A SYSTEMIC APPROACH TO MITIGATING GREENHOUSE GAS EMISSIONS AND OTHER ENVIRONMENTAL IMPACTS AT A SWINE FARM

Doorn, M.R.J., ARCADIS, P.O. Box 13109, Research Triangle Park, North Carolina 27709, United States.
Hobbs, A.O., Department of Mechanical Engineering,
North Carolina State University, Raleigh, NC 27695, United States.

ABSTRACT

This paper evaluates methane (CH_4) and nitrous oxide (N_2O) emissions from a swine farm. In identifying mitigation options for N_2O emissions, a systemic or integrated approach is used that works in concert with the natural nitrogen cycle. A similar statement can be made for emissions and sinks associated with the carbon cycle.

Use of innovative solutions has been demonstrated at Barham Farms, a swine farm in North Carolina, USA, where treated effluent from an anaerobic digester is used to hydroponically fertilize tomato plants in greenhouses. The tomatoes are sold locally as high-end produce. Another facet of the integrated approach at this farm is that biogas from the anaerobic digester is used to fuel a combined heat and power engine/generator. The electric power reduces the need for fossil fuel generation from the utility and the captured waste heat reduces the need for propane fired heaters.

By applying systemic improvements, Barham Farms has greatly reduced CH_4 and ammonia (NH_3) emissions, and is likely to have significantly reduced N_2O emissions.

1.0 INTRODUCTION TO SYSTEMIC APPROACH

All humans combined perhaps contain three megatons of nitrogen (Smil, 1997). This nitrogen is obtained from the consumption of agricultural products, and to a minor degree from hunting, gathering and extensive herding. To maintain this nitrogen, humans undertake a myriad of processes that add about 150 megatons per year of fixed nitrogen to the biosphere. These processes include massive chemical nitrogen fixation from the manufacture of synthetic fertilizers, as well as from combustion for transportation and energy generation. Issues associated with nitrogen fixation include atmospheric climate change and ozone formation, eutrophication of waterways and oceans, acidification of soils, large-scale agricultural monoculture and associated loss of biodiversity. Similar observations may be made for other biogeochemical cycles such as the carbon cycle and the phosphorus cycle.

Modern agriculture in the United States has been changed to conform to contract farming operations by vertically integrated businesses that have access to the retail market. Farms once diversified in raising both crops and animals have become increasingly specialized and intensively operated. This "industrialization" of agriculture allows the higher feed costs per animal which should accrue to separate activities to be offset by economies of scale and the efficiency of specialization. Animal producers have increased their revenues by expanding and concentrating their operations in recent decades so that in the swine industry 75% of the inventory is held by 9.6% of the farmers according to USDA 2002 statistics. Many other small producers have left the business. The management of animal manure and its associated environmental impacts have become complicated by the economic model used for modern concentrated animal feed operations (CAFOs). Historically, animal manure could be recycled safely and easily within the production system by applying it on adjacent croplands, on which farmers could grow animal feed. As the processes of crop and animal production have become disconnected, this once widespread practice is being used less and less, in favor of massive application of artificial fertilizers, bringing into question the sustainability of current practices.

Today, an agricultural operation is usually viewed as a strictly economic enterprise in which at least some of the environmental and societal effects have not been monetized. And while the operation needs to be economically sustainable, it could also be viewed from a more systemic perspective. Characteristics of such a perspective include recognizing that a system is dynamic and cyclical with different components that are interrelated and multi-disciplinary, and that the system does not stop at the physical boundaries of the farm. In essence a farm is a biological system that is artificially maintained, or even more simply put, a disturbed ecosystem. The modern farmer interferes with the balance of inter-relationships between soil, plants and animals that naturally occurs in a particular geographical area and imposes an artificial order which will not persist without continual intervention and input of external energy and nutrients. The greater the diversion from the original natural ecosystem, the greater the required level of intervention and monitoring (Wilson,1988). As such, an increased understanding of the entire farm operation as a system may lead to the development of practices that are more in concert with the aforementioned characteristics, thus reducing the required level of intervention and monitoring, which can subsequently result in benefits that are both economic and environmental for the farmer, as well as the surrounding social and biological communities.

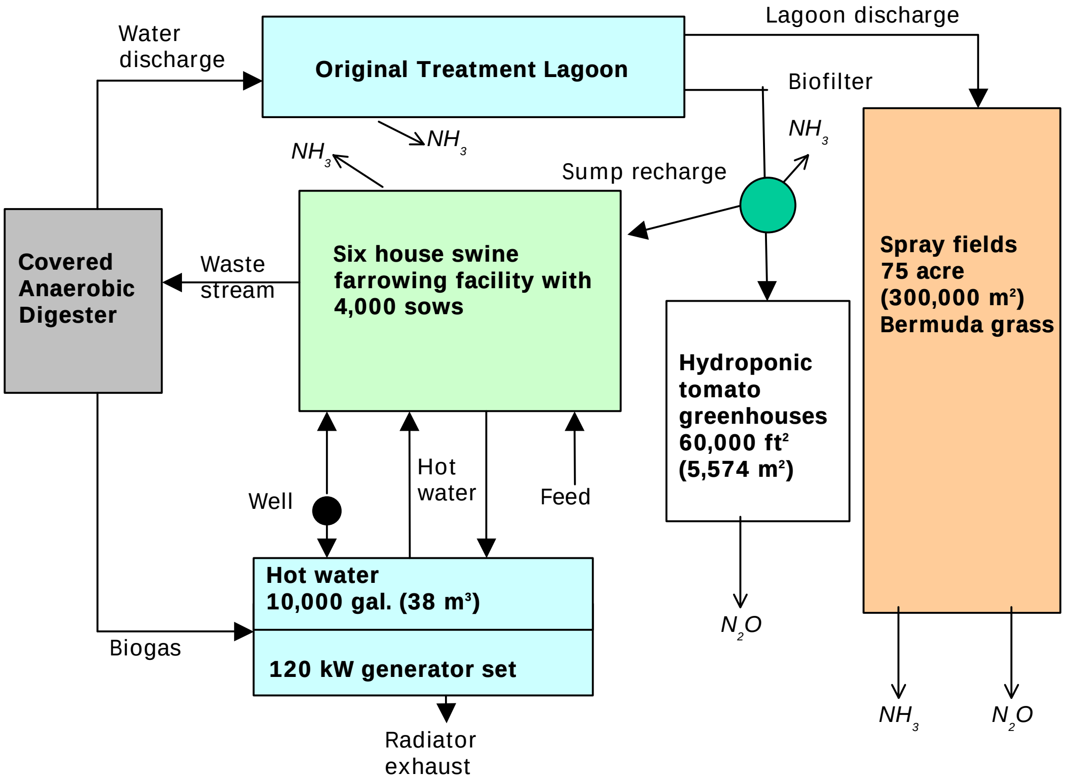
2.0 CASE STUDY, BARHAM FARMS

A systemic approach was applied at Barham Farms in Zebulon, North Carolina. Barham Farms is a 4000 sow farrow-to-wean hog facility with four gestation houses and two farrowing houses. Swine waste was traditionally treated in a single open lagoon as required by state regulations, while the effluent was sprayed on Coastal Bermuda grass which has a high nitrogen uptake. In general, this system when properly sized and operated provides effective waste treatment with no liquid discharge from the farm. Due to increasing pressure from encroaching development and anticipated environmental regulations, Barham Farms envisioned several creative systemic improvements that were aimed at complying with anticipated regulatory action, reducing odors, and reducing the amount of effluent that needed to be disposed of on grass land, while generating revenue for the farm. While not specifically part of the primary objectives, these improvements have also decreased GHG emissions from the farm. These improvements consist of the installation of an in-ground covered anaerobic digester (ICAD) for capturing the energy component of the waste and a series of greenhouses, which utilize a portion of the nutrient component of the waste.

2.1 ANAEROBIC DIGESTER

With support from the U.S. Environmental Protection Agency's AgSTAR program, Barham Farms installed a 6.9 million gallon (26.1 m^3) ICAD separate from but adjacent to the original treatment lagoon. The direct waste treatment benefits of the ICAD are the elimination of potential lagoon overflows due to rain or snow water influx, the reduction of pathogens in the effluent, and the elimination of the open anaerobic lagoon as an odor source. Figure 2 includes flows and likely N_2O and NH_3 emissions pathways.

Figure 2 - Barham Farms Flow Diagram



In addition the ICAD produces biogas, which is used to offset both electrical and heat requirements on the farm. The average biogas production at Barham Farms is 700 ft^3/hr (20 m^3/hr) in the winter and 1,400 ft^3/hr (40 m^3/hr) in the summer. Based on an average CH_4 concentration of 70%, the Barham Farms digester produces an average of 560 and 990 kWh of electricity per day in winter and summer respectively (Cheng, et al., 2003).

At Barham Farms, the biogas is currently put to two uses; hydronic heat and power generation. Hydronic heat is used year round to provide “comfort heat” for newborn piglets. Prior to the use of hydronic heat, this need was served with 75 kW of infrared lamps which have been eliminated. Hot water from a storage tank is pumped out to mats in the pens where the piglets are kept. Water is circulated in an independent loop through a biogas-fired hydronic furnace to maintain high water temperature in a 10,000 gallon (38 m^3) storage tank. An additional hot water circulation loop passes through a heat exchanger on the engine/generator system which captures waste engine heat. As a backup, a propane fired hydronic furnace is also connected to the heating loop. Figure 3 is a picture of the generator and heaters with the storage tank in the background.

Figure 3. Barham Farms Biogas Combined Heat and Power

Power is generated year-round with the biogas, usually during peak electrical demand. If the need arises, excess biogas can also be burned in a flare to maintain the integrity of the cover on the ICAD while destroying odor causing gas components. While there is significant value to the farm associated with hydronic heat, power production is harder to place a value on due to the variability of the biogas available for power generation and the complexity of the utility rates. The value of the biogas is dependent on its utilization and the current price of competing fuels. Based on billing statements, the biogas fueled generator produced about 25% of the total electric power demand on the farm. On average, 41 percent of energy is converted into heat going to the storage tank (Singer, et al., 2001 and Hobbs, et al., 2002).

Savings on the power utility bill are estimated at an average of $1,022/month over estimated costs without generation, assuming equivalent demand charges. Electrical utility savings are higher in the summer billing cycles than in the winter billing cycles because of higher on-peak pricing. Heat provided by the generator set and hydronic boiler has resulted in an estimated $2,500/month in utility bill savings. Average O&M expenses for the generator set are estimated at $500/month which may be subtracted from the $3522/month value for a total operating payback of approximately $36,000 per year. The initial cost of the ICAD, generator and heat utilization equipment was $264,474 according to estimates made in 1996. This gives a simple payback of 7.34 years without monitizing the environmental and odor improvements.

2.2 TOMATO GREENHOUSES

The second major systemic improvement consisted of the construction of two 30,000 ft^2 (2784 m^2) greenhouses for growing hydroponic tomatoes. The tomatoes are sold in the local commercial food market. Effluent from the ICAD is nitrified in microbead biofilters, which were originally developed for aquaculture applications. Although the water is already practically pathogen free, it is only applied to the roots of the plants through drip irrigation. The Barham Farms tomato greenhouses consume an average of 1.6 kg of nitrogen (or 12 m^3 of nitrified water) per day with an average nitrogen concentration of 133.5 mg/L (Cheng, et al., 2003). This quantity of water is now released via evapotranspiration from the plants each day instead of into the surrounding environment via effluent spraying. Figure 4 is a view inside the greenhouses.

Figure 4. Barham Farms Tomato Greenhouse

The utilization of biogas at Barham Farms has received considerable attention over the past few years and is well documented. The use of ICAD effluent for hydroponic greenhouse tomato production is currently receiving attention from North Carolina State University researchers. The program focus has been on:

(1) Monitoring the organics degradation in the ambient temperature anaerobic digester and the water quality of the digester effluent;
(2) Establishing the nitrification biofilters to control NH_3 emissions and evaluate the effects of the nitrification biofiltration on the water and air quality of the swine waste management system;

(3) Evaluating a greenhouse tomato production system for utilization of nutrients in treated swine wastewater; and
(4) Simulating the utilization of the waste heat from the electricity generation system using biogas produced in the anaerobic digester in a tomato production greenhouse.

In the July 2003 monthly report the farm's energy balance, nitrogen and carbon cycles have been summarized (from Cheng, et al., 2003). The performance of the ICAD has been monitored based on analyses of samples from the influent and effluent of the digester. Samples have been taken every other week. Ammonium in the influent and the effluent of the anaerobic digester was almost the same with little reduction of TKN observed. An efficient degradation of organics was observed in the anaerobic digester. Chemical Oxygen Demand (COD), Total Organic Carbon (TOC), Total Suspended Solids (TSS), and Volatile Suspended Solids (VSS) were reduced by approximately 92%, 85%, 73%, and 88%, respectively. Significant reduction of TP, phosphate, copper, and zinc was also observed and is possibly due to the precipitation of calcium phosphate and other insoluble salts.

From the above reported results it is evident that the ICAD performs very well in removing carbon but does not remove nitrogen. Because lagoon effluent continues to be sprayed on fields this remains a significant source of both NH_3 and associated N_2O emissions.

Microbead biofilters were installed for biological nitrification to convert the NH_4^+ in the effluent of the ICAD to NO_3^- to improve nutrient utilization by the plants. This also improves the denitrification which occurs as the NO_3^- is held in the storage pond and applied to the hydroponic media. The effluent of the anaerobic digester is pumped to a storage pond, distributed onto the beads, and nitrified by the bacteria attached on the beads. Air is bubbled up through the microbeads to aid the bacteria in oxidizing the NH_3. The nitrified water is used to recharge the pits in the pig houses, as well as being used in the greenhouses for drip irrigation and fertilization.

Before the nitrification biofilters were installed, Mr. Barham had used the liquid in the storage pond that contained high ammonium to recharge the pits under the swine houses. Based on Mr. Barham and his workers' observations, the air quality inside the pig houses has improved significantly since the nitrified water was used to recharge the pits.

At Barham Farm, excess irrigation water from the greenhouses is returned to the storage pond, thus maintaining a closed cycle in terms of nutrient discharge. Small amounts of additional nutrients are added to produce a well rounded hydroponic mixture. Fresh water was added as needed to maintain the desired salt concentration in the hydroponic water. During certain periods, as little as 20% of fresh water was required, with biofilter water making up the remainder.

Initially, Estes and Peet (1999) estimated annual operating cost for conventional greenhouse tomato production in NC to be approximately \$4.15/ft^2 (\$44.65/m^2), including heating, cooling, labor, media, plants and supplies. Subtracting from that an estimated \$0.33/ft^2 (\$3.55/m^2) fuel savings from the use of the waste heat (2/3 of the needs of 1 greenhouse, or 1/3 of the needs of both) and \$0.25/ft^2 (\$2.69/m^2) for sharing labor with the swine operation (1/2 of the estimated labor costs for the greenhouses), the resulting operating cost was estimated at \$3.72/ft^2 (\$40.03/m^2). The annual return from year-round production was estimated to be about \$11.25/ft^2 (\$121.05/m^2) per year [30 lbs (13.6 kg) per plant @ \$1.50/lb (\$0.68/kg)]. Adding to that the savings in spray field application costs [60% of \$40,000 or \$0.43/ft^2(4.63/m^2)] gives a return of \$11.68/ft^2 (\$125.68/m^2) per year. Subtracting the \$3.72/ft^2 (\$40.03/m^2) operating cost gives a net return of \$8.21/ft^2 (\$88.34/m^2).

The total investment for the greenhouses, biofilters and nitrogen removal system is estimated at \$12.07/ft^2 (\$129.87/m^2) (\$240,000 for the first house plus \$436,000 for the head house and the second green house). This will amortize an 8.5% loan in 1.6 years. As indicated above, this scenario assumes a production rate of 30 lbs per plant. While this is on the high side of normal for year round production, it is certainly achievable. A more conservative estimate can be obtained, however, by assuming a production rate of 20 lbs per plant, the low side of normal. This results in a net return of \$4.46/ft^2 (\$47.99/m^2), which amortizes the principal in 3.08 years.

During this most recent reporting time period, the greenhouses produced an average of 711 kg/day of marketable tomatoes (Cheng, et al, 2003). While prices vary considerably during the year the NCSU researchers have assumed that the tomatoes are sold at a gross price of \$2.20/kg. For 300 days of production each year this yields a market income of approximately \$8.17/ ft^2 (\$87.91/m^2) Tomato production as high as 79 g/plant/day has been observed. Quality was as high or higher than other greenhouse tomato operations in the area, and anecdotal evidence suggests flavor was improved by the use of the waste derived irrigation water. Tomato production at such a rate should make the greenhouse operation financially attractive to farms who might want to diversify their operations.

3.0 DISCUSSION AND CONCLUSIONS

3.1 AMMONIA AND ODOR EMISSIONS

There is evidence that the practice of flushing and recharging of pits with regular (NH_3-laden) lagoon water provides a significant portion of the NH_3 emissions from swine houses (Doorn, et al., 2002). As was indicated, there is anecdotal evidence that the air quality in the Barham houses has significantly improved now that nitrified water is used for flushing and recharging the pits as opposed to water direct from the lagoon. This improvement is in large part due to a drop in NH_3 and odor emissions in the houses. Thus, Barham Farms has:

- reduced NH_3 emissions from the lagoon by covering it,
- significantly lowered NH_3 and odor emissions from houses, and

- reduced emissions from spraying operations by installation of the tomato greenhouses and using the water there.

Reduction of NH_3 in the atmosphere has a further indirect positive effect on greenhouse gas emissions, because NH_3 can redeposit on the earth surface, where it will become available for uptake by organisms. The associated denitrification can produce N_2O. A quantification of this N_2O is beyond the scope of this paper, and may be suggested as a further research topic.

3.2 GREENHOUSE GAS EMISSIONS

The systemic improvements at Barham Farms have resulted in significant greenhouse gas emission reductions. According to the EPA (AgStar website), the anaerobic digestion processes at Barham Farms result in a net CH_4 emission reduction of 50 metric tons CH_4 or 1,050 metric ton carbon equivalent (MTCE) per year, using a Global Warming Potential of 21 (TAR). Of this, 21 tons (41 percent) is used in the boiler.

This figure does not take the additional reductions in carbon dioxide (CO_2) into account that result from offsets in fossil fuel consumption. If CH_4 (from the biogas) would not be available, the boiler would be fired by propane gas (C_3H_8). The heating value ratio of propane-to-CH_4 is 1.18, so 21 tons of CH_4 equal 17.7 tons of propane, which equals 3 x 17.7 = 53 tons of CO_2 (the molecular weights of propane and CO_2 are the same, 44 gram, and 1 mole of propane produces 3 moles of CO_2). The water jacket and exhaust heat exchanger on the engine/generator together provide roughly an equivalent amount of CHP heating which is equal to another 53 tons of CO_2 on the basis of spot measurements made during normal operation.

The average amount of electricity generated at Barham Farms by the biogas equals 271,724 kWh/year. Using USEPA Power Profiler (EPA, 2002), we can estimate a conversion into CO_2 emissions reductions by using renewable biogas rather than fossil fuels. According to the EPA source, the average national CO_2 emission rate for electrical production is 1.392 lbs CO_2 /kWh. Assuming line losses of 9% there is an additional offset of CO_2 emission of 187 MTCE/yr. Under current EPA guidelines, the environmental advantage of reduced SO_X and NO_X resulting from a renewable fueled distributed generator accrue to the host utility if the power is supplied to the grid. The utilities further assume that the CO_2 credits and the green attributes of the generation would also pass to them to satisfy emission reduction goals. Consequently, with the current heat and power scenario, Barham Farms reduces total greenhouse gas emissions by 1,050 + 187 + 53 + 53 = 1,343 MTCE per year.

This number does not include additional fossil fuel offsets from heating the greenhouses with on-farm heat, because this is not currently practiced at Barham Farms. Nor does it include potential reductions in nitrous oxide (N_2O) emissions. Theoretical N_2O emissions follow three mechanisms. First, the nitrified lagoon effluent associated with tomato irrigation is not sprayed onto land, where it would result in N_2O emissions. Second, there is an offset in synthetic fertilizer that would otherwise be applied to the tomatoes. Third, because of the drip irrigation, optimum nitrogen uptake is assured, resulting in reduced N_2O emissions. The impact of the Barham system on nitrogen and N_2O pathways could be an object for further study.

There are 4,000 sows on Barham farm, equaling a live weight of 1.6 million pounds (not counting piglets). In North Carolina, there are approximately 10 million pigs with an approximate live weight of 1,400 million pounds. Consequently, installing a system similar to that on Barham Farms, could potentially reduce greenhouse gas emissions in the state by more than 1.18 million MTCE/year. This number does not allow for any differences between sows and finishing pigs regarding feed and waste management.

Additional options for systemic improvements at Barham farms are briefly summarized below.

- Carbon dioxide (CO_2) enrichment to promote greenhouse plant growth. A brief experiment with the addition of cooled CO_2 – rich exhaust gas was conducted in 2001. It was found that the particular air stream at Barham Farms contains constituents that are harmful to tomato plants. However, no detailed scientific assessment has been performed to date.
- Lagoon effluent that is not used in the greenhouses still needs to be disposed of by land irrigation. Barham Farms grows Coastal Bermuda grass with a yield of 6 tons of hay per acre per year, resulting is several hundred tons of hay per year that must be disposed of. Because the market for Bermuda hay in North Carolina is limited, disposal presents a nonproductive expense for Barham Farms. Currently, experiments with direct combustion of the hay are planned for heat utilization. Further study would be needed to ascertain the effects of Bermuda hay combustion on the nitrogen, carbon, and energy balances and associated greenhouse gas emissions or offsets.
- Other options that have been or are under consideration at the Farm, including Bermuda hay composting and pyrolysis.

3.3 CONCLUSIONS

By applying systemic improvements, Barham Farms has substantially reduced GHG emissions. As a result of installing an ICAD and generating heat and power from biogas, Barham Farms has achieved a combined reduction of lagoon CH_4 emissions and CO_2 offsets of approximately 1,343 MTCE per year. The use of additional on-site heat for use in the tomato greenhouses is being evaluated, which would result in further CO_2 offsets. Additional emissions reductions in N_2O have already been achieved due to the tomato fertilization with nitrogen-rich lagoon effluent but have not been quantified. Table 1 provides a summary.

In addition, Barham Farms has reduced NH_3 emissions from the lagoon, lowered NH_3 and odor emissions from houses, and has also significantly reduced emissions from spraying operations. It is recommended to develop a complete nitrogen mass balance for Barham farms that includes NH_3 and N_2O emissions changes as a result of the installation of the ICAD, greenhouses and biofilters.

Table 1. Existing greenhouse gas emission reductions at Barham Farms

Gas	Mechanism	Quantification
CH_4	Control of CH_4 by covered lagoon.	50 metric tons CH_4 / year, (1,050 MTCE/year).
CO_2	Use of biogas offsetting fossil fuel use.	293 MTCE/year.
N_2O	Reduced effluent application on sprayfields.	Can be quantified with generic N_2O emission factor.
N_2O	Offset resulting from reduced fertilizer use on tomatoes.	Can possibly be quantified with generic N_2O emission factor.
N_2O	Reduction as a result of precision drip irrigation compared to normal nitrogen application.	Unknown.
N_2O	Indirect effect due to reduced NH_3 emissions from lagoon, houses, and sprayfields.	NH_3 emission estimates for the farm are available. These may be combined with deposition data and generic N_2O emission factors.
CO_2	Use of waste heat for greenhouses in winter, offsetting fossil fuel use.	Design stage. Can be quantified similar to other offsets.

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