Aerobic Treatment of Manure Lagoons showing Environmental and Economic Benefits with Eco-System Service Paybacks

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Deliverables:

- Demonstrate eco-system service paybacks for aerobic reduction of methane and nitrous oxide emissions from manure lagoons.
- Validate new Eco-System Service paybacks through demonstration on 11 farm sites across three upper Midwest states.
- Evaluate and disseminate results showing environmental, economic and on-farm benefits of aerobic lagoon treatment (liquid composting) at demonstration sites.
- Develop new NRCS practice standards for aerobic treatment and management of livestock manure.
- Attend at least one NRCS CIG showcase or comparable NRCS event during the period of the grant.

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EXECUTIVE SUMMARY

This Conservation Innovation Grant successfully demonstrated innovative and affordable aerobic treatment for animal nutrient waste lagoons to meet designated NRCS environmental priorities, including:

- ✓ **Air Quality Priorities** by avoiding the formation of severe greenhouse gasses (GHG's) such as methane and nitrous oxide in lagoons and from field application of manure, by eliminating other noxious gasses, odors and pathogens and by reducing emissions from fossil fuel consumption required for agitating and applying nutrients on farm fields.
- ✓ **Water Quality Priorities** by retaining and transforming more manure nutrients into odor- and pathogen free, crop-ready, liquid fertilizer for direct application onto crops during the growing season, thereby avoiding fall, winter and spring applications onto farm fields and avoiding the production of nitrates.
- ✓ **Soil Quality Priorities** by delivering aerobic microbial soil amendments in large quantities to reverse years of lost microbial fertility in degraded soils as well as offering the potential to reverse phosphorous and potassium tie-up in soils.

This project installed a total of 100 floating oxygenation-circulator platform (OCP) units on lagoons at 11 animal production sites in Wisconsin, South Dakota and Nebraska to manage manure from over 10 million pounds of animal body weight. This was done to demonstrate the benefits, performance and reliability of continuous re-oxygenation and complete mixing of manure lagoons. At several sites, odor and pathogen free "safe water" was recycled for barn cleaning to eliminate gas and odor from the barn.

The project intended to provide enhanced air, water and soil quality from precision aerobic manure management while adding farm revenues to help pay for these eco-system services.

- **Air Quality Goals and Objectives** Specifically the project reduced or eliminated the production of
  - ✓ Severe GHG's, especially methane and nitrous oxide from lagoons and farm fields
  - ✓ Other gas and odors such as hydrogen sulfide, ammonia and VFA's
  - ✓ Pathogens, specifically measured as E. Coli
  - ✓ GHG emissions from consumption of fossil fuel during manure management

  Direct evidence from on site observations and data from demonstration locations, lab testing of manure samples and microbial matrix analysis clearly indicates air quality goals have been achieved.
- **The project reduced severe GHG's including methane and nitrous oxide** by supplying sufficient oxygen to inactivate methanogens while avoiding excess oxygen that would

support the formation of nitrite and nitrate, precursors for nitrous oxide. Microbial Matrix Analysis consistently reported methane producing methanogens as the lowest group of microbes. This group was consistently below 300,000 CFU/g compared with other microbial groups in the 10 million to 10 billion range. Desired levels of oxygen were specifically targeted within the ± 150mV ORP range to be maintained in the lagoon by means of total lagoon circulation. This level of oxygen supply requires less energy and avoids N-conversion into undesirable nitrites and nitrates. Nitrates can be undesirable because they are difficult to control in the environment. They move easily through the soil and readily denitrify under anoxic conditions, losing valuable nitrogen to the atmosphere. From an air quality perspective, production and long term storage of nitrites and nitrates in the lagoon or in the soil promotes nitrous oxide emissions. Lab samples consistently showed nitrate at less than 0.002% and reaching 0.0003% in demonstration lagoons.

- **The project reduced ammonia gas and retained more available-N for crops** by supporting conditions favorable for converting ammonia (NH3) to ammonium (NH4+). This reduced N-loss from ammonia volitilization, reduced emissions of ammonia (NH3), hydrogen sulfide and other PM precursors while retaining more manure-N in plant available, crop ready condition for direct application onto growing crops. Manure reports consistently show higher available-N, some with NH4+ reaching as high as 95% of total-N.
- **The project eliminated odor from lagoons, field application and barn cleaning.** The most reliable measure of potential odor is Volatile Fatty Acid (VFA's) found in the lagoon. VFA's in untreated manure lagoons are typically measured between 5,000 ppm and 10,000 ppm. Research has shown that a sensitive human nose is able to detect and identify odors from liquids containing as little as 250ppm of VFA. Below this threshold, odors are undetectable. Lab samples from aerobic demonstration lagoons consistently reported VFA's at or below 100ppm – indicating that no detectable odor could be produced.
- **The project reduced or eliminated pathogens from manure lagoons**. Not always discussed as an air quality issue, pathogens can become airborne when pit fans are turned or whenever animal wastes are applied to fields. E. coli is most often used as a measure for the presence or absence of other undesirable pathogens. E. coli levels in manure are typically found between 3,000-50,000 cfu/g. In demonstration lagoon samples E. coli consistently reported below 100 cfu and often below 10cfu/g, the infectious dosage limit for humans. Important limiting factors for pathogens are UV-sunlight, oxygen, low or high pH and dilution. These conditions are supported by oxygenation circulators.
- **The project planned to develop carbon credit protocols** to supplement farm income and help pay for improved air quality and other beneficial eco-system services provided by aerobic treatment. With the collapse of US carbon markets just as the project was getting under way, new carbon credit protocols were no longer being accepted. However, it had already become apparent that other significant aerobic revenues, both savings and income

would be available from improved farm productivity, less expensive, easier and environmentally better manure handling, more recovered nitrogen in ammonium (NH_4^+) form and increased crop yield from in-season fertigation (to name a few sources). Carbon credits may return for consideration in the future, but they are not the only source of additional income available to pay for aerobic manure management.

- **Aerobic Installations were completed at 11 sites** within budgets allocated for each site. Project funds were spent as anticipated with the exception of carbon credit components which were re-allocated to pay for identification of alternative revenue streams available to farmers who elect to use aerobic manure management. As a result of a more diversified approach, project outcomes have demonstrated a strong business case for the use of aerobic lagoon treatment to improve the economics and the management of manure for enhanced air, water and soil quality and improved profitability for livestock sites.
- **Demonstrating the reliability and performance of floating oxygenation- circulator equipment** was an important outcome from this project. After more than twenty years since floating circulators first appeared, earlier equipment had developed a reputation for failure to stand up to harsh conditions on manure lagoons and for failing to provide the amount of oxygenation and circulation required by high BOD manure. As a result, many farmers who hoped for the benefits offered by affordable aerobic manure management were skeptical of the reliability and performance offered by this type of equipment. During this project, equipment problems and machine failures were almost non-existent. Machines kept running under harsh conditions. Out of the entire 100 machines installed, only two manufacturing defects were encountered and were easily corrected. Oxygen and circulation stayed within desired ranges except on those ponds where minimum treatment was lacking or field and barn trash was allowed to enter the lagoon and rag up impellers. The equipment itself delivered desired performance with little or no signs of wear after 3 years of installed use. In high wind areas, several machines took on water from wave action. This was resolved by installation of an additional water seal around the lid.
- **An extensive list of benefits and paybacks from Aerobic Manure Management emerged.** Each is explained in detail in the body of this report. The project demonstrated significant air quality and other environmental benefits from aerobic manure management – while providing additional farm income to pay for improved ecosystem services. It was important to demonstrate how benefits and paybacks offset expense for improvements in manure management practice. Example paybacks discussed immediately below illustrate some of the savings and additional income available with aerobic manure management. Positive revenue outcomes were seen from eliminating lagoon agitation, increasing nitrogen retention and availability, reducing field application costs and fossil fuel consumption as well as increasing crop yields with fertilizer application when crops need nutrients most. EC levels were consistently below 12mhos and often below 6mhos, suitable for application directly onto mature crops and sometimes onto tender young crops.

- ✓ **Agitation**: With circulators installed lagoons can be pumped at any time without further agitation. A 10,000 place (25,000 pigs/year) swine finishing barn generates about 5,000,000 gallons of waste nutrient per year. At $0.01/gallon, field application costs about $50,000 per year. Often half this cost is lagoon agitation. Eliminating agitation saves about $25,000/year or about $1.00/year/pig through the barn. Circulators cost about $0.50/pig over 10 years, providing a 100% profit each year from agitation savings.
- ✓ **Nitrogen**: Total-N in swine lagoons typically averages about 4.4lbs/1000 gallons and is usually reported in the 25%--40% ammonium range. With aerobic circulators, one large swine facility reported total manure-N at 14.2lbs/1000 gallons with 85% ammonium. Nearly three times more total nitrogen than average lagoon and 2-3 times more ammonium in crop available form. The added value of more retained nitrogen can be easily calculated at a current fertilizer N-price of $0.69/lb at that time.
- ✓ **Fertigation**: Aerobic treatment transforms raw animal waste into crop ready liquid fertilizer to be sprinkled directly onto growing crops without odor or pathogens and without plant stress or leaf yellowing. EC levels below 12mhos and often below 6mhos made this material suitable for direct application onto mature row crops and sometimes on young or tender crops. With dry matter (DM) content of demonstration lagoons less than 1%, this material can be applied by center pivots without clogging nozzles. Center pivot application typically saves the farmer between $50 and $75 per acre and eliminates both the expense and the GHG's from diesel consumption for knifing or tillage.
- ✓ **Crop yield boost**: In addition, the farmer can expect a yield boost of 20bu-40bu more corn per acre from applying the same amount of crop-ready fertilizer at times when crops need nutrients most. This can only be done when manure is transformed into aerobic crop-ready fertilizer that won't burn or yellow the plants.

- **Aerobic soil amendments promise to improve degraded farm fields**. Microbial Matrix Analysis of samples from aerobic demonstration lagoons reported beneficial levels of Phosphorous and Potassium Solubilizing Bacteria (PSB and KSB) among other microbial groups. After years of repeat application, heavily manured fields can become burdened by high levels of P and K tied up in the soil. PSB's and KSB's from aerobic lagoons can release soil bound nutrients back to the crops and lower the levels of P and K tied up in farm fields.
- **Control of lagoon design and operation problems** were found to be critical elements in achieving good results at demonstration sites. Recommended practice standards with operations plans to support effective aerobic manure management have been prepared and are included in the Appendix to this report. A number of problems were observed:
  - ✓ ***Where lagoons were undersized*** for the number of animals using the facility, where they did not offer adequate depth or surface area for circulation, or where they did not maintain the required minimum treatment volume (MTV), aerobic processes could not keep up with incoming waste. Manure sludge and solids build up in poorly designed or

poorly operated lagoons. However, aerobic circulation still delivered noticeable gas and odor reduction at all demonstration sites, despite undersized lagoons.

- ✓ ***Where foreign matter was allowed to enter the lagoon,*** circulation was reduced. For example: afterbirth, hoof wrap, bale netting, silage bag or other plastic, tumble weeds or field trash entering the lagoon will rag up impellers and reduce circulation effectiveness. Screening influent sources, practicing good barn management, using trash lanes or settling ponds and placing farm field fencing of sufficient height around the lagoon help to prevent problem materials from entering the lagoon.
- ✓ ***Where biocides, disinfectants, harsh cleaning chemicals or antibiotics*** enter the lagoon, microbial activity can be reduced or inactivated and the lagoon may cease to function aerobically. Farmers were alerted that organic cleaning products should be used. Many were already using such products. Although several farms used feed grade antibiotics, these did not cause microbial problems in the lagoon. The hypothesis is that with continuous surface exposure from bottom-to-top circulation, UV sunlight degrades antibiotic residue. The project did not have the budget to conduct AB residue testing.
- ✓ ***Where equipment failed to maintain neutral pH***, due to reduced circulation from ragged up impellers and insufficient circulation, struvite can become an issue for farms in high magnesium areas that wish to recycle safe water for barn cleaning. Increased oxygenation and circulation can bring down pH and reduce struvite formation.

- **The customers and stakeholders** to benefit from this project include the farmers, farm workers and animals, farm families, rural towns and neighbors who benefit from better air quality and improved health as well as local and global environmental benefits arising from reduced agricultural Green House Gas (GHG) emissions. Demonstrations at each of the farm sites provided an active learning environment against which other farmers may consider and evaluate the likelihood of beneficial outcomes and profitable operations using aerobic manure treatment at their farm. It is critically important that interested farmers get the opportunity to make a thorough and informed decision.
- **The project provided a detailed evaluation of the economic costs and environmental improvements** from aerobic manure management systems. Valuable lessons were learned about the likelihood of successful aerobic installations fitted to existing manure lagoons not previously designed or managed for aerobic treatment. At least two participating sites were greatly disappointed after experiencing the benefits of odor-free lagoons for six to twelve months, when unsuspected foreign materials in the lagoon were resurrected out of the receding sludge at the bottom of the lagoon and ragged up the impellers. In one case, design of the lagoon 15 years earlier included landscape netting covering the sides of the lagoon presumably for planting. After sludge had been removed by aerobic digestion, pieces of partially decomposed netting began to emerge and rag up the impellers. At another flushed dairy, herdsmen commonly disposed of afterbirth, hoof wrap, plastic bags

and straw bale netting into the flush alleys. Of course these materials would quickly rag up impellers and reduce circulation. Aerobic service at these sites had to be discontinued until foreign materials could be cleaned out of the bottom of the lagoons.

- **Federal, State, and local support** to help expand odor-free aerobic manure management are worth serious consideration. Aerobic manure management has proved successful in reducing air quality impacts, eliminating noxious gas and odor for farmers, farm workers, neighbors and animals, thus improving the environment, health and quality of life in rural areas. Currently, with narrow livestock margins, many producers lack the capital to invest in new environmental projects. Federal EQIP funds combined with state and local programs would provide financing, technical and education support to help stimulate the transition to aerobic manure management.
- **We conclude** that well-designed and well-managed oxygenation circulator treatment systems on adequately-sized hog and dairy lagoons are effective and affordable in improving air quality, and reducing nutrient losses, environmental impacts and manure management costs. Aerobic treatment systems can prove financially attractive for farmers while providing enhanced local and global environmental benefits. But there are specific requirements for design and operation of aerobic facilities. The project employed reliable and innovative technology in the form of redesigned oxygenation circulator equipment. The technology enhanced existing farm sites by reducing greenhouse gas emissions, odors, and other volatile organic compounds as well as by providing improved and lower cost manure handling and field application alternatives. This technology is recommended for common use and New Aerobic Practice Standards are suggested for NRCS consideration.

INTRODUCTION

OVERVIEW: This Conservation Innovation Grant successfully demonstrated innovative aerobic manure management using low cost and low energy, floating oxygenation-circulator platforms (OCP's) placed on manure lagoons to meet designated NRCS priorities.

The project installed OCP equipment to demonstrate, evaluate, refine and validate the conditions for success of promising aerobic technology to provide enhanced air, water and soil quality. Floating oxygenation-circulator platforms were installed on selected swine and dairy manure lagoons at 11 sites across Wisconsin, South Dakota and Nebraska. Aerobic technology transforms raw manure into odor-free, pathogen-free, crop-ready, plant-available, true liquid fertilizer with EC levels at or below 12 mhos, suitable for fertigation directly onto field crops during the growing season.

Floating oxygenation-circulators draw oxygen deficient water up from the bottom and spread it across the surface of the lagoon in contact with atmospheric oxygen and direct UV sunlight. Since water is never lifted out of the lagoon and air is not forced into the lagoon, less energy is required. Less than one horsepower is needed to manage manure from 100,000 lbs of animal body weight. At design speed, this type of equipment will induce a toroidal vortex circulation of $9m^3$/sec, about 8 million gallons of water per hour and bring over 6,000 gallons/minute to the surface. (See Appendix for full description of the mode of action for this equipment.)

Sufficient units (100) and sites (11) were set up to provide a credible demonstration of the benefits, reliability and usability of aerobic technology under varied weather conditions on different farms. Sufficient time was allowed to verify results achieved year after year and show that equipment would perform reliably beyond the initial one year warranty period. The project was extended to cover a three-year time frame.

The project team included: Wm F. Tooley, BA, MA, PhD Studies, the Project Director with over 30 years of agricultural innovation research and consulting for global Ag corporations, government agencies, NGO's, farm groups and farmer associations. John Reis, PE, NRCS-TSP and former dairy farmer has over 20 years of experience in environmental and geo-tech engineering for agriculture and has worked in manufacturing quality control. T.J. Tooley, President of Ag Systems of Wisconsin has 50 years experience with innovative agricultural systems in the US, Canada and overseas. T.J. has used and recommended aerobic manure technology for over 20 years. Kerwin Miller, Ag Tec has worked with farmers on the profit side of CAFO operations for over 30 years. Margaret Bobertz, MA, has 25 years experience in research, business and grants administration and is president of The THULE Group.

PROJECT GOALS AND OBJECTIVES: The goals and objectives of the project were designed to address NRCS-CIG priorities in the following ways:

Severe GHG reduction. Environmental benefits included reduced production of severe greenhouse gases, both methane and nitrous oxide by maintaining a balanced supply of oxygen sufficient to inactivate methanogens but not enough to support the further conversion of ammonium to nitrites or nitrates – precursors of nitrous oxide. Conversion to nitrate requires more oxygen and therefore more energy. Oxygen supply in demonstration lagoons was targeted to maintain an Oxidation Reduction Potential (ORP) range of $\pm$ 150mV.

Methane reduction. Methanogens in demonstration lagoons were found to be very low from a microbial perspective, typically below 300,000 ug/ – less than 1/100th – 1/1,000 the cfu's for other beneficial microbial groups in the same lagoon.

Odor and noxious gas reduction. In addition to methane reduction, air quality included reduction or elimination of odors and noxious gasses. Aerobic manure treatment eliminated odor from lagoons, from flushed barns and during field application. The most reliable measure of odor production is the level of Volatile Fatty Acids (VFA'S) found in the liquid. VFA's in anaerobic manure lagoons typically range between 5,000 and 10,000 ppm or higher. Research has shown that a sensitive human nose is able to detect and identify odors from lagoon liquids containing as few as 250ppm of VFA. Below this threshold, odors are undetectable. Lab samples from aerobic lagoons in this demonstration consistently reported VFA's at less than 100ppm. This level of odor production is completely undetectable.

Pathogen reduction in manure lagoons. Not always discussed as an air quality issue, pathogens become airborne when pit fans are turned or when untreated animal wastes are agitated and applied to fields or recycled to clean barns. E. coli is often used as a measure for the presence or absence of undesirable pathogens. E. coli can survive in deep anaerobic pits and undisturbed lagoons and are typically measured between 3,000-50,000 cfu/g. E. coli samples in aerobic demonstration lagoons consistently reported below 100 cfu and most often below 10cfu/g, below the infectious dosage for humans. Important limiting factors for pathogens are exposure to UV-sunlight, adequate oxygen supply, low or high pH and dilution. Conditions adverse for pathogen survival are well supported by oxygenation circulators.

Paybacks and Economic Incentives were examined as a means to pay for improved air quality and manure management. It was hoped this might be done by tapping Carbon Credit dollars and other eco-system service paybacks to make superior aerobic treatment more affordable.

With the collapse of US carbon markets early in the project, new carbon credit protocols were no longer being accepted. However, it was already apparent that significantly enhanced farm revenue, both savings and income, would be readily available from aerobic lagoon treatment.

In addition to air quality improvements, including reduced human and animal health risks from odor, pathogens and improved quality of farm life, demonstration projects showed significant revenue paybacks from enhanced farm productivity including reduced manure management costs, more retained nitrogen as crop available ammonium (NH4+), reuse of livestock water for barn cleaning and rescue irrigation and increased crop yield from timely fertigation. Carbon credits may reappear in the future, but they are no longer considered the major source of additional income available to the farmer from aerobic manure management practices.

SCOPE OF PROJECT TASKS: The project installed floating oxygenation-circulator platforms (OCP's) on 11 manure lagoons across Wisconsin, South Dakota and Nebraska. Oxygenation-circulators draw oxygen-deficient water from the bottom and spread it across the surface of the lagoon into direct contact with UV sunlight and oxygen. Since water is never lifted out of the lagoon, very little energy – less than one horsepower – is required to fully oxygenate manure from 100,000 lbs of animal body weight. At design speeds, this type of circulator maintain total top to bottom lagoon circulation down to more than 30' and bring over 6,000 gallons per minute to the surface.