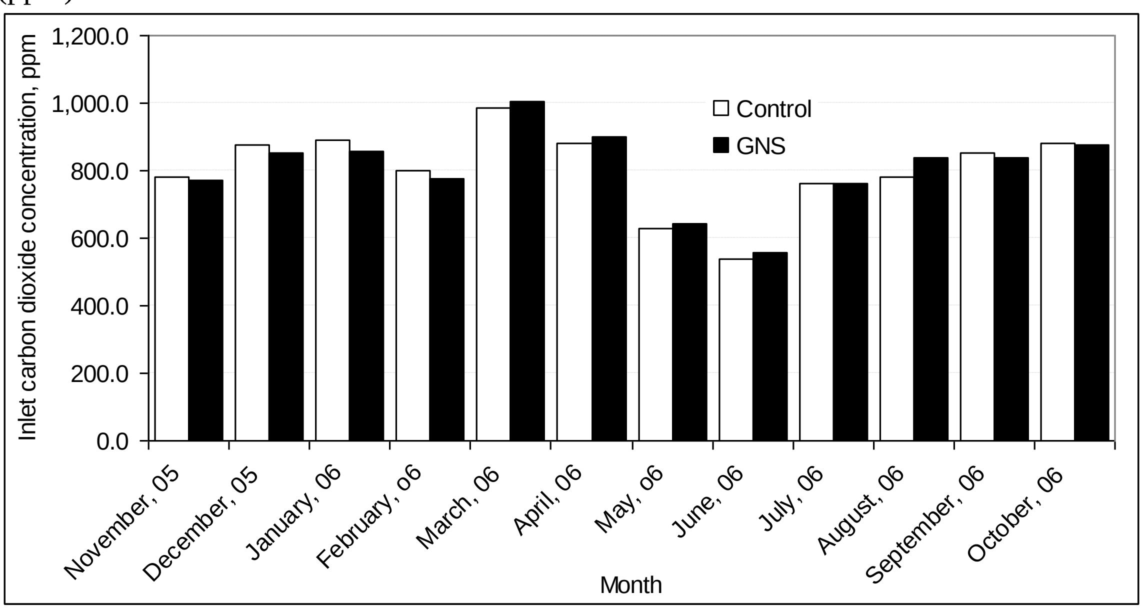


Appendix 12. Monthly treatment means for carbon dioxide concentrations (ppm) at the barn air inlet.

	Treatment			
	Control	GNS	SEM	P Value
November 2005	782	771	0.6	0.05
December 2005	877	853	9.0	0.31
January 2006	890	858	12.8	0.33
February 2006	798	778	17.4	0.58
March 2006	985	1,005	23.3	0.67
April 2006	883	898	18.2	0.67
May 2006	628	642	9.9	0.51
June 2006	537	557	12.4	0.46
July 2006	763	764	2.4	0.91
August 2006	782	778	0.9	0.21
September 2006	852	838	5.8	0.34
October 2006	879	876	3.1	0.56

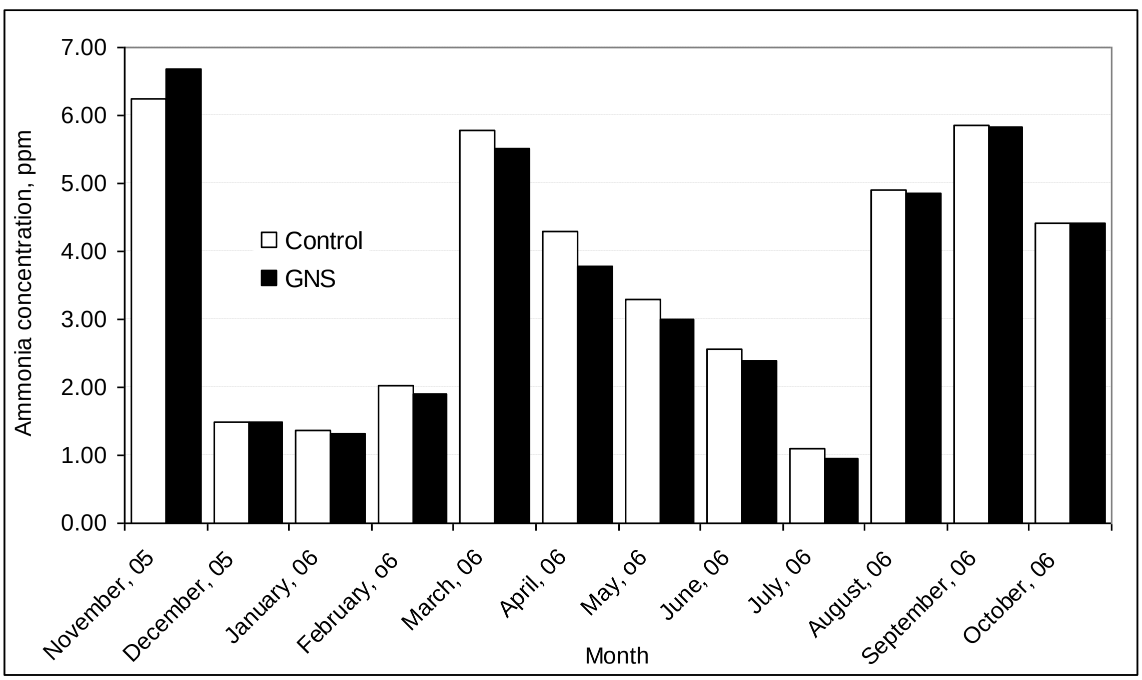
SEM = Standard error of the mean

Appendix 12 (continued). Monthly treatment means for carbon dioxide concentrations (ppm) at the barn air inlet.



Appendix 13. Monthly treatment means for ammonia concentrations (ppm) at the exhaust fans[a].

Appendix 13 (continued). Monthly treatment means for ammonia concentrations (ppm) at the exhaust fans[a].



[a]Average of concentration at two room-exhaust and one pit fan.

	Treatment			
	Control	GNS	SEM	P Value
November 2005	6.24	6.69	0.301	0.48
December 2005	1.49	1.48	0.025	0.91
January 2006	1.36	1.32	0.011	0.20
February 2006	2.03	1.91	0.014	0.11
March 2006	5.78	5.51	0.032	0.11
April 2006	4.30	3.77	0.060	0.10
May 2006	3.29	2.99	0.095	0.27
June 2006	2.57	2.40	0.021	0.11
July 2006	1.09	0.96	0.081	0.45
August 2006	4.91	4.85	0.032	0.44
September 2006	5.85	5.83	0.007	0.30
October 2006	4.42	4.42	0.014	0.99

SEM = Standard error of the mean.

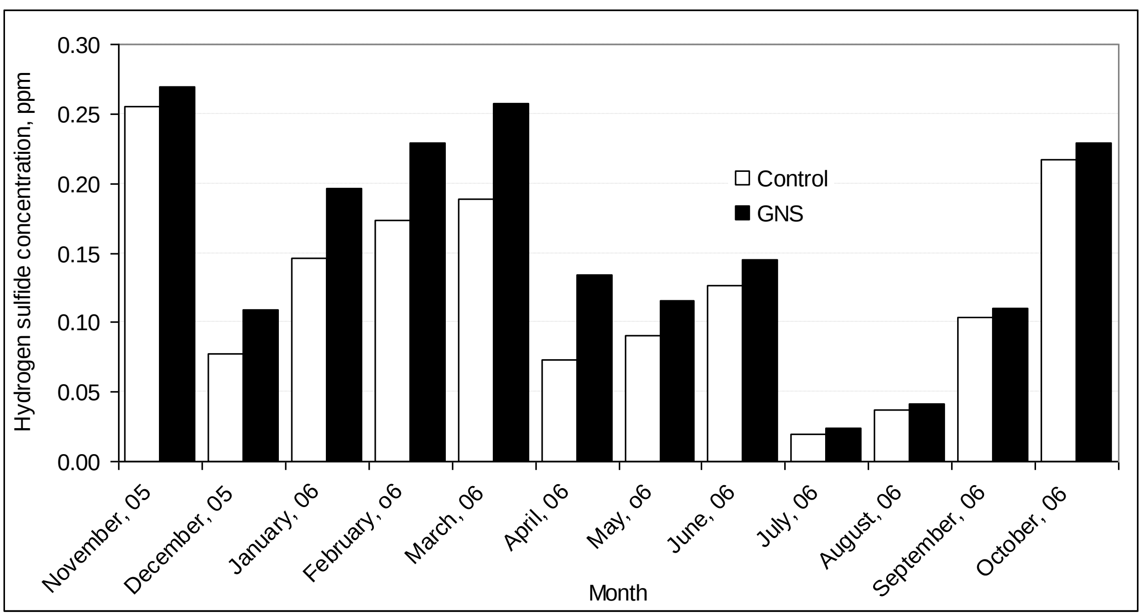
[a]Average of concentration at two room-exhaust and one pit fan.

Appendix 14. Monthly treatment means for hydrogen sulfide concentrations at the exhaust fans[a].

	Treatment			
	Control	GNS	SEM	P Value
November 2005	0.255	0.269	0.0173	0.68
December 2005	0.078	0.109	0.0081	0.23
January 2006	0.146	0.196	0.0152	0.26
February 2006	0.174	0.229	0.0311	0.43
March 2006	0.189	0.258	0.0385	0.43
April 2006	0.073	0.134	0.0060	0.09
May 2006	0.091	0.116	0.0191	0.52
June 2006	0.127	0.145	0.0028	0.14
July 2006	0.020	0.024	0.0001	0.001
August 2006	0.037	0.041	0.0001	0.001
September 2006	0.104	0.110	0.0131	0.82
October 2006	0.217	0.229	0.0216	0.75

SEM = Standard error of the mean
[a]Average of concentration at two room-exhaust and one pit fan.

Appendix 14 (continued). Monthly treatment means for hydrogen sulfide concentrations at the exhaust fans[a].



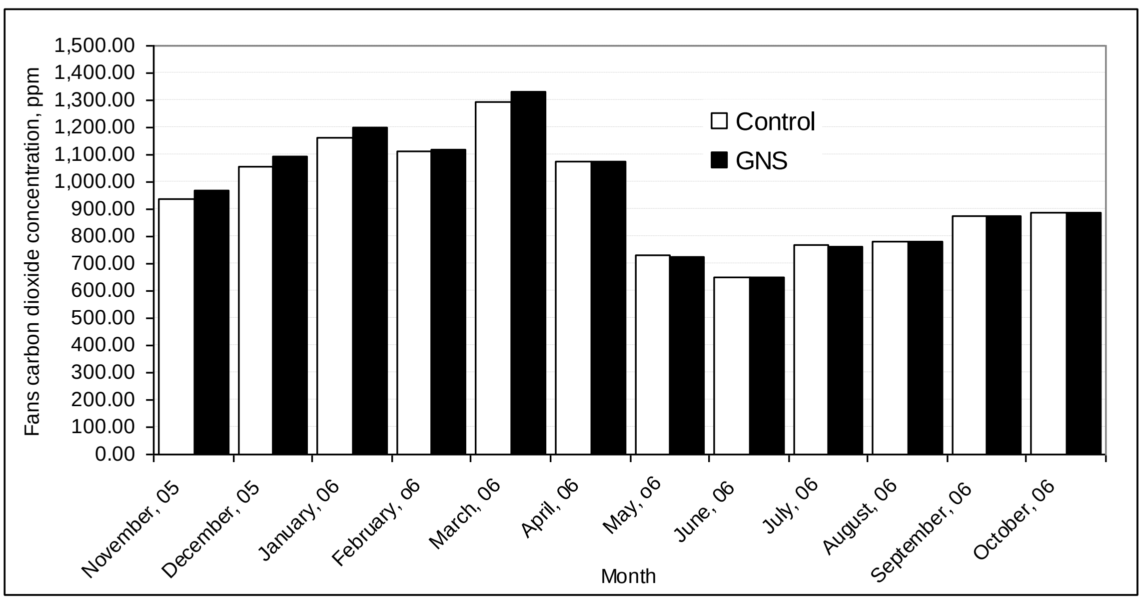
[a]Average of concentration at two room-exhaust and one pit fan.

Appendix 15. Monthly treatment means for carbon dioxide concentrations (ppm) at the exhaust fans[a].

	Treatment			
	Control	GNS	SEM	P Value
November 2005	937	971	18.4	0.42
December 2005	1,055	1,095	6.3	0.14
January 2006	1,163	1,200	26.5	0.50
February 2006	1,110	1,116	25.0	0.89
March 2006	1,292	1,333	23.1	0.43
April 2006	1,073	1,075	7.8	0.90
May 2006	730	724	6.0	0.60
June 2006	652	647	2.5	0.37
July 2006	770	762	4.6	0.46
August 2006	784	782	3.3	0.69
September 2006	876	874	6.1	0.81
October 2006	888	887	1.7	0.78

SEM = Standard error of the mean
[a]Average of concentration at two room-exhaust and one pit fan.

Appendix 15 (continued). Monthly treatment means for carbon dioxide concentrations (ppm) at the exhaust fans[a].



[a]Average of concentration at two room-exhaust and one pit fan.

Appendix 16. Monthly treatment means for ammonia emission rates (g/day)

	Treatment			
	Control	GNS	SEM	P Value
November 2005	47	31	20.7	0.69
December 2005	65	69	13.5	0.88
January 2006	93	140	1.9	0.04
February 2006	286	281	75.8	0.98
March 2006	883	1,087	157.0	0.53
April 2006	1510	1,236	66.1	0.21
May 2006	1939	1,420	5.6	0.01
June 2006	592	579	149.9	0.96
July 2006	295	61	122.1	0.41
August 2006	116	74	6.8	0.15
September 2006	70	32	26.6	0.50
October 2006	258	266	100.9	0.96

SEM = Standard error of the mean

Appendix 17. Monthly treatment means for hydrogen sulfide emission rates (g/day).

	Treatment			
	Control	GNS	SEM	P Value
November 2005	11.7	15.9	9.37	0.81
December 2005	7.9	17.2	0.59	0.06
January 2006	26.6	58.8	10.17	0.27
February 2006	59.6	93.0	9.20	0.24
March 2006	101.4	227.0	19.36	0.14
April 2006	68.1	168.9	12.94	0.11
May 2006	128.8	161.5	59.85	0.76
June 2006	100.5	153.1	2.17	0.04
July 2006	6.4	13.3	8.10	0.65
August 2006	15.0	17.8	8.14	0.85
September 2006	82.6	20.7	43.79	0.50
October 2006	150.4	33.9	83.82	0.51

SEM = Standard error of the mean

Appendix 18. Monthly treatment means for carbon dioxide emission rates (g/day).

	Treatment			
	Control	GNS	SEM	P Value
November 2005	35,075	55,940	23,620.9	0.64
December 2005	55,480	81,985	15,609.4	0.44
January 2006	101,790	185,970	29,507.6	0.29
February 2006	204,450	228,310	5,830.1	0.21
March 2006	313,430	475,570	9,676.8	0.05
April 2006	370,850	353,440	53,740.1	0.86
May 2006	323,650	222,720	33,135.0	0.28
June 2006	456,410	373,430	43,441.1	0.41
July 2006	55,885	8,085	40,107.1	0.55
August 2006	25,060	46,450	6,448.8	0.26
September 2006	85,235	196,830	12,770.3	0.10
October 2006	51,365	56,085	2,948.6	0.46

SEM = Standard error of the mean