Proc. of Workshop on Agricultural Air Quality: State of the Science. June 5-8, 2006.
Bolger Conference Center, Potomac, Maryland. (www.esa.org/AirWorkshop)

Greenhouse Gas Emission Reductions and Carbon Credits from Implementation of Aerobic Manure Treatment Systems in Swine Farms

Matias B. Vanotti[1], Ariel A. Szögi[1] and Carlos A. Vives[2]
[1] US Department of Agriculture, ARS, Coastal Plains Soil, Water, and Plant Research Center
2611 W. Lucas Street, Florence, SC 29501, USA.
[2] Agrosuper, Agricola Super Limitada, Rancagua c.c. 333, Chile.

Abstract
Trading of carbon and NOx emission reductions is an attractive approach to help producers implement cleaner treatment technologies to replace current anaerobic lagoons. Our objectives were to determine greenhouse gas (GHG) emission reductions from implementation of aerobic technology (Supersoil project) in North Carolina swine farms. Emission reductions were determined using approved methodology in conjunction with monitoring information collected during full-scale demonstration of the new treatment system in a 4,360-head swine operation in North Carolina. Emission sources for the project and baseline manure management system were methane emissions from the decomposition of manure under anaerobic conditions and nitrous oxide 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 98.9%, from 4,712 Tonnes of carbon dioxide equivalents (CO_2-eq) to 50 Tonnes CO_2-eq/year. Total net emission reductions by the project activity in the 4,360-head finishing operation were 4,632.8 Tonnes CO_2-eq per year. The dollar value from implementation of the Supersoil project in this swine farm was $9,960.54/year. This translates into a direct economic benefit to the producer of $0.91 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 North Carolina.

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 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 hog 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 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;
5. Substantially eliminate nutrient and heavy metal contamination of soil and groundwater.

Selection of EST candidates to undergo performance verification involved a request of 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 technologies 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, five 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 (figure 1). The system was constructed and operated by Super Soil Systems USA of Clinton, NC, 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).

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

The system had two components: 1) an on-farm wastewater treatment system 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, more than 99% of its biochemical oxygen demand and odor-causing components, and produced a disinfected liquid effluent (Vanotti et al., 2006). 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 nitrogen into a stabilized product that met Class A biosolids standards due to high pathogen reduction (Vanotti, 2005).

Although this clean technology was determined to be technically and operationally feasible and it was able to meet the strict technical environmental performance standards of an environmentally superior technology (EST), a contingency project was subsequently planned to demonstrate a second-generation, lower-cost version of the treatment system (i.e., annual cost should be similar to baseline lagoon technology) to meet unconditional EST status. Second-generation technology development involved simplification of processes and operation based on lessons learned during testing of the first-generation system.

Capital investment is the most important barrier for widespread adoption of 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. 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 was implemented years ago using the North Carolina traditional anaerobic lagoon treatment model. To accomplish this purpose, Agrosuper developed a project activity at a 118,800 finishing swine facility in Chile that led to an approved UNFCCC/CCNUCC 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 other approved methods for quantification of GHG emission reduction in animal manure systems (i.e., AM0016). 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.

Our objectives were to determine greenhouse gas (GHG) emission reductions from implementation of the cleaner aerobic technology (Supersoil project) in North Carolina swine farms compared to the current anaerobic lagoon system (baseline scenario). GHG emission reductions were determined using approved methodology AM0006 in conjunction with monitoring information collected during full-scale demonstration of the treatment system.

Materials and Methods

The baseline activity was the traditional anaerobic lagoon–sprayfield technology for a farm with 4,360-head finishing pigs in North Carolina. The project activity consisted of the implemented advanced system (Supersoil project) in an identical farm. Determination of GHG emission reductions by the environmentally superior technology was made using approved methodology described in AM0006 (2004).

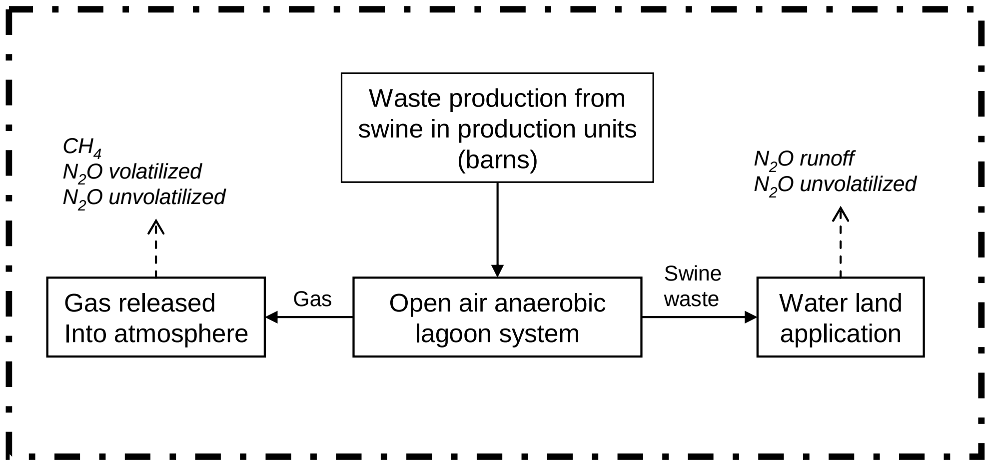

Figure 2. Baseline scenario boundary

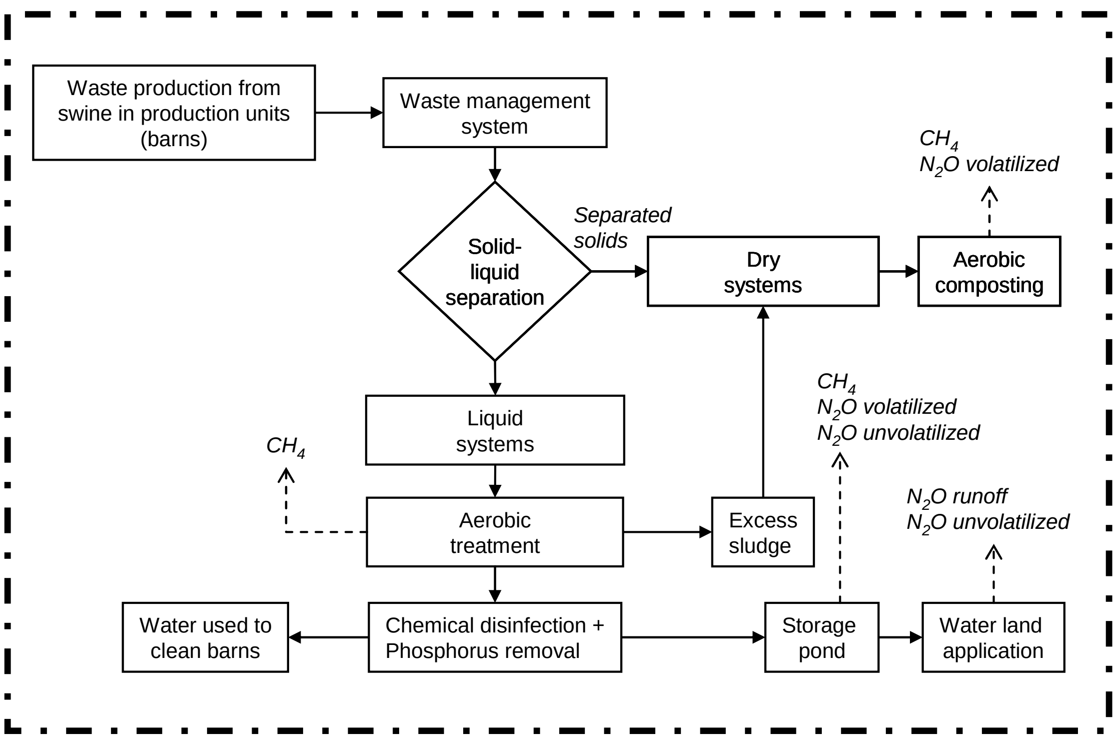

Figure 3. Project activity boundary

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 figures 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.

Emission factors used for each treatment stage were accepted values that are provided in the 1996 Revised IPCC Guidelines (IPCC, 1996) and in the IPPC Good Practice Guide (IPPC, 2000). 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., 2006) and at Hickory Grove farm (composting facility) near Clinton, Sampson County, North Carolina (Vanotti, 2005). Total volatile solids (VS) and the nitrogen supplied to the manure management system were determined by the excretion rates of VS and N and the monitored livestock populations. Average pig weight (two years in six barns) was 73.08 kg per head. A partition variable (FracLIQUID) was created to divert the excreted VS and N into the liquid system (figure 3). FracLIQUID was determined based on monitored BOD_5 and TN before and after solid-liquid separation. The difference (FracSOLID = 1 – FracLIQUID) determined the amount of VS or TN that was diverted into the dry system. For second and subsequent stages, methane emissions 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). The BOD_5 was adjusted using monitored water temperature and the Van't-Hoff-Arrhenius relationship. Similarly, emissions of N_2O in second and subsequent stages were calculated based on measurements of the N content in the manure flowing to that treatment stage and monitored flow rates of the manure.

Emission reductions of CH_4 and N_2O were expressed in terms of CO_2 equivalents using approved Global Warming Potentials (21 for CH_4 and 310 for N_2O). Direct economic benefits from emission reductions were determined using current trading value ($2.15 per Ton of CO_2) at the Chicago Climate Exchange (www.chicagoclimatex.com).

Results and Discussion

A total of 4,712 Tonnes of CO_2-eq were generated in a year by the baseline scenario (anaerobic lagoon–sprayfield technology) in the 4,230-head finishing operation in NC (table 1). Most (85.8%) of the GHG emissions were due to methane (CH_4) produced during anaerobic digestion in the open lagoons, and the remainder (14.2%) 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 50 Tonnes CO_2-eq during the same one-year period that resulted in a 98.9% decrease in GHG emissions (table 2). Generation of methane in the project activity was < 0.5% of that produced by the baseline, and generation of N_2O in the project activity was 5% of that generated by the baseline.

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 PAM flocculation. 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.

Table 1. Detailed baseline emissions for 4360-head finishing swine operation using anaerobic lagoon technology at Goshen Farm, Duplin Co., NC.

Emissions Source [1]	Emissions (Tonnes CO_2-eq per year) [2]
Lagoon CH_4	4,044.50
Lagoon N_2O (volatilized)	75.67
Lagoon N_2O (unvolatilized)	30.27
Land Application N_2O (unvolatilized)	278.35
Land Application N_2O	183.64
Total Baseline	4,712.43

[1] Baseline scenario boundary and emission sources shown in figure 2.
[2] Carbon dioxide (CO_2) equivalents. Global warming potential of methane (CH_4) and nitrous oxide (N_20) are 21 and 310, respectively.

Table 2. Detailed project emissions for 4360-head finishing swine operation using aerobic manure treatment system (Supersoil project) at Goshen Farm, Duplin Co., NC and aerobic composting of separated solids at centralized facility.

Emissions Source [1]	Emissions (Tonnes CO_2-eq per year) [2]
Aerobic Treatment of Separated Liquid	1.55
Storage Pond CH_4	0.30
Storage Pond N_2O (volatilized)	9.06
Storage Pond N_2O (unvolatilized)	0.90
Land Application N_2O (unvolatilized)	11.32
Land Application N_2O (runoff)	6.79
Aerobic Composting of Solids CH_4	14.71
Aerobic Composting of Solids N_2O	5.27
Total Project Activity	49.90

[1] Project activity boundary and emission sources shown in figure 3.
[2] Carbon dioxide (CO_2) equivalents. Global warming potential of methane (CH_4) and nitrous oxide (N_20) are 21 and 310, respectively.

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 3). Electricity consumption was small (29.7 Tonnes CO_2-eq) compared to the emission reductions (4662.5 Tonnes CO_2-eq) by the project activity, and for this reason, the AM0006 methodology considers that electricity consumption by aerobic treatment should not be considered in the overall net reduction calculations. Nevertheless, we included this amount to add conservativeness in our GHG emission reduction determinations. Total net emission reductions by the project activity in the 4,360-head finishing operation were 4,632.81 Tonnes CO_2-eq per year (table 3). Implementation of aerobic systems is more advantageous than anaerobic systems in terms of carbon credits. For example, the project activity implemented by Agrosuper at their 118,800 swine operation in Chile reduced annual GHG emissions by 81,026 Tonnes CO_2-eq using anaerobic digester and flaring to replace anaerobic lagoon technology (baseline). In a second phase of the same project, they further reduced annual GHG emissions to a total of 116,993 Tonnes CO_2-eq with the installation of aerobic post-treatment of the liquid before land application.

Table 3. Overall results – Emission reductions per annum and dollar value for the implementation of the project activity using aerobic treatment system in the 4,360-head finishing swine operation in North Carolina.

CH_4 emission reductions (ER_{CH4}) due to project activity [1]	4,027.94 T CO_2-eq/year
N_2O emission reductions (ER_{N2O}) due to project activity [2]	634.59 T CO_2-eq/year
Leakage effect (L) from electricity consumption [3]	29.72 T CO_2-eq/year
Total net emission reductions (ER) due to project activity [4]	4,632.81 T CO_2-eq/year
Value of net emission reductions for 4,360-head farm [5]	$ 9,960.54 /year
Value of net emission reductions for each market pig produced [6]	$ 0.91 /finished pig

[1] Amount of CH_4 that would be emitted to the atmosphere during a crediting period of one year in the absence of the project activity (table 1) minus the amount of CH_4 emitted by the project activity in the same period (table 2), expressed in tons of CO_2 equivalents.
[2] Amount of N_2O that would be emitted to the atmosphere during a crediting period of one year in the absence of the project activity (table 1) minus the amount of N_2O emitted by the project activity in the same period (table 2), expressed in tons of CO_2 equivalents.
[3] Changes in electricity demand due to project activity (403.9 kwh/d x 365 d), expressed in terms of tons of CO_2 equivalents.
[4] Total annual emission reductions of the project are the sum of CH_4 and N_2O annual emission reductions adjusted for leakage effects ($ER = ER_{CH4} + ER_{N2O} – L$).
[5] Calculation uses current trading value of $2.15 per ton of CO_2 at the Chicago Climate Exchange (CCX) (March 2, 2006).
[6] Calculation uses actual turnover rate of 2.5 pigs/year monitored at Goshen Ridge farm. Thus, a 4,360-head farm produces 10,900 market pigs per year (0.91 = $9,960.54/10,900 finished pigs).

The dollar value from implementation of the Supersoil project in this farm was $9,960.54/year. This translates into an economic benefit of $0.91 per finished pig (table 3). We also projected these results to other farm sizes ranging from 4,000 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 4 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 $9,100/year to $27,500/year that can greatly help finance the installation cost of the environmentally superior technologies.

Table 4. 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 (Tonnes CO_2-eq per year) [1]	Total value ($/year)
4,000-head farm	4,250	9,138
6,000-head farm	6,275	13,491
8,000-head farm	8,501	18,277
10,000-head farm	10,626	22,846
12,000-head farm	12,751	27,415
10,000,000 swine in North Carolina	10,625,711	22,845,279

[1] Projected amount of emission reductions based on results obtained by implemenation of project activity in the 4,360-head finishing facility at Goshen Ridge farm.
[2] Calculation of total dollar value uses projected annual emission reductions and current trading value of $2.15 per ton of CO_2 at the Chicago Climate Exchange (CCX) (March 2, 2006).

Conclusions

Our objectives were to determine greenhouse gas (GHG) emission reductions from implementation of environmentally superior technology in North Carolina swine farms. Emission reductions were determined using approved UNFCCC/CCNUCC methodology AM0006 that is appropriate for quantification of GHG emission reductions in manure management systems that utilize aerobic processes. We found that replacement of the lagoon technology with the cleaner aerobic technology in a 4,360-head swine operation reduced GHG emissions 98.9%, from 4,712 Tonnes of carbon dioxide (CO_2-eq) to 50 Tonnes CO_2-eq/year. The dollar value from implementation of the cleaner technology was $9,960.54/year. This translates into a direct economic benefit to the producer of $0.91 per finished pig. Therefore, GHG emission reductions can be an important component to facilitate producer adoption of environmentally superior technologies to replace current anaerobic lagoons in North Carolina.

Acknowledgements

This research was part of USDA-ARS National Program 206: Manure and By-product Utilization; CRIS Project 6657-13630-003-00D "Innovative Animal Manure Treatment Technologies for Enhanced Environmental Quality." Technology verification study of the project activity was partially funded by North Carolina State University and its sponsor Smithfield Foods, Inc. through USDA Agreement 58-6657-2-202, NCSU Subcontract #2002-0478-02. The authors are grateful to Super Soil Systems USA, Clinton, NC for help during project design and monitoring, and to Premium Standard Farms for providing farm records on animal weight and production. Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

References

Aneja, V.P., J.P. Chauhan, and J.T. Walker. 2000. Characterization of atmospheric ammonia emissions from swine waste storage and treatment lagoons. *J. Geophys. Res.* 105(D9):11535-11545.

AM0006. 2004. "GHG emission reductions from manure management systems." Approved baseline methodology AM0006, United Nations Framework Convention on Climate Change (UNFCCC).

Barker, J.C. 1996. Lagoon design and management for livestock waste treatment and storage. North Carolina Cooperative Extension Service. Pub. No. EBAE 103-83.

IPCC. 1996. Revised 1996 IPCC guidelines for national greenhouse gas inventories. Intergovernmental Panel on Climate Change, National Greenhouse Gas Inventories Programme (IPCC-NGGIP). United Nations Framework Convention on Climate Change (UNFCCC).

IPCC. 2000. Good practice guidance and uncertainty management in national greenhouse gas inventories. Intergovernmental Panel on Climate Change, National Greenhouse Gas Inventories Programme (IPCC-NGGIP). United Nations Framework Convention on Climate Change (UNFCCC).

Loughrin, J.H., A.A. Szogi, and M.B. Vanotti. 2006. Reduction of malodorous compounds from a treated swine anaerobic lagoon. J. Environ. Qual.35(1):194-199

Mallin, M.A. 2000. Impacts of industrial animal production on rivers and estuaries. American Scientist 88(1):26-37.

Sobsey, M.D., L.A.Khatib, V.R. Hill, E. Alocilja, and S. Pillai. 2001. Pathogens in animal wastes and the impacts of waste management practices on their survival, transport and fate. In: White Papers on animal agriculture and the environment.   MidWest Plan Service (MWPS), Iowa State University, Ames, Iowa, (Chapter 17).

Szogi, A.A., M.B.Vanotti, and A.E. Stansbery. 2006. Reduction of ammonia emissions from treated anaerobic swine lagoons. Transactions of the ASABE (in press)

Vanotti, M.B., D.M.C. Rashash, and P.G. Hunt. 2002. Solid-liquid separation of flushed swine manure with PAM: Effect of wastewater strength. Transactions of the ASAE 45(6):1959-1969.

Vanotti, M.B., A.A. Szogi, and P.G. Hunt. 2005. Wastewater treatment system. U.S. Patent 6,893,567. U.S. Patent Office.

Vanotti, M. B. 2005. Evaluation of Environmentally Superior Technology: Swine waste treatment system for elimination of lagoons, reduced environmental impact, and improved water quality (Centralized composting unit). Phase II: Final Report for Technology Determination per Agreements between NC Attorney General & Smithfield Foods, Premium Standard Farms, and Frontline Farmers. July 25, 2005. Available at: http://www.cals.ncsu.edu/waste_mgt/smithfield_projects/phase2report05/reports/A1.pdf

Vanotti, M.B., A.A. Szogi, P.G. Hunt, P.D. Millner, and F.J. Humenik. 2006. Development of environmentally superior treatment systems to replace anaerobic swine lagoons in the USA. *Bioresource Technol*. (in press).

Williams, C.M. 2005. Development of Environmentally Superior Technologies. Phase II Report for Technology Determination per Agreements Between the Attorney General of North Carolina and Smithfield Foods, Premium Standard Farms and Frontline Farmers. July 25, 2005. Available at: http://www.cals.ncsu.edu/waste_mgt/smithfield_projects/phase2report05/front.pdf