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Greenhouse gas emission reduction and environmental quality improvement from implementation of aerobic waste treatment systems in swine farms

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Abstract

Trading of greenhouse gas (GHG) emission reductions is an attractive approach to help producers implement cleaner treatment technologies to replace current anaerobic lagoons. Our objectives were to estimate greenhouse gas (GHG) emission reductions from implementation of aerobic technology in USA swine farms. Emission reductions were calculated using the approved United Nations framework convention on climate change (UNFCCC) methodology in conjunction with monitoring information collected during full-scale demonstration of the new treatment system in a 4360-head swine operation in North Carolina (USA). Emission sources for the project and baseline manure management system were methane (CH_4) emissions from the decomposition of manure under anaerobic conditions and nitrous oxide (N_2O) emissions during storage and handling of manure in the manure management system. Emission reductions resulted from the difference between total project and baseline emissions. The project activity included an on-farm wastewater treatment system consisting of liquid–solid separation, treatment of the separated liquid using aerobic biological N removal, chemical disinfection and soluble P removal using lime. The project activity was completed with a centralized facility that used aerobic composting to process the separated solids. Replacement of the lagoon technology with the cleaner aerobic technology reduced GHG emissions 96.9%, from 4972 tonnes of carbon dioxide equivalents (CO_2-eq) to 153 tonnes CO_2-eq/year. Total net emission reductions by the project activity in the 4360-head finishing operation were 4776.6 tonnes CO_2-eq per year or 1.10 tonnes CO_2-eq/head per year. The dollar value from implementation of this project in this swine farm was US$19,106/year using current Chicago Climate Exchange trading values of US$4/t CO_2. This translates into a direct economic benefit to the producer of US$1.75 per finished pig. Thus, GHG emission reductions and credits can help compensate for the higher installation cost of cleaner aerobic technologies and facilitate producer adoption of environmentally superior technologies to replace current anaerobic lagoons in the USA.
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1. Introduction

Anaerobic lagoons are widely used to treat and store liquid manure from confined swine production facilities (Barker, 1996). Environmental and health concerns with the lagoon technology include emissions of ammonia (Aneja et al., 2000; Szogi et al., 2006), odors (Loughrin et al., 2006), pathogens (Sobsey et al., 2001), and water quality deterioration (Mallin, 2000). Widespread objection to the use of anaerobic lagoons for swine manure treatment in North Carolina (USA) prompted a state government-industry framework to search for alternative technologies that directly eliminate anaerobic lagoons as a method of treatment. In July 2000, the Attorney General of North Carolina reached an agreement with Smithfield Foods, Inc. and its subsidiaries (the largest swine producing companies in the USA) to develop and demonstrate environmentally superior waste management technologies for implementation onto farms located in North Carolina that are owned by these companies. In October 2000, the

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Attorney General reached a similar agreement with Premium Standard Farms, the second largest pork producer in the USA. The agreement defines an environmentally superior technology (EST) as any technology, or combination of technologies, that: (1) is permittable by the appropriate governmental authority; (2) is determined to be technically, operationally, and economically feasible; and (3) meets the following five environmental performance standards (Williams, 2005):

1. Eliminate the discharge of animal waste to surface waters and groundwater through direct discharge, seepage, or runoff;
2. Substantially eliminate atmospheric emissions of ammonia;
3. Substantially eliminate the emission of odor that is detectable beyond the boundaries of the swine farm;
4. Substantially eliminate the release of disease-transmitting vectors and airborne pathogens and
5. Substantially eliminate nutrient and heavy metal contamination of soil and groundwater.

Selection of EST candidates to undergo performance verification involved a request for proposals and competitive review by the Agreement's designee and a panel representing government, environmental and community interests, the companies, and individuals with expertise in animal waste management, environmental science and public health, and economics and business management. This process yielded 18 technology candidates from about 100 submitted projects. Subsequently, the selected technologies completed design, permitting, construction, startup, and performance verification under steady-state operational conditions. In July 2005, 5 of the 18 technologies tested were shown to be capable of meeting the environmental performance criteria necessary for the technologies to be considered environmentally superior (Williams, 2005). Only one of the technologies selected treated the entire waste stream from a swine farm (Fig. 1). The system was constructed and operated by Super Soil Systems USA of Clinton, North Carolina, and the technology demonstration project was identified as "Supersoil Project." This on-farm technology used liquid–solid separation and aerobic processes to treat both the separated liquid and solids. It was developed to replace anaerobic lagoon technology commonly used in the USA to treat swine waste (Vanotti et al., 2005).

The system had two components: (1) an on-farm wastewater treatment system (Vanotti et al., 2006b) consisting of liquid–solid separation using flocculants and screens, treatment of the separated liquid using aerobic biological N removal, and chemical disinfection and soluble P removal using lime, and (2) a centralized solids processing facility where separated manure solids were combined with cotton gin residue and aerobically composted to reduce the wastes into stable humus used to manufacture peat substitutes used in potting soil, soil amendments, and organic fertilizers. The on-farm system removed more than 97% of the suspended solids from wastewater. It removed 95% of total P in the liquid, 99% of its ammonia, and more than 99% of its biochemical oxygen demand and odor-causing components, and it produced a disinfected liquid effluent (Vanotti et al., 2006b). In addition, the old wastewater lagoon was converted into clean water that substantially reduced odor and ammonia emissions (Loughrin et al., 2006; Szogi et al., 2006). The centralized facility produced quality composts that conserved 96.5% of the separated solid's nitrogen into a stabilized product that met Class A biosolids standards due to high pathogen reduction (Vanotti, 2005; Vanotti et al., 2006a).

Fig. 1. Full-scale wastewater treatment system (project activity, foreground) that replaced the anaerobic swine lagoon (baseline scenario, background), in Duplin County, North Carolina.

Capital investment is the most important barrier for widespread adoption of a cleaner treatment technology due to higher costs involved compared to the baseline lagoon technology. On the other hand, proven environmental benefits from implementation of the new superior technologies are often difficult to translate in terms of direct economic benefits that can offset the investment barrier. Fortunately, new programs are being created on global reduction of anthropogenic emissions of greenhouse gases (GHG) that can help compensate for the higher installation cost of the cleaner technologies, and therefore favor technology adoption by producers. Such a program was recently implemented by Agricola Super Limitada (Agrosuper), the largest swine production company in Chile. The company initiated a voluntary adoption of advanced waste management systems (anaerobic and aerobic treatment of manure); implementation of the more expensive technology was greatly influenced by the adoption of the Kyoto protocol and the clean development mechanism (CDM). As a result, advanced technologies are being phased in gradually in all of Agrosuper's swine production units to replace the existing anaerobic lagoon technology. The company used revenues from the sale of certified emission reductions (CERs) to partially finance the advanced waste management systems. This voluntary adoption case is significant to North Carolina because the company is phasing out lagoon technology that were implemented years ago using the North Carolina traditional anaerobic lagoon treatment model.

To accomplish this voluntary adoption of advanced waste management systems, Agrosuper developed a project activity at a 118,800 head finishing swine facility in Chile that led to an approved UNFCCC methodology AM0006 (2004). The advantage of this methodology is that it considers aerobic components in addition to anaerobic digesters and flaring that are the focus of the other approved method for quantification of GHG emission reduction in animal manure systems (i.e., AM0016, 2006). Thus, the methodology is very suitable for quantification of GHG emission reductions in the Supersoil project which relies heavily on aerobic processes to treat the manure. Starting Dec. 22, 2006, the two methodologies approved for animal manure systems, AM0006 and AM0016, were combined by the CDM Executive Board into an approved consolidated baseline methodology ACM0010 (2006). The consolidated methodology is also applicable to manure management on livestock farms where the existing anaerobic manure treatment system, within the project boundary, is replaced by one or a combination of more than one animal waste management systems, aerobic or anaerobic, that result in less GHG emissions.

Our objectives were to estimate greenhouse gas (GHG) emission reductions from implementation of the cleaner aerobic technology (Supersoil project) in North Carolina swine farms, replacing the current anaerobic lagoon system (baseline scenario). GHG emission reductions were estimated using the original Approved Methodology AM0006 in conjunction with monitoring information collected during full-scale demonstration of the treatment system.

2. Methods

The baseline activity was the traditional anaerobic lagoon-sprayfield technology for a farm with 4360-head finishing pigs in North Carolina. The project activity consisted of the implemented advanced system (Supersoil project) in an identical farm. Calculation of GHG emission reductions by the environmentally superior technology was made using the UNFCC approved methodology AM0006 (2004) and its supporting project design document NM0022 (2004).

The AM0006 methodology includes the following emission sources for the project and baseline manure management system: (1) Methane (CH_4) emissions from the decomposition of manure under anaerobic conditions, and (2) Nitrous oxide (N_2O) emissions during storage and handling of manure in the manure management system. Baseline and project boundaries are shown in Figs. 2 and 3, respectively. Greenhouse gas emissions included in the boundary are calculated separately for the project and the baseline manure management system, using the same methodological approach. Emission reductions are the difference between total project and baseline emissions. Non-volatile and volatile N_2O emission components are also referred to as direct and indirect N_2O emissions, respectively.

Emission factors used for each treatment stage (Tables 1 and 2) were accepted values provided in the 1996 Revised IPCC Guidelines (IPCC, 1996) and in the IPCC Good Practice Guide IPCC (2000). Equations used to estimate emissions are detailed in Design Document NM0022 (2004) (Eq. 1–14, p. 73–78) and AM0006 (2004). Monitoring data and site-specific information were obtained during full-scale project activity demonstration at Goshen Ridge Farm (on-farm treatment) near Mount Olive, Duplin County, North Carolina (Vanotti et al., 2006b) and at Hickory Grove farm (composting facility) near Clinton, Sampson County, North Carolina (Vanotti, 2005; Vanotti et al., 2006a). Total volatile solids supplied to the manure management system (VS_{site}) was determined by the VS default excretion rates ($VS_{default}$) of 0.5 kg/swine head/day and associated swine weight of 82 kg/head ($W_{default}$) taken from Table B-6, p. 4.46 in the Reference Manual of IPCC (1996) and corrected for the animal weight monitored at the project site (W_{site}) in the following way, assuming that the volatile solid excretion is proportional to the weight of the animal:

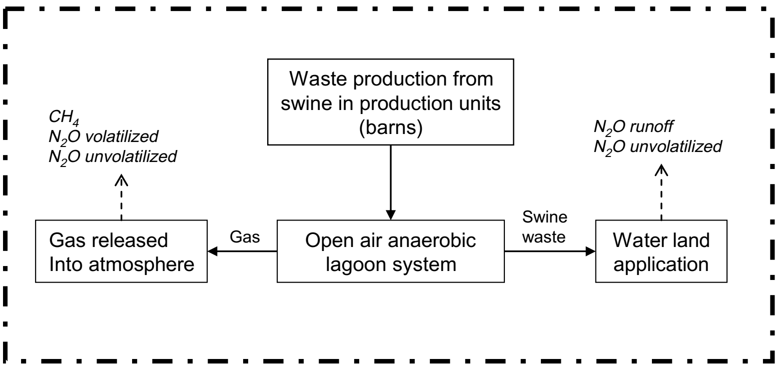

Fig. 2. Baseline scenario boundary.

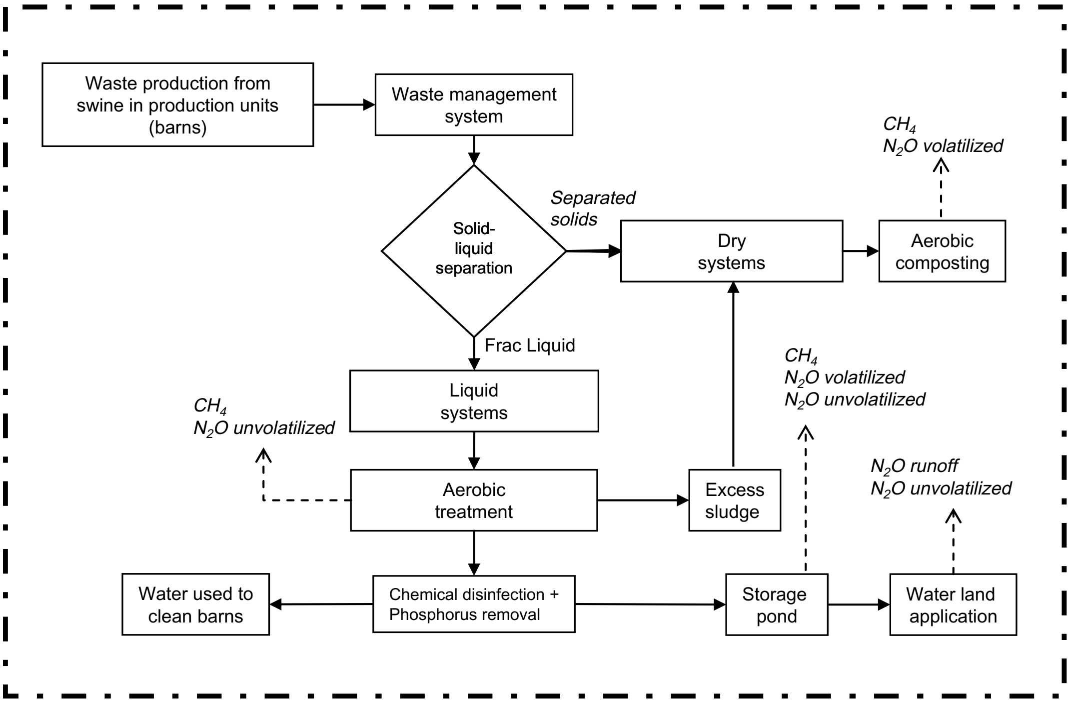

Fig. 3. Project activity boundary.

Table 1
Emission factor parameters involved in the methane (CH_4) emission calculations for each scenario[a]

Parameter	Description	Emission source	Value	Reference
Bo	Maximum CH_4 production capacity from manure	All sources	0.45 m^3 CH_4/kg VS	Table B-6, p. 4.46, Vol. 3, IPCC (1996)
MCF	Methane conversion factor for manure management systems	Anaerobic swine lagoon	90%	Table B-3, p. 4.43, Vol. 3, IPCC (1996)
		Aerobic treatment of liquid using forced aeration	0.1%	Table 4.11, p. 4.37, IPCC (2000)
		Storage liquid	45%	Table 4.10, p.4.36, IPCC (2000)
		Aerobic in-vessel composting	0.5%	Table 4.11, p. 4.37, IPCC (2000)
D_{CH_4}	CH_4 density	All sources	0.67 kg/m^3	AM0006, 2004

[a] Emission factor for manure management (EF) = $VS_{LIQUID\ or\ SOLID\ SYSTEM} \cdot 365 \cdot Bo \cdot D_{CH4} \cdot MCF$.
CH_4 emissions = EF $\cdot$ GWP_{CH_4} $\cdot$ Stock of animals/1000; GWP_{CH_4} = 296 and Stock = 4360 animals. For storage pond (second stage liquid system), Eq. (3) described in text was used.

$$VS_{site} = (W_{site}/W_{default}) \cdot VS_{default} \quad (1)$$

Similarly, the nitrogen supplied to the manure management system (NEX_{site}) was determined by the default value for the nitrogen excretion ($NEX_{default}$) of 20 kg/animal/year for swine in North America from Table 4-20, p. 4.99 in the Reference Manual of IPCC (1996) adjusted by the monitored animal weight:

$$NEX_{site} = (W_{site}/W_{default}) \cdot NEX_{default} \quad (2)$$

Average monitored pig weight (2 year in 6 barns) was 73.08 kg per head (W_{site}). The VS_{site} and NEX_{site} thus obtained were 0.446 kg-VS/animal/day and 17.83 kg-N/animal/day, which were used for both the baseline and project activity calculations. A partition variable (FracLIQUID, Fig. 3) was created in this work to divert the excreted VS (VS_{site}) and N (NEX_{site}) into the liquid system (and by difference into the dry system) based on the solid–liquid separation efficiency obtained. The FracLIQUID for volatiles was based on BOD_5 separation efficiency, and for nitrogen it was based on total nitrogen (TN) separation efficiency. For example, liquid–solid separation efficiency for BOD_5 at the project site was 65.6% (from 3132 mg/L before separation to 1078 mg/L after separation) and $FracLIQUID_{VS}$ was 0.344. Similarly, TN in the liquid stream was reduced from 1584 to 954 mg/L (39.8% separation efficiency) and $FracLIQUID_{TN}$ was 0.602. The difference (i.e., FracSOLID = 1 − FracLIQUID) determined the amount of VS or N that was diverted into the dry system.

For the second and subsequent stages, emissions of N_2O were calculated based on measurements of TN content in the manure flowing to that treatment stage and monitored flow rates (F) of the manure liquid. Similarly, emissions of

Table 2
Emission factors involved in the nitrous oxide (N_2O) emission calculations for each scenario

Parameter	Description	Units	Value	Emission source	Reference
EF_1	Emission factor for direct soil emissions	kg N_2O-N/kg N input	0.0125	Water land application (N_2O unvolatilized)	Table 4-18, p. 4.89, Vol. 3, IPCC (1996)
EF_3	Emission factor for manure management system	kg N_2O-N/kg N excreted or N content	0.001	Direct emission from anaerobic lagoon and storage pond (N_2O unvolatilized)	Table 4-8, p. 4.14, Vol. 2, IPCC (1996)
			0.005	Aerobic treatment of liquid using forced aeration systems	Table 10.21, p. 10.63, IPCC (2006)
EF_4	Emission factor for atmospheric deposition	kg N_2O-N/kg NH_3-N and NO_x-N emitted	0.01	Indirect emissions from animal waste management systems (N_2O volatilized)	Table 4.18, IPCC (2000)
EF_5	Emission factor for leaching/runoff	kg N_2O-N/kg N input	0.025	Water land application (N_2O runoff)	Table 4.23, p. 4.105, Vol. 3, IPCC (1996)
FracGASM	Fraction of livestock N input that volatilizes as NH_3 and NO_x	kg NH_3-N + NO_x-N/kg N input	0.20	Partitioning fraction for volatilization in liquid systems (except aerobic treatment)	Table 4.19, p. 4.94, Vol. 3, IPCC (1996)
			0	Aerobic treatment using large populations of nitrifying bacteria	Vanotti et al. (2000)
			0.035	Aerobic composting using 2:1 cotton waste and swine solids	Vanotti et al. (2006a)
FracLEACH	Fraction of the manure N lost to leaching and surface runoff	kg N/kg manure non-volatilized N	0.30	Partitioning fraction for leaching and runoff	Table 4.24, p. 4.106, Vol. 3, IPCC (1996)

CH_4 during the second and subsequent treatment stages were calculated based on the measurement of the monitored BOD_5 and the quantity of manure flowing to that treatment stage (Option A in method AM0006, 2004):

$$E_{CH_4,i,y} = 0.25 \cdot BOD_{lt,i,y} \cdot F_{i,y} \cdot MCF_i \cdot GWP_{CH_4} \cdot 10^{-6} \quad (3)$$

where $E_{CH_4,i,y}$ are the CH_4 emissions in the second or subsequent treatment stage i of the project activity during the year y in tonnes of CO_2 equivalents; $BOD_{lt,i,y}$ is the average long-term biochemical oxygen demand of the manure flow to treatment stage i during the year y in mg/L; $F_{i,y}$ is the manure flow to the treatment stage i during the year y in m^3; MCF_{CH_4} is the methane conversion factor (MCF) for the treatment of manure in stage i in percent; and GWP_{CH_4} is the approved Global Warming Potential of CH_4. The 0.25 factor in Eq. (3) is the CH_4 production (kg) for each kilogram of stabilized long-term BOD based on the stoichiometric relations describing: (1) glucose transformation to CH_4 and CO_2 in anaerobic conditions ($C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4$), and (2) the intrinsic BOD of the CH_4 for its final conversion into CO_2 and steam ($3CH_4 + 6O_2 \rightarrow 3CO_2 + 6H_2O$). The long-term BOD was calculated with the measured BOD_5 and the reaction constant k for the biochemical oxygen demand as follows:

$$BOD_{lt} = BOD_5/(1 - 10^{-5k}) \quad (4)$$

The reaction constant k, which is approximately 0.1 for wastewater at 20 °C (Tchobanoglous and Burton, 1991), was adjusted using monitored water temperature and the Van't–Hoff–Arrhenius relationship:

$$k = k_{20} \cdot \theta^{(T-20C)} \quad (5)$$

where T is the monitored temperature of the wastewater in degrees Celsius; and θ is a constant with values of 1.056 for temperatures between 20 and 30 °C, and 1.135 for temperatures between 4 and 20 °C.

Option A for the second and subsequent treatment stage described above was used only to calculate CH_4 and N_2O emissions from the liquid stream after aerobic treatment (pond and water land application). Specific conditions were the following: BOD_5 and TN concentrations monitored in the liquid flowing into the storage pond (effluent of the treatment plant) were 10 and 247 mg/L, respectively; liquid flow F was 9417 m^3 (25.8 m^3/d); and the average liquid temperature T was 22.52 °C (Vanotti et al., 2006b).

Emission reductions of CH_4 and N_2O were expressed in terms of CO_2 equivalents using approved Global Warming Potentials (23 for CH_4 and 296 for N_2O) (IPCC, 2001). Direct economic benefits from emission reductions were determined using the current trading value (US$4.00/t of CO_2) at the Chicago climate exchange (www.chicagoclimatex.com).

3. Results and discussion

3.1. Processes in the project activity

Solid–liquid separation in the project activity diverted 65.6% of the VS and 39.8% of the TN contained in raw manure into the dry system (Fig. 3). VS separation efficiencies of only 7% are typical for swine manure that goes through screening without flocculation treatment (Vanotti et al., 2002). However, high separation efficiencies in the project activity were obtained using polyacrylamide (PAM) flocculation (Vanotti and Hunt, 1999). Thus, the amount of VS diverted to dry and liquid systems is technology dependent and should be corrected for specific solid–liquid separation technology using actual monitoring information.

After solid–liquid separation, the liquid was treated aerobically using forced aeration with a nitrogen removal process that uses large populations of nitrifying bacteria entrapped in polymer pellets (Vanotti et al., 2006b). This high concentration of bacteria in the treatment tanks is specially suited for treatment of nitrogen in high-strength animal wastewaters; for example, numerous studies with this technology have shown quantitative conversion of ammonia without loosing ammonia to volatilization (Vanotti et al., 2000; Vanotti and Hunt, 2000). For this reason, the FracGASM variable used for calculations of indirect (volatilized) emissions in the aerobic N removal stage was set to 0 (Table 2); i.e., all N_2O emissions in this stage were direct or unvolatilized (Fig. 3).

3.2. Greenhouse gas emission reductions due to advanced treatment technology

A total of 4972 t of CO_2-eq were generated in a year by the baseline scenario (anaerobic lagoon-sprayfield technology) in the 4360-head finishing operation in North Carolina (Table 3). Most (89.1%) of the GHG emissions were due to methane (CH_4) produced during anaerobic digestion in the open lagoons, and the remainder (10.9%) was due to nitrous oxide (N_2O) emissions, mostly emitted during land application of the digested liquid. In contrast, implementation of the project activity (Supersoil project) on the same farm generated only 153 t CO_2-eq during the same 1 year period that resulted in a 96.9% decrease in GHG emissions (Table 4). Generation of methane in the project activity was reduced 99.6% compared to the baseline, and generation of N_2O in the project activity was reduced 75.2%.

Total annual emission reductions due to the project activity were calculated from the sum of CH_4 and N_2O annual emission reductions adjusted for leakage effects due to changes in electricity consumption (Table 5). Electricity consumption in the project activity (treatment of liquid and solids) was 435.4 kWh/d (158,932 kWh/year), which converts to 42.5 t CO_2-eq using an emission factor of 20.3 t C/TJ (1 TJ = 277,778 kWh; 1 t C = 3.66 t CO_2-eq). This emission factor assumes a less favorable scenario where 100% electricity is derived from fossil fuels. A weighted average was used following USA fossil fuel consumption distribution (47.1% petroleum, 26.6% coal, and 26.3% natural gas; DOE, 2006) and corresponding emission factors (20.0, 25.8 and 15.3 t C/TJ; Table 1-1, IPCC, 1996). Nevertheless, emissions due to electricity consumption (42.5 t CO_2-eq) were small compared to the emission reductions in CH_4 and N_2O by the project activity (4819.1 t CO_2-eq) (Table 5), and for this reason, the AM0006 methodology considers that electricity consumption by aerobic treatment should not be considered in the overall net reduction calculations. However, this amount was included in the calculations to be conservative in our GHG emission reduction estimates. Total net emission reductions by the project activity in the 4360-head finishing operation were 4776.58 t CO_2-eq per year (Table 5).

Table 3
Detailed baseline emissions for 4360-head finishing swine operation using anaerobic lagoon technology at Goshen Farm, Duplin Co., NC

Emissions source[a]	Emissions (t CO_2-eq per year)[b]
Lagoon CH_4	4429.69
Lagoon N_2O (volatilized)	72.25
Lagoon N_2O (unvolatilized)	28.90
Land application N_2O (unvolatilized)	265.78
Land application N_2O	175.35
Total baseline	4971.97

[a] Baseline scenario boundary and emission sources shown in Fig. 2.
[b] Carbon dioxide (CO_2) equivalents. Global warming potential of methane (CH_4) and nitrous oxide (N_2O) are 23 and 296, respectively.

Table 4
Detailed project emissions for 4360-head finishing swine operation using aerobic manure treatment system (Supersoil project) at Goshen Ridge farm, Duplin Co., NC and aerobic composting of separated solids at centralized facility, Sampson Co., NC

Emissions source[a]	Emissions (t CO_2-eq per year)[b]
Aerobic treatment of separated liquid CH_4	1.70
Aerobic treatment of separated liquid N_2O	109.4
Storage pond CH_4	0.33
Storage pond N_2O (volatilized)	2.16
Storage pond N_2O (unvolatilized)	0.86
Land application N_2O (unvolatilized)	10.81
Land application N_2O (runoff)	6.48
Aerobic composting of solids CH_4	16.11
Aerobic composting of solids N_2O	5.03
Total project activity	152.88

[a] Project activity boundary and emission sources shown in Fig. 3.
[b] Carbon dioxide (CO_2) equivalents. Global warming potential of methane (CH_4) and nitrous oxide (N_2O) are 23 and 296, respectively.

3.3. Approaches for reducing GHG emissions in animal manure systems

There are two basic approaches to reduce CH_4 emissions from agricultural manure management operations. In one approach, methane is produced using anaerobic digestion in closed and controlled conditions, followed by thermal destruction of the methane. In other words, in this approach the volatile solids in manure are first converted to CH_4 and CO_2, and the methane portion is subsequently oxidized to CO_2. The other approach, shown in this study, is the use of aerobic treatment that directly converts (oxidizes) the VS into CO_2 or stabilized C compounds. In both cases, emission reductions result from the difference between offset project and baseline emissions. Aerobic treatment of manure is an accepted manure management system under protocols adopted through the United Nations Framework Convention on Climate Change (IPCC, 1996, 2000, 2006).

Implementation of aerobic systems is more advantageous than anaerobic systems in terms of carbon credits. For example, the project activity implemented by Agrosuper at its 118,800 head swine operation in Chile reduced annual GHG emissions by 81,026 t CO_2-eq (63.3% reduction) using anaerobic digester and flaring to replace anaer-

Table 5
Overall results – Emission reductions per annum and dollar value for the implementation of the project activity using aerobic treatment system in the 4360-head finishing swine operation in North Carolina

CH_4 emission reductions (ER_{CH_4}) due to project activity[a]	4411.55 t CO_2-eq/year
N_2O emission reductions (ER_{N_2O}) due to project activity[b]	407.54 t CO_2-eq/year
Leakage effect (L) from electricity consumption[c]	42.51 t CO_2-eq/year
Total net emission reductions (ER) due to project activity[d]	4776.58 t CO_2-eq/year
Value of net emission reductions for 4360-head farm[e]	$19,106.32/year
Value of net emission reductions for each market pig produced[f]	$1.75/finished pig

[a] Amount of CH_4 that would be emitted to the atmosphere during a crediting period of 1 year in the absence of the project activity (Table 3) minus the amount of CH_4 emitted by the project activity in the same period (Table 4), expressed in tonnes of CO_2 equivalents.

[b] Amount of N_2O that would be emitted to the atmosphere during a crediting period of 1 year in the absence of the project activity (Table 3) minus the amount of N_2O emitted by the project activity in the same period (Table 4), expressed in tonnes of CO_2 equivalents.

[c] Changes in electricity demand due to project activity (wastewater treatment = 403.9 kWh/d × 365 d; solids composting = 31.5 kWh/d × 365 d), expressed in terms of tonnes of CO_2 equivalents (using carbon emission factor of 20.3 t C/TJ).

[d] Total annual emission reductions of the project are the sum of CH_4 and N_2O annual emission reductions adjusted for leakage effects ($ER = ER_{CH_4} + ER_{N_2O} - L$).

[e] Calculation uses current CO_2 trading value of US$4.00/t at the Chicago Climate Exchange (CCX) (June 2, 2006).

[f] Calculation uses actual turnover rate of 2.5 pigs/year monitored at Goshen Ridge farm. Thus, a 4360-head farm produces 10,900 market pigs per year (1.75 = US$19,106/10,900 finished pigs).

Table 6
Potential benefits from sale of GHG emision reduction credits due to installation of aerobic manure treatment systems (Supersoil project activity) on swine farms in North Carolina

Farming scenario	Emission reductions (t CO_2-eq per year)[a]	Total value ($/year)[b]
4000-head farm	4400	17,600
6000-head farm	6600	26,400
8000-head farm	8800	35,200
10,000-head farm	11,000	44,000
12,000-head farm	13,200	52,800
10,000,000 swine in North Carolina	11,000,000	44,000,000

[a] Projected amount of emission reductions based on results obtained by implementation of project activity in the 4360-head finishing facility at Goshen Ridge farm.

[b] Calculation of total dollar value uses projected annual emission reductions of 1.10 tonnes CO_2-eq per head per year and current CO_2 trading value of $4.00/t at the Chicago climate exchange (CCX) (June 2, 2006).

obic lagoon technology (baseline). In a second phase of the same project, they further reduced annual GHG emissions to a total of 116,993 t CO_2-eq (91.4% reduction) with the installation of aerobic post-treatment of the liquid before land application (NM0022, 2004).

3.4. Potential economic benefits

The dollar value from implementation of the Supersoil project in this farm was US$19,106.32/year. This translates into an economic benefit of US$1.75 per finished pig (Table 5). We also projected these results to other farm sizes ranging from 4000 to 12,000-head typically found in North Carolina and to a scenario of widespread adoption of the cleaner technology by most of the swine farms in North Carolina. Results of these calculations shown in Table 6 indicate that implementation of aerobic systems can represent substantial direct economic benefits to swine producers in North Carolina. These benefits represent an income range from about US$17,600 to US$52,800/year, which can greatly help finance the additional cost of the environmentally superior technologies. For example, the annualized cost of the environmental technology (initial investment financed at 7% for 10 year plus operational costs) for a 6000-head farm is US$84,080, or US$5.61 per finished pig (L. Fetterman, Super Soil Systems USA, personal communication, Clinton, NC, 28 June 2006). After carbon credits benefits, the cost of the environmental technology is reduced to US$3.86 per finished pig, which is lower than the cost of traditional anaerobic lagoon technology of US$4.59 per finished pig (US$85 per 1000 lb steady-state live weight). Therefore, this new aspect of agricultural waste management can be an important component for supporting the introduction of environmentally superior technology by pricing of environmental benefits for society, in this case GHG emission reductions.

4. Conclusions

Our objectives were to estimate greenhouse gas (GHG) emission reductions from implementation of environmentally superior technology in North Carolina (USA) swine farms. Emission reductions were calculated using approved UNFCCC methodology AM0006 that is appropriate for quantification of GHG emission reductions in manure management systems that utilize aerobic processes. It was found that replacement of the lagoon technology with the cleaner aerobic technology in a 4360-head swine operation reduced GHG emissions 96.9%, from 4972 t of carbon dioxide (CO_2-eq) to 153 t CO_2-eq/year. The dollar value from implementation of the cleaner technology was US$19,106.73/year. This translates into a direct economic benefit to the producer of US$1.75 per finished pig, which can make a difference whether the cleaner technology is economically more or less attractive than the baseline anaerobic lagoon technology. Therefore, GHG emission reductions can be an important component to facilitate producer adoption of environmentally superior technologies to replace current anaerobic lagoons in the USA.

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