Conservation Innovation Grants

Final Report

December 2014

Title: Implementation of Biofiltration Technology

Grantee Name: University of Idaho

Name of the principle investigator: Dr. Lide Chen

Timeframe covered by the report: September 2011- September 2014

Grant number: 69-3A75-11-189

Date of submission: 12/26/2014

Deliverables identified on the grant agreement:

A. Construction of four biofilters in both Idaho and Iowa.

B. Development of an on-farm biofilter design manual.

C. Development of an educational video demonstrating biofilter basics.

D. A national biofilter conference.

E. Two biofilter field days held in Idaho and Iowa.

F. Two peer-reviewed publications.

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Executive Summary

This proposal addressed 2011 CIG's primary priority areas of **Air Quality and Atmospheric Resource.** The goals of this project was to demonstrate, evaluate, and encourage the widespread adoption of biofiltration systems to document benefits and increase awareness among producers, extension educators, and NRCS staff. This was done via: 1). Construction four biofilters (two closed-bed down flow on a Idaho commercial swine farms and two open-bed up flow on a Iowa swine farms); 2) on-farm demonstration and evaluation of biofilter effects on mitigating odor and gas (ammonia and hydrogen sulfide) emissions; 3) two biofilter field days presenting and demonstrating biofilter technology; 4) a national biofilter workshop held in Ames, Iowa; 5) development of educational materials including field day hands-outs, presentation materials, an educational video; and 6) peer reviewed journal papers and extension publications.

The original time period projected for this project was two year. A No Cost Time Extension (NCTE) of 12 months was requested because a rescheduled national biofiter conference and we needed to improve biofilters that have been installed on the site. The approved NCTE let the biofilter conference be held in August of 2014 which fit better into farmers and researchers' busy schedules and improved the conference attendance. With the NCTE, all the objectives of this project were successfully completed.

Customers that have benefited from this project and/or will benefit include swine farmers, local communities, NRCS local/state staff, and extension personnel. The swine farmers have learned and/or will learn about how the demonstrated biofiltration technique works, how to build and maintenance on-farm biofilters, and how the technique benefits the environment, leading to a good neighbor relationship. Wide adoption of biofilters improves air quality which benefits local communities. The results of this project also benefit extension personnel for their extension activities and benefit future biofilter designs and constructions as well.

The main parts of project funds were spent as anticipated, except some sub-contract funds were left. Field days, literature data combined with our field data (olfactometry analysis, pressure drop data, ammonia and hydrogen sulfide gas tube data, and cost analysis), presentations, panel discussion, peer reviewed publications, and education videos were employed to demonstrate the biofiltration technology in this project.

Quantifiable physical results from this project include four on-farm biofilters, two field days, field day hands-out materials, a national biofilter conference, three presentations at two conferences, a biofilter design manual, two educational videos, two journal papers, and three peer reviewed extension publications.

Our major recommendations include: 1) biofiltration is a technically sound, economically viable and environmental friendly technology which could be used at confined animal operation sites to control aerosol emissions, 2) supporting materials showing biofilter basics and its effects on reducing aerosol emissions are needed to encourage biofilter adoption, and 3) field days are a good platform for both research and demonstrations of new techniques. Producer' collaboration and full participation are very important to make a CIG project success.

Introduction

This CIG project sought to demonstrate, evaluate, and develop supporting materials to encourage the widespread adoption of biofilters. This project was a collaborative effort, drawing on the expertise of a team of researchers and extension specialists/educators at both the University of Idaho and Iowa State University. The project's success also relied heavily on the active participation of swine producers.

Here are brief descriptions of key personnel and their qualifications:

- Lide Chen, PhD, Assistant Professor and Extension Waste Management Engineer, has several years' experience working on developing and testing both lab- and pilot-scale biofilters. He took part in two multi-state projects related to air emissions. He also participated in a couple of manure treatment projects with a goal of mitigating odor and gas emissions. He has served as PI on a number of federal and industry funded projects.
- Steven Hoff, PhD, PE, Professor, Iowa State University. Dr. Hoff has conducted several research projects on the use of agricultural biofilters. He has published five refereed journal papers on the topic as well as several presentations pertaining to biofilters. He has served as PI or Co-PI on several federal, state, and commodity group funded projects.
- Howard Neibling, PhD, PE, Extension Water Management Engineer, University of Idaho, has 34 years' experience in research and teaching/extension in soil and water

conservation/management and irrigation water management. During his 18 years at the University of Idaho, he has published a number of extension materials, developed two ASABE Blue Ribbon videos, and averages 40-50 extension presentations per year to agricultural clientele and agency personnel in Idaho and surrounding states. He has considerable experience in construction and operation of innovative field research equipment.

- Jay Harmon, PhD, PE, Professor, Iowa State University, has assisted in several research projects on the use of agricultural biofilters and through his active extension program. He has experience with conference organization and implementation.
- Brian He, PhD, PE, Professor, University of Idaho, is a chemical engineer by training. Dr. He's expertise is in the areas of biological/ biochemical/ chemical processes for renewable energy and value-added industrial products from bio-based resources. As a PI / co-PI, he has conducted multiple research projects totaling $3.5 million in funding in the past seven years on new technologies for biodiesel production, quality control, and byproduct utilization. He has published in the areas of biodiesel production and utilization, biomass conversion for renewable energy, and bioconversion for secondary metabolites from fungal and plant cell cultures.
- Mario De Haro Marti, Associate Professor, Extension Educator, University of Idaho, has several years of experience working with dairy waste management, air emissions, odor control, and pollution prevention. He has considerable experience in close contact with dairy producers.
- Marsha Neibling, a private nutrient management consultant with experience in developing nutrient management plans for dairy, beef and poultry facilities in Idaho and in evaluating the impact of these plans on cropland receiving liquid or solid manure. She founded Neibling Environmental Consulting 13 years ago and has worked with over 100 producers and with local, state and federal agencies.

This team, along with a postdoc, graduate and undergraduate students at both the University of Idaho and Iowa State University, worked together with participating producers throughout the whole project and the objectives proposed in this project were fully fulfilled.

The project goals and objectives identified in this grant were as follows:

- The objective of this project was to demonstrate, evaluate, and encourage the widespread adoption of biofiltration systems to document benefits and increase awareness among producers, extension educators, and NRCS staff.

- Specific objectives of the project were to:
    - Construct and evaluate biofilters at Idaho and Iowa swine sites to demonstrate biofiltration effects on mitigating odor and gas (NH_3 and H_2S) emissions from fan exhaust air;
    - Develop an on-farm biofilter design manual;
    - Plan and host one national biofiltration conference during this project period;
    - Conduct two field days during this project period;
    - Develop an educational video demonstrating biofilter basics.

- The scope of the project tasks included: 1) design, build, and maintain on-farm biofilters, 2) develop field day hands-out materials, 3) identify and inform the field day target participants, 4) plan, organize and hold the field days, 5) evaluate biofilter effects on reducing odor and gas emissions from fan exhaust air, and monitor biofilter pressure drop, 6) plan, organize and hold the national biofiter conference; 7) biofilter literature studies, 8) develop the biofilter design manual, 9) develop the educational video, and 10) showcase the project. More broadly, the project provided researchers, extension personnel, and stakeholders opportunities for learning and exchanging opinions on biofiltration technique and sought to increase awareness of biofilters among producers, extension educators, and government officials and encourage widespread adoption of on-farm biofilters which offer potential solutions for addressing the aerosol emission challenges facing animal industries.

- This project was facilitated through relationships with individual swine producers, state NRCS stuff, the project technical contact, a private environmental consultant, and academic partners. The project PIs worked closely with the participating swine producers on designing, building, and maintaining biofilters, planning and organizing field days and the biofilter conference including a panel discussion. A number of nationwide known experts in the biofilter area presented at the biofilter conference. An environmental consulting expert joined the project to add expertise in relating project results to potential solutions of several environmental issues common to Southern Idaho dairies. A postdoc, two graduate students, and three undergraduate students were involved in the biofilter construction, sample collection and data analyses, and numerous extension activities showing this project. In addition, both the Iowa State University Olfactometry Laboratory and Purdue University Odor Laboratory helped with odor sample evaluations.

- This project was funded through a 50% cost share with this CIG program. All PIs and cooperator producers donated their time as cost share.

Background

With the intensification of animal production in the U.S., the reduction of odor, gas, and particulate matter (PM) emissions from concentrated animal feeding operations represents a significant challenge for livestock producers. Most odors and gas emissions from building and manure storage sources are by-products of anaerobic decomposition and transformation of organic matter in manure by microorganisms. These by-products result in a complex mixture of over 168 volatile compounds of which 30 have a detection threshold of 0.001 mg/m^3 or less, and hence are most likely to be associated with odor nuisance. Therefore, any successful odor emission reduction technology must be able to accommodate the challenges of odor-producing compound complexity. Although a number of air pollution control technologies such as activated carbon adsorption, wet scrubbing, and masking agents have been developed, they often transfer odor-causing materials from the gas phase to scrubbing liquids or solid adsorbents, and their derivatives have resulted in wastewater and solid waste concerns. Biofiltration, which can be cost effective and has the ability to treat a broad spectrum of gaseous compounds, has been regarded as a promising odor, gas, and PM mitigation technology.

Considerable research on the impact of biofilter designs such as horizontal and vertical air flow, open and closed, single and multi-stage biofilters on reducing odors, gases, PMs, and volatile organic compounds (VOCs) has been conducted under both laboratory- and pilot-scales. Under laboratory conditions, up to 100% reduction efficiency has been demonstrated for gasses (NH_3 and H_2S) and some VOCs. On-site studies have shown reduction efficiency up to 99% for odors, up to 100% for NH_3 and H_2S, and up to 86% for odorous compounds. A wide variety of packing materials such as compost (from various sources), wood chips, wood bark, coconut fiber, peat, granular activated carbon (GAC), perlite, and polystyrene beads have been tested in both laboratory and on-site studies. These materials were selected to provide high surface area, high porosity, high water holding capacity, rich mineral nutrient available for bacteria's needs, and compressive strength. Some materials, such as compost and wood chips, provide satisfactory conditions for microorganism growth, as well as provide a rich community of bacteria and have been recommended as agricultural biofilter media.

Although laboratory and on-site research have shown that biofiltration is a technically sound, economically viable and environmental friendly technology which could be used at confined animal operation sites to control aerosol emissions, the rate of on-farm adoption continues to be low. This project was initiated to address the 2011 CIG's primary priority areas of Air Quality and Atmospheric Resource. Our hope was that this study can successfully demonstrate on-farm use of the technology and develop support materials to further encourage biofilter adoption.

The sectors which benefit from this project include both livestock industries and communities nationwide. Biofilters provide livestock producers (especially, swine farms) a technically sound, economically viable solution to reduce aerosol emissions from fan ventilated air which helps maintain good neighbor relationships, thus leading to a sustainable livestock industries. In addition, widely adaption of biofilters will benefit the environment due to reduced emissions of odor, ammonia, hydrogen sulfide, particulate matters, and volatile organic compounds.

Natural resource issues addressed in this project include improved air quality due to reduced emissions of odor, gases, PMs, and VOCs. There are no negative effects on the environment or community. For adapting this demonstrated technique, there are initial costs for building biofilters and potential replacement of ventilation fans. However, in the long term, biofilters will help the livestock industries keep good neighbors and community relationships, reduce regulatory pressures, thus supporting a sustainable animal agriculture.

Review of methods

Innovative aspects of this project include the following:

- The closed-bed down airflow biofilters demonstrated at an Idaho site is new. This type of biofilters fits the semi-arid climate well in terms of biofilter media moisture. In southern Idaho, the ambient air humidity is around or less than 25% during most days of a year. The closed-bed structure reduces water evaporation of biofilter media, thus reducing water supply and keeping biofilter media moisture at a suitable level leading to better biofilter performance. One important benefit of down airflow biofilters as compared to the traditional up airflow biofilters is the ability to maintain higher, more uniform water content throughout the biofilter media since both the water supply and air entrance are at the top of media. A reported problem with up airflow biofilters is a dry lay of media at the bottom of biofilter.
- The demonstrated two-stage biofilter facilitates biofilter media selection and could reduce pressure drops compared with single-stage biofilters with the same depth of media. The traditional biofilters set their media on a single support, the media compaction is heavier in a long run compared with the two-stage structure, resulting in higher pressure drops. With the two-stage structure, it is easier to apply two different biofilter media which could benefit biofilter performance.
- The two Iowa biofilters are modular in nature, implying that they can be easily installed at a farm after pre-construction completion in a shop. Also, the biofilter modules could be stacked vertically to accommodate adequate biofiltration needs without increasing the foot-print area required which is important to facilities with limited surrounding space.
- One unique feature of the horizontal biofilter demonstrated in an Iowa site is that it has been fitted with a by-pass louver system that will allow impact-based odor control using the control system. During calm stable weather conditions, the exhaust air from livestock buildings could be forced to go through the biofilter. Under unstable weather conditions, natural atmospheric mixing could be used, thus bypassing biofilter operation.

Comparison to existing practices:

- Any technology used to mitigate odors and gases will be an added expense for animal production. Biofilters have been proven to be the most cost-effective method for treating ventilation exhaust air. The biofiltration technology needs initial investment in building biofilters and potential replacement of ventilation fans, and needs operation/maintenance money. However, the new investment has environmental benefits and creates better neighbors and community relationships which, in long run, will support sustainable livestock industries.

Schedule of events:

- October 2011 - April 2012: Initiated this project. The University of Idaho team met formally and informally a number of times to plan the project approach, assign duties and review the project time line. Subgroups discussed biofilter design options and equipment needs and sources. Project members visited the swine farm a couple of times and discussed the biofilter design with the swine farmer based on his specific building characteristics and ventilation systems. The biofilter location and orientation were determined. Over 100 relevant papers on biofilters were identified and copied for project planning and use. The Iowa State University group established weekly meetings to discuss project objectives and for the successful completion of this research project. A graduate research assistant were hired and put completely on this research project. In addition, two hourly undergraduate students were hired for the summer months to work on this research project. Also, the Iowa State University team worked on new biofilter designs, constructing prototypes, and getting ready to install their prototypes at their cooperator site. Purchased sampling equipment for this project.
- May 2012 – October 2012: the University of Idaho team purchased biofilter materials, installed two down-flow biofilters (one-stage and two-stage vertical down-flow) at a swine farm, developed and tested the biofilter water supply systems, collected odor samples from both the one-and two-stage biofilters. Both the one- and two-stage biofilters were checked and maintained regularly. The Iowa State University group developed two unique biofilter modules in the laboratory, tested airflow performance characteristics in the laboratory, and installed these biofilters at two cooperator research farms.

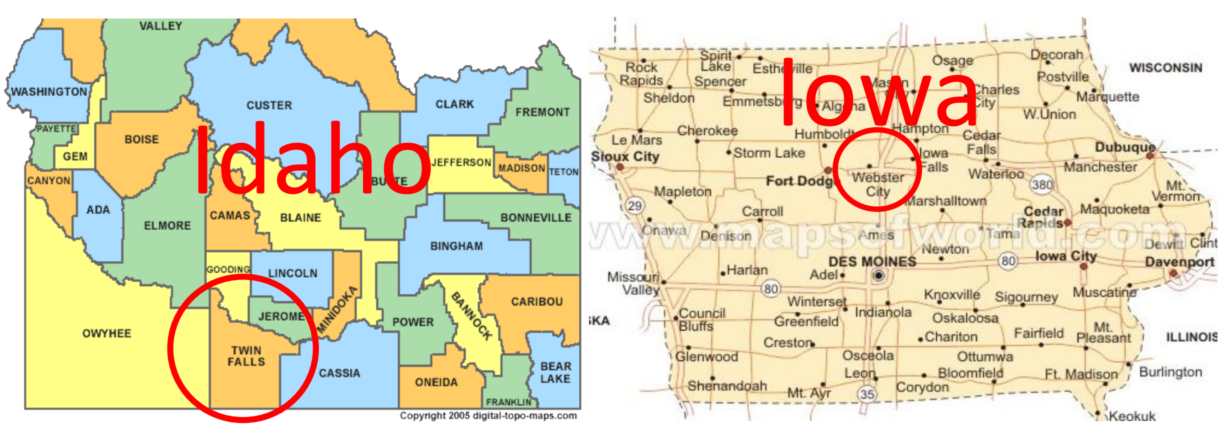
- November 2012 – April 2013: the Iowa State University group completed installation and initial operation of two unique biofilter modules at two cooperator research farms. Initial odor sampling was conducted and work was completed on the water distribution system for maintaining proper biofilter media moisture levels. In addition, The Iowa State University team worked to refine the development of a control system to implement impact-based odor control for one of the two installed biofilters. The University of Idaho hired a new post-doc for this project. A couple of team member meetings were held. Based on the problems occurred during past on-farm demonstrations, we decided to conduct lab tests to find the optimum mixing ratio of different sizes of wood chips for a better balance of media water holding capacities and pressure drops. Also, a modification plan for the two on-farm biofilters were made. We prepared materials and test equipment for the lab tests and on-site modifications.
- May 2013 – October 2013: the Iowa State University group reactivated both on-site biofilters (i.e. watering system reactivated) and made improvements to the water application control system. Gas sampling was conducted as well at both biofilters for ammonia and hydrogen sulfide concentrations. In addition, the Iowa group continued the development of a control system to implement impact-based odor control for one of the two installed biofilters. The Iowa State University team also developed video/audio footage on the construction of both biofilter modules. Finally, the Iowa State University team started collaborations with an on-campus conference development group to plan for the proposed biofilter conference. A date for this workshop was set for August 19, 2014. Plans were made to secure speakers and prepare announcements. The University of Idaho modified both the one- and two-stage on-site biofilters. Two lab-scale biofilters were built for lab tests. We improved water supply systems based on newly conducted lab tests, added two shallow pans underneath both the biofilter supports to collect biofilter leachate and drainage systems were also added to move potential leachate back to the site's waste stream. Plastic sheeting were installed inside the biofilter walls to reduce possible air leak. Odor samples were collected and evaluated. Ammonia and hydrogen sulfide concentrations were also monitored from both biofilters. The University of Idaho team also recorded video footage showing the construction steps. A biofilter field day were planned on November

5th, 2013. The field day flyers were sent out and the field day hands-out materials were prepared.

- November 2013 – April 2014: the Iowa State University group concentrated efforts on developing the biofilter conference in conjunction with this research project, and started the process of editing all biofilter construction video suitable for the web. The biofilter conference were set for Wednesday August 20, 2014 on the Iowa State University campus. The program for this conference was set, with advertising to begin mid-May. The University of Idaho worked on data collected from both the one- and two-stage on-site biofilters. Two journal papers based on the collected data were developed and submitted for peer review. One extension publication titled "Biofilters in animal agriculture" was published at: http://www.cals.uidaho.edu/edcomm/pdf/CIS/CIS1207.pdf. A biofilter presentation was given during the biofilter field day held on November 5, 2013 at the Idaho biofilter site.
- May 2014 – September 2014: Edited biofilter video, developed biofilter design manual, held biofilter conference including panel discussion and on-site biofilter demonstration, prepared final report.

Map of project:

This project was conducted at two swine sites in both Idaho and Iowa. The Idaho swine farm is located near Kimberly in Twin Falls County. The Iowa site is located in Hamilton County. The following map shows the two counties.



Summary of successes and failures:

This demonstration project mainly focused on on-farm biofilter demonstration, evaluation, and development of supporting materials to encourage biofilter adoption. Thanks to the team members' strong backgrounds and experiences in the biofiltration area we were able to well complete this project as proposed in the proposal. However, we had to request a NCTE for another 12 months to better accommodate the biofilter conference to the conference attendees' schedules and to improve biofilters on the sites to better fulfil the project objectives.

Quality Assurance

- Project site description (Idaho site): This project was conducted at a commercial swine nursery facility, which consisted of four 4.3 m × 12.8 m, 120-head nursing rooms, near Kimberly, Idaho. Each room had an independent tunnel ventilation system. Air entered the rooms through an inlet located on the south wall of each room. There were two variable speed exhaust fans (primary and secondary) in the north wall of each room. A shallow pit with a depth of 0.6m was constructed below the slatted floor to collect manure and washing water. Around 60-70% of total volume in the shallow pit was drained to the lagoons every 5 days. Small pigs were moved in at about 5-7 kg and were raised to approximate 64-68 kg at the nursery facility. After the pigs moving out, the room was completely flushed with well water before new small pigs were moved in. The two vertical down-flow biofilters were installed in the front of rooms 7 and 8 (N7 and N8) to treat the exhaust air from the first stage fans (Multifan, 4E40Q, Schuyler, NE, USA).
- Biofilters: The biofilters were 2.15 m × 2.26 m in cross-section and 1.22 m in height. Both of the biofilters had the media depth of 381 mm. The single stage biofilter (BF1) was installed in the front of room N7 and the two stage biofilter (BF2) was installed in the front of room N8. Biofilters were connected to the primary exhaust fan of their respective rooms using a rectangular duct made of plywood. Both biofilters were constructed with 20 mm thick plywood boards. Biofilter plywood room areas were covered with thin metal sheets to protect them from rainfall. Metal mesh (10 mm diameter holes) with support on the ground was built to support the biofilter media. In BF2, two horizontal metal mesh surfaces

were constructed with a vertical spacing of 381 mm. The interior walls and roof of the biofilters were covered with plastic sheets to protect the plywood from sprinkled water. On the bottom of each biofilter, a rectangular metal pan was provided to collect the leachate from the biofilter, which was drained to the manure collecting lagoon by PVC pipes.

- Biofilter media: Preliminary laboratory tests conducted on three locally available different wood bark media (i.e., shredded wood bark (SWB), medium wood bark (MWB) and small wood bark) indicated that the combination of SWB and MWB could be superior for low pressure drop and higher moisture retention. Thus, these two products were decided to be the media for the field scale biofilters. The biofilter media composition was SWB: MWB = 1:2 on a volume basis (1:2.15 on a mass basis). SWB was used for the top layer (127 mm) and MWB for the bottom layer (254 mm).
- Biofilter media water supply: Tap water was supplied to the biofilter media via four customized sprinkler heads in each biofilter. Each sprinkler head used a dual spray nozzle to evenly distribute water to the biofilter media. The water system was controlled using a battery operated propagation timer (Model# 6020P/61512, Drip inc. Concho, AZ 85924, USA).The water supply pressure was controlled within a range of 262-283 kPa by a pressure gauge (Pro Plumber, PP100G, Mansfield, Ohio 44907, USA). Water was supplied for 20-30 s every 15-240 min, depending upon the duration of the exhaust fan operations and environmental conditions.
- Sampling and sample analysis: Odor samples were collected using 10 L Tedlar bags. Two vacuum pumps and airtight boxes were used to simultaneously fill the bags from the inlets and outlets of the biofilter chambers. All samples were analyzed within 24 h of collection by a dynamic forced-choice olfactometer (AC'SCENT International Olfactometer; St. Croix Sensory, Inc. Stillwater, Minn.) based on ASTM E679-04 (ASTM, 2004). The NH_3 and H_2S concentrations in the inlets and outlets of the biofilter chambers were measured with detection tubes and a gas sampler (Gastec Co. Ltd.). The detection ranges of the NH_3 and H_2S gas tubes were 0.25–75.00 ppm and 0.05–8.0 ppm, respectively. Biofilter media was manually sampled from different depths. In BF1, media samples were collected from depths of 25, 127 and 254 mm. In BF2, media samples were collected from 25 and 125 mm in both the first and the second stages. Three replications were taken from different positions at each collection depth. The media moisture content was calculated by taking

the average of sample moisture content from different depths, and was measured by oven drying at 105 °C for 24 h.

- Cost analysis: The cost generally can be split into two parts: construction and operation/maintenance costs. A detailed costs of horizontal and vertical biofilters (Iowa side) are summarized in appendices in the Biofilter Summary Document attached with this final report. At the Idaho site, the installation costs for a closed-bed biofilter with a 50:50 by weight mixture of wood chips and shredded bark were approximately $800 per 1000 cfm air treated. It is worth to point out both capital and operation/maintenance costs are highly variable.

Findings

1. Odor and gas (ammonia and hydrogen sulfide) samples from the demonstrated biofilters showed biofilters reduced both odor and gas emissions dramatically (95% or greater for ammonia and hydrogen sulfide, 73-77% for odor). The odor and gas reduction results together with literature data indicate the feasibility of biofilter applications on farms.
2. Biofilter media moisture control is essential for the success of biofilters. A range of 40-65% is suitable for the wood bark-based biofilters.
3. Empty bed residence time (EBRT) is another key factor affecting biofilter performance (reduction efficiency and pressure drop). Three to five seconds are reasonable for ventilation air from animal facilities.
4. On-farm field days are a great tool to demonstrate and encourage the application of innovative techniques. They also can serve as a research platform, allowing collecting quality data. Farmers' collaboration and full participation during all phases of the project is very important.
5. Identifying progressive and pioneer producers that are already applying the demonstrated technique or are willing to take the new technology is important to develop this kind of on-farm experience. In general these individuals are also willing to share their knowledge, experience, and results with others to promote the adoption of such a new technique.

6. Having a producer hosting and presenting during the field day at their own facilities as opposed to a dedicated research facility stimulates others enthusiasm and helps creating a friendly environment for conversations and exchanges of ideas.
7. Involving governmental officers, experts, and producers in the biofilter conference is a good way to encourage idea exchanges among different groups having different opinions.

Recommendations

These are summarized in the executive summary and are not reproduced here.

Appendices

A. Biofilter design manual
B. Biofilter field day hands-out materials
C. Biofilter conference presentations 1-11
D. Biofilter summary document (Iowa side)
E. Paper published in Journal of Environmental Management
F. Paper published in Journal of Biosystems Engineering
G. Three extension publications