CONSERVATION INNOVATION GRANTS

Final Report

Cover Page

Grantee Name: The Pennsylvania State University	
Project Title: Without Carrot or Stick: Promoting BMPs on Small Dairy Farms	
Agreement Number: 69-3A75-10-160	
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Deliverables identified on the grant agreement (From Project Objectives): The overall goal was: To reduce sediment loss by 320,000 tons, nitrogen loss by 8 million pounds, phosphorus loss by 480,000 lbs through adoption of cover crops after corn silage on 160,000 new acres. The specific objectives were: 1. Measure the performance of innovative cover crop mixtures and manure injection at retaining nutrients and providing on-farm benefits at 10 field scale demonstration sites; 2. Organize field days, farmer meetings, and conference workshops on innovative cover crops and manure injection that are attended by 1,000 farmers. 3. Produce four videos (~5 minutes each) on innovative cover crops and manure injection techniques that are viewed by 2000 farmers; 4. Develop case studies, fact sheets, and a website on innovative cover crops and manure injection that are read by 5,000 farmers.	

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Executive Summary

This project meets the NRCS Strategic Goal to get more conservation on the ground. Specifically, it addresses Objective 1.1, Advance the performance of voluntary, incentive-based conservation solutions, and the Strategic Initiatives to solve natural resource problems of erosion and nutrient losses at local and landscape scales; effectively deliver conservation technical assistance and programs to agricultural producers and landowners; and help farmers comply with existing environmental regulation and obviate the need for further regulation (5-year USDA-NRCS Strategic Plan fiscal years 2011-2015).

The purpose of this project was to reduce sediment, nitrogen, and phosphorus losses from farmland in the Chesapeake Bay watershed through farmer adoption of innovative cover cropping and manure injection methods. The goal was to reduce sediment losses by 320,000 tons, nitrogen losses by 8 million pounds, and phosphorus losses by 480,000 pounds through adoption of cover crops on 160,000 acres of new farmland following corn silage.

The use of cover crops after corn increased by an estimated 367 thousand acres in Pennsylvania between 2009, the year before the project started, and 2013, the last year of the project. Remote sensing analysis was used to measure the change in cover crop use after corn in 4 major agricultural counties in the watershed, close to the outlet of the Susquehanna River into the Chesapeake Bay (Table 1). The analysis showed that cover crop use after corn (both grain and silage corn) increased 94% in Berks (from 34% to 66%), 48% in Lancaster (from 50% to 74%), 58% in Lebanon (from 40% to 63%), and 109% in York (from 23% to 48%). For the four counties, this represented an increase of 96,706 acres of corn followed by a cover crop, or 26% of the corn acres in these counties. If we assume 26% of corn acres in Pennsylvania were followed by cover crop in 2013 that were not followed by cover crop in 2009, that represents a 366,878 acre increase in cover crop acres. We therefore far exceeded our goal of 160,000 acres of new cover crop acres and the estimated reduction of sediment, nitrogen, and phosphorus.

Table 1. Number of farms, corn grain and silage acres, corn acres followed by cover crop in 2009 and 2013, and increase in cover crop use after corn in 4 counties, extrapolated to Pennsylvania

County	Farms *	Corn grain	Corn silage	Total corn	Cover crops after corn in 2009	Cover crops after corn in 2013	Increase in cover crop use after corn	
	#	acres*	acres*	acres*	(%)	(%)	%	Acres
Berks	2,039	52,813	21,530	74,343	34%	66%	94%	23,790
Lancaster	5,657	101,005	72,539	173,544	50%	74%	48%	41,651
Lebanon	1,219	27,434	19,306	46,740	40%	63%	58%	10,750
York	2171	68,654	13,407	82,061	23%	48%	109%	20,515
Total of 4 counties				376,688				96,706
Pennsylvania		998,376	412,695	141,1071				366,878

* from 2012 Census of Agriculture

The specific objectives were 1) to measure performance of innovative cover crop mixtures and manure injection at retaining nutrients and providing on-farm benefits at 10 field scale demonstration sites; 2) organize field days, farmer meetings, and conference workshops on innovative cover crops and manure injection that are attended by 1,000 farmers; 3) produce four videos (~ 4 minutes each) on innovative cover crops and manure injection techniques that are viewed by 2,000 farmers; 4) develop case studies, fact sheets, and a website on innovative cover crops and manure injection that are read by 5,000 farmers.

Every fall of the project period, we established about 10 farm demonstration sites spread from north to south Pennsylvania. We held 52 cover crop field walks and gave 27 in-door presentations, attended by 1886 persons. Therefore, we exceeded our objective to reach 1000 people in meetings and field days. We produced 5 videos viewed more than 5000 times. We therefore think it is reasonable to suggest we met our goal to reach 2000 farmers with 4 videos. Finally, we produced 21 articles in Field Crop News, the weekly electronic newsletter produced by the Field and Forage Team of PSU with 1800 subscribers, one fact sheet, and had 2 articles in Lancaster Farming (56,000 subscribers). We therefore reached our goal of 5000 famers with these written publications.

We hypothesized that the educational approach would be more cost-effective than enforcement or subsidies. Assuming our estimate of new cover crop acres in Pennsylvania is correct, we can compare the cost of our approach with that of alternatives. We estimated that use of cover crops increased on 360,000 acres over the project period in Pennsylvania. If a subsidy of $40 was paid per acre (a very modest subsidy compared to, for example the Maryland cover crop program that pays $80 or more per acre), this would have represented $14.4 million per year, excluding administration costs, or $43.2 million over the 3-yr project period. Enforcement of this program would have been costly as well. If we assume 4 new staff persons to administer and enforce cover crop use on such a large area at a cost of $100,000 per staff person (salary+benefits, office and equipment, vehicle, mileage etc.), the cost would have been $400,000 per year or $1.2 million over the project period. In comparison, the costs of this educational program to the government were $256,950 over the entire project period. In addition, the effects of this project will continue without expense to the government in contrast to subsidy or enforcement programs. ***The enforcement approach would have been almost 5 times as expensive and the subsidy approach 170 times as expensive as the educational approach used here.***

A combination of researcher-established cover crops in on-farm small-plot trials and farmer-managed large fields with cover crops of their choice proved to be a great way to collect high-quality data while engaging the farmers. To use either one approach in isolation would have led to a lack of credibility to farmers or a lack of credibility to researchers, service providers and policy makers.

The use of remote sensing to monitor the increase in adoption of cover crops worked well in some counties. Transect surveys have been used to monitor adoption of observable practices such as no-tillage or cover crops. This is labor intensive and is limited to observations along roads. By using remote sensing we were able to gauge cover crop adoption across the entire footprint of the imagery, which usually covered most of the 4 counties we focused on. Like any methodology, remote sensing has its shortcomings too. For example, sometimes no usable image could be found at the desired dates due to cloudiness or snow cover. Narrow strips or small fields also represented a challenge for remote sensing because one unit of observation (pixel) could have bare fallow, cover crop and perennial vegetation in it making it difficult to use this method in areas where fields were small or stripcropping was common.

Cover crop mixtures provide added benefits versus single cover crop plantings. Cereal rye was the most reliable cover crop due to greatest winterhardiness among all cover crops tested. However, it also has its shortcomings such as limited growth in the fall and very fast growth in the spring when stem elongation starts, making it challenging to manage this cover crop. Among the many different species evaluated in this project after corn silage there were cover crops such as oats, annual ryegrass, hairy vetch, crimson clover, and triticale, which showed promise for increased fall forage production (oats), high-quality feed in the spring (annual ryegrass, crimson clover and triticale), and nitrogen fixation (hairy vetch and crimson clover). When cover crops produced large quantities of biomass, large quantities of nutrients were absorbed from the soil and protected from loss to surface or ground water, the soil was protected by the biomass, while farmers had to purchase less feed which increased on-farm nutrient cycling. By mixing and matching species according to the desired objectives, multiple benefits could be achieved. The cost of mixtures was sometimes lower, sometimes higher primarily reflecting seeding rate. Some small-seeded cover crops such as annual ryegrass and crimson clover were very economical to plant. Some cover crops tested, particularly hairy vetch, forage radish and rape showed limited use for planting after corn silage.

Use of cover crops for feed. The potential to use cover crops for feed proved to be a big motivator for the farmers to spend money to purchase cover crop seed, establish the cover crop immediately after corn silage harvest, and increased nutrient recycling on the farm instead of purchase of nutrient-containing feed from outside the farm. This is a major finding of this project and we recommend it be integrated in policies and programs stimulating cover crop adoption.

Manure injection reduces potential of nutrient loss by volatilization (N) or runoff (P and N). However, it involves purchase of new equipment and slows down manure application. However, an added benefit is the reduction of odor which proved to be as important to the farmers as the other benefits. The project allowed us to work with a manure hauler who mounted injectors on several manure tankers and now offers this as a service to farmers so they don’t have to purchase the equipment themselves.

Introduction

This project began in 2010 with the idea to address sediment and nutrient losses from dairy farms by using an extensive educational program without recourse to subsidies (‘carrots’) or legal instruments (‘sticks’). We believed this approach would be most cost effective in reaching and motivating farmers to use cover crops now and in the future. We worked through our existing Cooperative Extension network of main campus faculty and staff and county-based agronomy educators. The agronomy educators selected collaborating farmers. We combined research with outreach by establishing innovative cover crop mixtures in small plots while the farmers planted and managed a large field with a cover crop mixture of their choice. We organized our outreach program around these research/demonstration sites. We focused on the ‘low hanging fruit’: the fields left fallow after corn silage harvest until next season’s summer plantings. These fields are harvested earlier than grain corn and soybeans, allowing greater opportunity for timely cover crop establishment. They are also bare because almost all crop residue is harvested, increasing the potential for sediment and nutrient losses to surface waters. Cover crops can therefore dramatically reduce the potential of soil from erosion on these fields. Additionally, these fields often receive manure because silage is almost exclusively grown by dairy and beef farmers who have to spread manure from their animal houses. The manure can be safely applied to cover crops and the nutrients will be protected by uptake by the cover crop roots. Finally, these farmers need forage, opening an additional incentive to planting cover crops with the potential to use them as animal feed.

The overall goal of this project was:
To reduce sediment loss by 320,000 tons, nitrogen loss by 8 million pounds, phosphorus loss by 480,000 lbs through adoption of cover crops after corn silage on 160,000 new acres.
The specific objectives were:

1. Measure the performance of innovative cover crop mixtures and manure injection at retaining nutrients and providing on-farm benefits at 10 field scale demonstration sites;
2. Organize field days, farmer meetings, and conference workshops on innovative cover crops and manure injection that are attended by 1,000 farmers.
3. Produce four videos (~5 minutes each) on innovative cover crops and manure injection techniques that are viewed by 2000 farmers;

Develop case studies, fact sheets, and a website on innovative cover crops and manure injection that are read by 5,000 farmers.

Key personnel were Sjoerd Duiker (Soil Management Specialist, PI on this project), Ron Hoover (On-Farm Research Coordinator), Heather Karsten (Associate Professor of Agronomy), Charles White (Research Associate), Dean Hively (USGS remote sensing specialist) and 12 agronomy extension educators. Dr. Duiker promotes improved soil management by doing research on and promotion of no-tillage systems, which include permanent no-tillage, cover crops, and diverse crop rotations. Ron Hoover is engaged in multiple on-farm research projects on farms throughout Pennsylvania and is also involved in outreach activities for farmers and agribusinesses throughout Pennsylvania and the U.S. Heather Karsten manages a large cropping systems research project at Penn State, and teaches several agronomy courses. Charlie White is involved in research and outreach on sustainable agriculture, specifically in cover cropping innovations. Dean Hively specializes in using remote sensing data to measure use of BMPs on the landscape. The Agronomy Educators are all professionals in their field, engaged in education of farmers, agribusinesses, and service personnel to improve field crop production practices in Pennsylvania and beyond. The collaborating farmers were selected by the Agronomy Extension Educators based on their leadership in their communities and passion for farming. Being leaders, other farmers look to them for innovations to improve their operations, which increased the potential impact of our project on cover crop adoption.

Every summer, the extension educators recruited farmer collaborators. This resulted in 12, 9 and 10 research/demonstration sites established in 2010, 2011, and 2012, respectively. A selection of cover crop mixtures was planted in small-plot replicated trials at each site by the on-farm research coordinator. Cover crop biomass was harvested every fall and spring by the agronomy educators and PIs, dried and weighed at University Park, PA, to form a database of cover crop performance in the different agroecological zones of Pennsylvania. A selection of samples was sent to a laboratory for nutrient and forage analyses. The farmers were also asked to dedicate a field (approximately 10 acres) to this project where they would grow a cover crop of their choice on a larger scale. Every fall and spring field days were organized on collaborating farms. Results of the research and farmer experiences were shared by participants with others at field days, winter meetings, conferences, through webinars, fact sheets, newsletter articles, and newspaper reports.

We committed to measuring cover crop use after corn over the project period to determine the impact of this project. Dean Hively of USGS developed a method using crops databases and remote sensing imagery to measure the ‘greenness’ of previous cornfields in the winter. This allowed us to document cover crop use after corn in four different counties in southeastern Pennsylvania, near the outlet of the Susquehanna River into the Chesapeake Bay. The results showed that cover crop use after corn increased by almost 100,000 acres in the four counties between 2009 and 2013. This represented an increase of 64% in cover crop use after corn in the four selected counties. If extrapolated to the state as a whole, this would represent an increase of more than 360,000 new acres of cover crops.

The project was possible because of the existing Cooperative Extension network of Agronomy Educators and their relationships with the farmers and agribusinesses in their area. The ‘hard’ funding that is already in place from County and State sources allowed Penn State to cost-share the contribution from USDA. In addition, the farmers participating in this project offered the use of a part of their farm to demonstrate innovative cover crop practices. The farmers also committed to being present at the field days organized on their property. The cost share contribution was: $

The project was funded by a national USDA-NRCS Conservation Innovation Grant and cost-shared with contributions from Penn State University and collaborating farmers.

Background

The project focused on reduction of sediment, nitrogen and phosphorus losses from small to medium size dairy farms to the streams and rivers feeding the Chesapeake Bay. Negative effects of sediment, nitrogen and phosphorus losses to surface waters present a loss of productive topsoil and crop nutrients to farmers, and a threat of environmental pollution with detrimental effects on human health and environmental quality.

Research has shown that cover crops are among the most cost-effective technologies to reduce sediment and nutrient losses from farm fields. They are crucial to provide soil cover in low residue situations such as after corn silage and soybean harvest, although they are also important to keep living vegetation on the land and living roots in the soil to favor soil health after other crops. Corn silage acres are the 'low-hanging-fruit' where cover crop adoption could make a large impact in sediment and nutrient losses to the Bay. Corn silage is grown on most dairy farms in Pennsylvania, representing 1/3rd of corn acres in Pennsylvania. After harvest, these fields frequently receive applications of manure in quantities that result in a high potential for nitrate leaching and particulate and soluble phosphorus runoff. In addition, the sediment losses after corn silage harvest can be substantial since nearly all the crop residue is removed leaving the soil almost bare.

Manure injection could help further improve the environmental performance of the corn silage production system. Manure injection has been proven to reduce soluble phosphorus and gaseous ammonia losses from no-till fields (reductions up to 60 lb N/A in ammonia loss have been reported in recent research). Placement of manure beneath the surface with injection will also reduce nuisance odors and can impact emissions of greenhouse gas nitrous oxide (N_2O).

The environmental benefits of cover crops and manure injection are well-established but how to get adoption by the farmers? Most of the time, policy makers have used either enforcement or subsidies, but these policies are costly and have many negative side-effects as we will discuss in the next session. Therefore, we wanted to test if an education and demonstration program built on the existing network and expertise of Cooperative Extension, could be an cost-effective alternative model to help farmers adopt these technologies.

Review of Methods

What is innovative about this project?

Although cover cropping for nutrient and sediment loss reduction is not a new idea, recent years have brought innovations in cover crops that include new species and the practice of planting mixtures of multiple cover crop species. For instance, forage radish (trademarked as “Tillage Radish” by one seed distributor) has shown significant environmental and agronomic benefits in studies conducted in Maryland and Pennsylvania. Forage radish had greater capacity to capture residual nitrogen in the fall than cereal rye (116 kg N/ha vs. 79 kg N/ha; Dean and Weil, 2009) and leaves large holes that can improve infiltration and reduce erosion. Forage radish winterkills and rapidly releases the accumulated nitrogen in late winter and early spring. Nitrogen accumulated by forage radish can be retained longer if it were planted in a mixture with a winter hardy species such as cereal rye which would take up the nitrogen released by forage radish upon winterkilling (White and Weil, unpublished). Forage radish residues also rapidly decompose, leaving the soil surface bare. If planted in a mixture with cereal rye, the rye residue would persist longer into the summer, protecting against erosion.

New and innovative cover cropping practices can enhance the environmental benefits and provide additional agronomic benefits such as supplemental forage, weed suppression, compaction alleviation and improved soil quality (Weil and Kremen, 2007; Chen and Weil, 2010). In a preliminary statewide cover crop demonstration project conducted by Penn State Extension in fall 2009 through spring 2010, several of the cover crop mixtures tested showed potential for use as a supplemental forage crop (White et al., 2010), producing up to 7,000 lbs/acre forage with a value of $150 to $350 per acre. Utilizing the cover crops as forage can offset imported feed and increase phosphorus removal from the soil, potentially improving the farm-level phosphorus balance. These on-farm benefits can spur adoption by farmers without the need for subsidies or regulations.

While no-tillage results in soil quality improvement and erosion reduction, vertical stratification of P creates a concern with runoff P losses (Duiker and Beegle, 2006; Sharpley et al., 1993; Sharpley, 1985). Surface applied manure can easily run off the field during periods when the soil is saturated (Withers et al., 2003; Preedy et al., 2001; Verbree et al., 2010). Manure injection may address these concerns, and can also improve nitrogen conservation by reducing ammonia volatilization (Mannheim et al., 1995; Huijsmans and Schils, 2009). Recent research has shown the benefits of coupling of manure injection and cover crops (Singer et al., 2006). After comparing five different manure application systems for no-till fields on the shallow, rocky and steep soils of the Northeast, Penn State and USDA-ARS (Doug Beegle, Peter Kleinman, Curtis Dell) found shallow disk injection can reduce ammonia- N emissions by as much as 80% and phosphorus run-off by up to 95%, with significant odor reductions (personal communication). In addition, whole farm computer simulations indicate that shallow disk injection reduces ammonia –N and soluble phosphorus losses across multiple field types in livestock farming systems, at break-even or very low cost to the farmer (Rotz et al., in review).

The benefits of no-tillage, cover crops, and manure injection seem clear, but how to achieve adoption is still being debated. Subsidies have long been used to help farmers provide public services: among them environmental ones (CRP, CREP, EQIP, Growing Greener). Enforcement is another, increasingly more popular, method to achieve adoption of environmentally benign practices on farms (e.g. cross-compliance, CAFO, Clean Streams Law). In the near future, EPA is likely to enforce all farmers to inject or incorporate all manure. Both subsidies and enforcement often have undesirable consequences. For example, subsidies are known to distort markets, reduce competitiveness, and may become prohibitively expensive to society. Enforcement often leads to high overhead costs, reduced profitability, and favors vertical integration and large farms. These undesirable side-effects can be avoided if farmers would adopt environmental practices without subsidies or enforcement. This is especially important in Pennsylvania because many farmers are small (average farm size in 2004 was 132 acres, and 58% of dairy farms had less than 100 milk cows), and have an aversion to government intervention or to receive government payments (e.g. the 51,000 Old Order Amish plus other Anabaptists). In 2004, there were 25,200 Amish in Lancaster County, and 52,000 Anabaptists (including Amish, Brethren, Mennonites, United Zion; http://pressroom.padutchcountry.com).

In this project we used extension and education instead of enforcement or subsidies to reach environmental quality goals. We used small replicated on-farm research trials of cover crops spread from northern to southern Pennsylvania, exposing the treatments to many different climatic and soil conditions. Additionally, each participating farmer planted up to a 10-acre field to a cover crop of his choice. This field was usually adjacent to the small replicated plots which made a great combination when we held field days at these sites. The field was managed by the farmer and was the major talking point of the farmer during the field days. This was a way of keeping the farmer engaged and grooming local expertise so that the farmer would become a 'go-to' person for people in the area. This farmer managed field was very important to show how these cover crops could be managed with farmer equipment and knowledge. Usually the farmer used cover crops after all his corn silage so this was a great testimonial to the other farmers that indeed this was something worth pursuing. We held field days or walks at each site two times a year – in the fall and in the spring. Although the field days normally drew small crowds they were very impactful. The farmers were usually present at the field day which was essential for impact. Not seldom a member of the local press would be present who would give additional publicity to the concept of cover crops after the event. We collected above-ground biomass data from the small plots in the fall at dormancy and at the time when the farmer would terminate the cover crop in the spring. The biomass was dried at 50 degrees Celcius until dry in drying ovens at Penn State. Sub-samples were ground and sent to an analytical laboratory for nutrient analysis. This allowed us to determine nutrient uptake in lbs/A in fall and spring to understand how much nitrogen was protected from loss and how well the cover crops protected the soil (most important for sediment and phosphorus losses). We also took some forage samples if this was justified to evaluate the value of the cover crops as forage. These samples were analyzed by a commercial laboratory. We also did a few manure injection outreach events.

Towards the end of the project five videos were created and posted on YouTube. These videos showcase cover crops and manure injection and the farmers managing them. Again they primarily showcase farmer testimonials instead of research. We believe this is more important than research data to stimulate adoption. We worked with USGS to determine the adoption of cover crops after corn in a few key counties in Pennsylvania using remote sensing and geographic information systems. Cost comparisons of the outreach method used in this project with enforcement or subsidies are presented in the 'Findings' section.

What did the producer have to do differently to accommodate the project

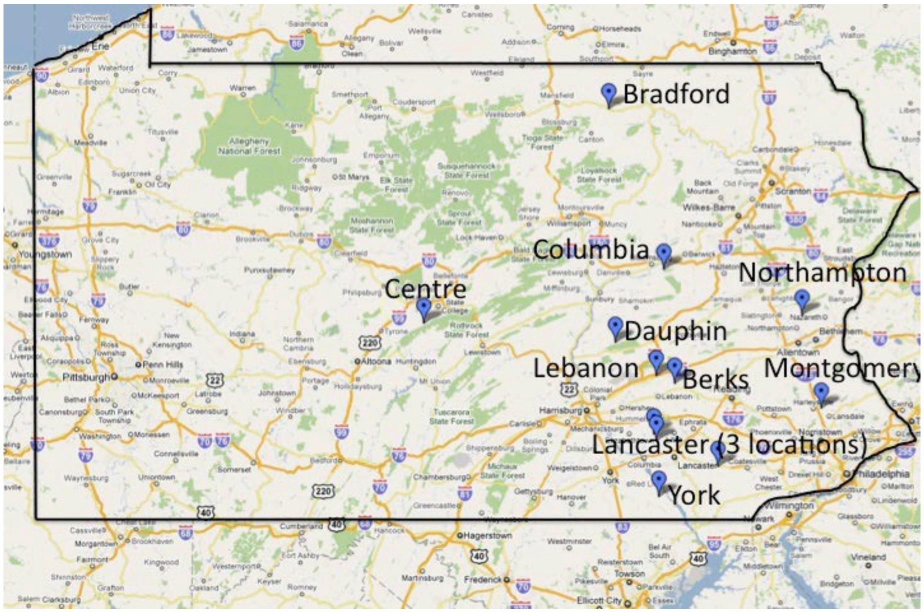
The producer would have to plant cover crops after corn silage, with all the costs and management that that entails. Most farmers have all the equipment to plant the cover crops (no-till drill, sprayer, tractor) so in general no new equipment would have to be purchased. Manure injection is more involved because many farmers do not have a manure injector. There are, however, several custom manure haulers in Pennsylvania who are now offering manure injection as a service for an additional cost. Manure injection is usually more time consuming than broadcasting manure on the surface so this is another disadvantage. However, cost-savings such as reductions in nitrogen fertilizer needs may make up for the increased cost of manure injection. Odor reduction may be another added benefit without economic value but great practical value especially in densely populated areas of Pennsylvania.

Schedule of events

August 2010 – Selection of farmer collaborators, purchase seed.
September 2010 – Establishment of small plot, replicated trials at 12 locations by on-farm research coordinator (map 1). Farmers establish large field with cover crop mixture.
November 2010 – Field walks in 9 different counties.
November/December 2010 – Cover crop biomass harvest and drymatter determinations. Cover crop biomass harvest and drymatter determinations. Sample processing for nutrient and forage analyses (throughout winter).
Winter 2011 – Videographer identified.
Winter 2011 – Four video cameras distributed to extension educators for farmer interviews
Winter 2011 – Powerpoint on cover crop research prepared and distributed to extension agents.
Winter 2011 – Presentations given at winter meetings.
Winter 2011 – Articles published on cover crop research results.
Winter/Spring 2011 – Web-site kept up-to date
Winter/Spring 2011 – Conducted windshield surveys for ground-truthing of remote sensing analysis of cover crop use.
April 2011 – Semi-Annual report for USDA-NRCS.
April 2011 – Field walks in 8 different counties.
April/May 2011 - Cover crop biomass harvest and drymatter determinations. Sample

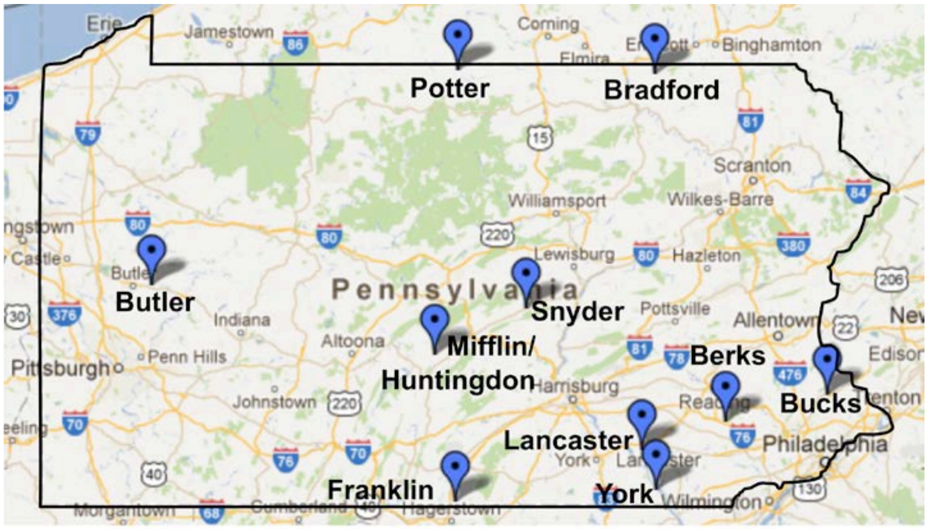
processing for nutrient and forage analyses (throughout summer).
August 2011 – Selection of farmer collaborators.
September 2011 – Establishment of small plot, replicated trials at 9 locations by on-farm research coordinator (map 2). Farmers establish large field with cover crop mixture.
October 2011 – Semi-Annual report for USDA-NRCS.
November 2011 – Field walks in 8 different counties.
November/December 2011 - Cover crop biomass harvest and drymatter determinations. Sample processing for nutrient and forage analyses (throughout winter).
Winter 2011 – Presentations given at winter meetings.
Winter 2011 – Articles published on cover crop research results.
Winter/Spring 2011 – Web-site kept up-to date.
March/April 2012 – Field walks in 7 different counties.
April/May 2012 - Cover crop biomass harvest and drymatter determinations. Sample processing for nutrient and forage analyses (throughout summer).
April 2012 – Semi-Annual report for USDA-NRCS.
August 2012 – Selection of farmer collaborators.
September 2012 – Establishment of small plot, replicated trials at 10 locations by on-farm research coordinator (map 3). Farmers establish large field with cover crop mixture.
October 2012 – Semi-Annual report for USDA-NRCS.
November 2012 - Field walks in 10 different counties.
November/December 2012 - Cover crop biomass harvest and drymatter determinations. Sample processing for nutrient and forage analyses (throughout winter).
Winter 2012 – Presentations given at winter meetings.
Winter 2012 – Articles published on cover crop research results.
Winter/Spring 2012 – Web-site kept up-to date.
April 2013 - Field walks in 10 different counties.
April/May 2013 - Cover crop biomass harvest and drymatter determinations. Sample processing for nutrient and forage analyses (throughout summer).
April 2013 – Semi-Annual report for USDA-NRCS.
September 2013 – Cover crop research trial established at PSU Agronomy Research Farm.
October 2013 – Semi-Annual report for USDA-NRCS.
Winter 2013 – Presentations given at winter meetings.
Winter 2013 – Articles published on cover crop research results.
April/May 2014 – Cover crop biomass determination for PSU research trial.
April 2014 - Semi-Annual report for USDA-NRCS.
Summer 2014 – Data processing continues.
October 2014 – Submit manuscript on remote sensing for cover crop adoption to Journal of Soil and Water Conservation.
November 2014 – finalization of 5 videos (one on manure injection, and four on cover crops).

Maps, diagrams and other materials showing the location of the project



Map 1. Cover crop research/demonstration sites established in fall of 2010.

Map 2. Cover crop research/demonstration sites established in fall of 2011.



Map 3. Cover crop research/demonstration sites established in fall of 2012.

Summarize what worked, what didn't work, and why

Adopting cover crops seemed to be an easy sell to the farmers, especially if they could use them as forage. The farmers also appreciated the soil improvement benefits of the cover crops and the ability to more easily spread manure on the fields with living cover. The farmers typically have the equipment needed to establish and manage the cover crops. No-till drills are now quite common in the state so even if a farmer does not have a no-till drill himself he will be able to rent or borrow one from a neighbor. The use of manure injection is more complicated. The availability of manure injection equipment is not widespread. Fortunately some manure haulers have jumped on the opportunity and are offering manure injection as a service. However, it comes at a price and since cost-savings due to reduced nitrogen fertilizer needs are not very clear yet the adoption of this technology will be slower.

The outreach methods proved to be very effective. The evaluation of different cover crop mixtures in small replicated plots at many different farms throughout the state added a lot of power to the research data we used for our outreach. Members of our team used these data in many different venues at field days, local county meetings, regional meetings, state-wide meetings, and national meetings. The data offered new information about species and mixtures that could work. Because we used a rigorous statistical design the data were high quality so a lot of confidence could be put in them. Although we were limited in the number of species and mixtures we could evaluate, there was a sufficient variety to offer farmers enough practical information for their decision making. It was also useful that we were able to change the treatments from year to year based on our findings. Although this might not be desirable from a research point of view it was better than having to justify keeping evaluating the mixtures which turned out to be very similar due to the dominance of one species (cereal rye). The combination of the small plots with demonstration of one particular mixture of the farmer's choice in a large, farmer managed field was important to guarantee the active involvement of the farmer. The voice of the farmer was crucial to get other farmers to adopt cover crops. Farmers tend to be very skeptical of research information that solely comes from scientists because of all the management details that are often not discussed but may be a major issue for a farmer. We also feel the collaborating farmers established themselves as leaders in their community on cover crops and this is something that will remain even though our project ended. As for the manure injection outreach, that was mostly focused on generating a video showcasing this technology. We cannot say much about the effectiveness of the cover crop and manure injection video clips yet because they were just recently posted. We have just started to inform people of these videos so many people would be unaware of their existence.

The remote sensing analysis of cover crop adoption worked well in areas that had large fields without too many strips of different types of vegetation. In northern parts of Pennsylvania fields were often interspersed with forest and in areas with steep slopes strip cropping was often practiced. This meant there were narrow strips of previous corn alternating with hay and this made it difficult to use remote sensing at currently available resolution.

What would be done differently if this project were started today?

It would have been very beneficial to have a few no-till drills for small plot work at different locations in the state with trailer and experienced personnel instead of having to rely on one individual to plant all the small plots. The forage data collection protocol (which involved cutting biomass at normal cutting height in contrast to the cover crop biomass which was cut to the soil surface) could have been developed better so we would have more robust data to present. However, this would involve twice as many samples to process. Another area we would like to expand on is how to integrate use of cover crops for grazing. We would have more emphasis on manure injection with dedicated funding to get equipment for the field demonstrations and a more rigid research protocol. We would probably have started producing the videos earlier so we could have collected impact data. We could have included bona fide transect surveys with the remote sensing monitoring to get another measure of cover crop adoption. However, judging from the adoption impact, the project was very impactful as it was.

Discussion of Quality Assurance

Project site description

Sites were presented in the ‘Methods’ section. These sites were located throughout Pennsylvania – from the northern part to the southern end. This meant a lot of different climatic and soil conditions were covered and relevant information was collected for farmers in the different parts of Pennsylvania. Seeding rates are presented in Table 2. All small plots were established with a 7 foot wide Esch no-till drill with 5.5 inch row spacing. Small seeds were usually planted through the small seed box, while the large seeds were planted through the large seed box. The drill was calibrated for each mixture by turning the drive wheel a number of rotations and collecting the seed of 5 openers to represent 100th of an acre. Seeding depth was adjusted based on seed size and field conditions.

Table 2. Seeding rates used in small, replicated plot studies in 2010, 2011, and 2012.

Mixture	**Seeding rate (lbs/A)**
2010/2011	
"Dixie" crimson clover + "KB Royal" annual ryegrass	15 + 10
"KB Royal" Annual ryegrass + "815" Triticale	5 + 84
"Aroostook" cereal rye + "Jerry" forage oat	84 + 70
"Bonar" rape + hairy vetch + "Aroostook"cereal rye	4 + 10 + 84
Tillage radish + hairy vetch + "Aroostook" cereal rye	3 + 10 + 84
Tillage radish + "Aroostook" cereal rye	5 + 112
"Aroostook" Cereal rye	112
2011/2012	
"Dixie" crimson clover + "402 KB" annual ryegrass	15 + 10
"Dixie" crimson clover + "815" Triticale	15 + 84
"Dixie" crimson clover + "Everleaf" forage oat	15 + 70
"402 KB" annual ryegrass + "Everleaf" forage oat	10 + 70
"Everleaf" forage oat + "Aroostook" cereal rye	70 + 84
"Hercules" grain oat + "Aroostook" cereal rye	70 + 84
Tillage radish + hairy vetch + "Aroostook" cereal rye	5 + 15 + 84
"Aroostook" cereal rye	112
2012/2013	
"Dixie" crimson clover + "KB Royal" annual ryegrass	15 + 10
"Dixie" crimson clover + "718" Triticale	15 + 84
"Dixie" crimson clover + "Hercules" spring oat	15 + 70
"KB Royal" annual ryegrass + "Hercules" spring oat	10 + 70
"Hercules" spring oat + "Aroostook" cereal rye	70 + 84
"Hercules" spring oat + "Huron" cereal rye	70 + 84
Tillage radish + hairy vetch + "Aroostook" cereal rye	5 + 23 + 77
"Aroostook" cereal rye	112

Sampling design

At each location, small cover crop plots were laid out in a randomized complete block design with typically 4 replications. In some cases 3 replications were used.

Sampling procedures etc

Cover crop biomass was sampled at onset of winter dormancy in the fall using a 0.5 square meter sampling frame and electrical clippers. The same procedure was followed in the spring just before the farmer intended to terminate the cover crop. Cover crop biomass of each plot was cut at the soil surface, put in a cloth bag, and transported to Penn State University main campus where it was placed in an oven at 50C until dry. Then the dry matter was weighed. A sample was ground and sent to an analytical laboratory for nutrient analysis. If there was sufficient biomass for forage analysis, a sample was cut from each plot at about 2 inches height and all the samples from one treatment were composited. These samples were placed in the oven until completely dry and sent to a laboratory for forage quality analysis.

Data reduction, analysis and reporting

The major objective of this project was not to do research but to promote adoption of well-established technologies. Therefore, tables 3-6 present outputs of the outreach program. In addition we present a selection of research: figures 1-3 summarize spring biomass and a table summarizing nitrogen in above-ground biomass (table 7) measured in the small plot, replicated cover crop trials for spring 2011, 2012 and 2013. This is only a sample of all the data collected in this project highlighting cover crop growth and nitrogen uptake. We also present four graphs showing the cover crop adoption data over the project period in four counties (Figs. 4-7).

Findings

Outreach

Fifty two field walks were organized within the context of this project (Table 3). The number of participants was not recorded at every meeting. However, in the fall of 2010 and spring of 2011 410 persons participated, while in the fall of 2011, 104 persons participated, for an average of 20 persons per field walk, which was typical. The total number of participants to the field walks is therefore estimated to be 1040 (52 field walks x 20 participants per field walk).

Table 3. Number of cover crop field walks organized as part of this project

	Fall 2010	Spring 2011	Fall 2011	Spring 2012	Fall 2012	Spring 2013
Number of field walks	9	8	8	7	10	10

Twenty-seven presentations were given at different conferences, webinars, and winter meetings, reaching almost 2000 people (Table 4). The total number of people reached through field walks and presentations at in-door meetings therefore exceeded 2800, significantly more than the goal of 1000 people. Admittedly, not all these attendees were farmers, but if they were not farmers themselves they probably were providing service to multiple farmers.

Table 4. Presentations at different venues given as part of this project.

Date	**Title**	**Venue**	**Number of attendees**
2/3/10	Multi-location evaluation of cover crops and cover crop mixtures in Pennsylvania.	Mid-Atlantic Fruit and Vegetable Convention, Hershey, PA	50
1/11/2013	Cover cropping for the no-tiller with livestock.	National No-Till Conference Organized by No-Till Farmer in Indianapolis, IN	100
11/17/10	Cover crops to improve soil	Mid-Atlantic Crop Management School, Ocean City, MD	100
1/18/11	Cover crops, the Pennsylvania way!	Pennsylvania Agronomic Education Society Conference, The Penn Stater, State College, PA.	30
2/8/2011	Overcoming the challenges of no-till and cover crops in corn production.	2011 Corn Day, Otesaga Resort Hotel, Cooperstown, NY	160
2/9/11	Successful cover cropping in Pennsylvania	Pennsdale, PA	45
4/13/11	The use of cover crops to enhance soil health and reduce agricultural runoff.	Potomac Valley Nutrient Management Workshop, Romney, WV	50
11/30/11	Cover crops for the Northeast	NRCCA Training, Doubletree Hotel, Syracuse, NY	70
1/17/12	Cover Crops.	Pennsylvania	40

Date	Title	Venue	Number of attendees
		Agronomic Education Society Conference, held in the Penn Stater. State College, PA	
1/22/13	Cover crop research update	Southeast Pennsylvania Crops Conference in Allentown, PA	8
1/23/13	Cover crop research update	Southeast Pennsylvania Crops Seminar in Frankonia, PA	15
1/24/13	Cover crop research update	Southeast Pennsylvania Crops Seminar in Wyomissing, PA	10
2/11/2013	Cover crops for soil health and nutrient management.	Webinar presentation	95
3/25/2013	Nitrogen management with cover crop mixtures.	Webinar presentation	91
3/26/13	Cover crops to make your system tick	16th Annual Western PA No-Till Conference, West Middlesex, PA	50
11/6/13	Cover crop mixtures after corn silage for the northeastern U.S.	Paper presented at 2013 ASA/CSSA/SSSA annual conference in Tampa, FL	30
11/13/2013	Manage forage risk by thinking beyond alfalfa and corn silage	Penn State University Dairy Cattle Nutrition Workshop held at Grantville Holiday Inn, Hershey, PA	300
12/10/13	Cover crops and soil management	Mifflinburg, Union County, PA	20
12/4/2013	Cover crop mixtures after corn silage.	Northeastern Region Certified	70

Date	Title	Venue	Number of attendees
		Crop Adviser Training, Double Tree, Syracuse, NY	
1/14/2014	Warmer winter temperatures have created opportunities for new cover crops in Pennsylvania.	Pennsylvania Agronomic Education Society Annual Conference, State College, PA	180
1/21/2014	Cover crops after corn silage	Southeast Pennsylvania Crop Conference, Allentown, PA	12
1/22/2014	Cover crops after corn silage	Southeast Pennsylvania Crop Conference, Frankonia, PA	12
1/23/2014	Cover crops after corn silage	Southeast Pennsylvania Crop Conference, Reading, PA	22
1/30/2014	Cover crops in sweet corn	Mid-Atlantic Fruit and Vegetable Conference in Hershey, PA	50
2/12/2014	Opportunities for double and triple cropping: Thinking beyond corn silage and alfalfa	PA Dairy Summit held at Penn State Conference Center, University Park, PA	110
2/20/2014	Cover crops after corn silage	No-Till & Cover Crop Symposium held in Burlington, Vermont.	75
2/26/2014	Planting green into cover crops	Soil health workshop held in Lewisburg, Pennsylvania	110
TOTAL			**1,905**

Five videos were produced and posted on Youtube as part of this project (Table 5). The topics ranged from nutrient management with cover crops, to manure injection and cover crop species and establishment. The total number of views was slightly more than 5000. Most of the views were for the video created by NRCS on nutrient management and cover crops as part of their national soil health campaign. It seems that video clips on the internet are emerging but as yet not widely used by farmers to obtain information.

Table 5. Topics and internet addresses of videos produced as part of this project and number of views.

Topic	Internet address	Number of views (as of 9/1/15)
Nutrient mgt and cover crops	https://www.youtube.com/watch?v=Qjd0NQ6Hc88	3998
Manure injection	https://www.youtube.com/watch?v=FfnGxE_kyEI	599
Rationale for cover crops	https://www.youtube.com/watch?v=dCGpmU8cg2M	263
Cover crop species and establishment	https://www.youtube.com/watch?v=TU2wqZl6lOw	97
Soil organic matter content	https://www.youtube.com/watch?v=dtRPcSEGwVw	165
TOTAL		5,122

Twenty-one articles were published in Field Crop News, the electronic newsletter produced on a weekly basis by the Field and Forage Crop Team of Penn State Cooperative Extension (Table 6). This newsletter is now received by approximately 1800 people. One factsheet was produced and published by the College of Agricultural Sciences. Two newspaper articles were published reporting on field days held for this project. Lancaster Farming has about 56,000 subscribers in Pennsylvania and beyond. We believe this statistics provide ample proof that communications written as part of this project were read by at least 5,000 farmers, one of the original objectives.

Table 6. Publications produced as a result of this project.

Author	Title	Series name
White, C.	Late Summer Cover Crop Options for Supplemental Forage Production published in	Field Crop News, July 26, 2011.
Hoover, R. and S. Duiker.	On-Farm Cover Crop Plots: Spring Pre-Burndown Biomass Yields published in	Field Crop News, August 23, 2011
Hoover, Ron.	Making Efficient Use of Your Time: Ideas to Consider When Planning On-farm Research?	Field Crop News, March 20, 2012
Duiker, S.	When to pull the trigger on cover crops.	Field Crop News Mar 20, 2012.
Duiker, S.	Summer cover crop seeding.	Field Crop News Jul 3, 2012.
Duiker, S.	Cover crop establishment timing.	Field Crop News Aug 21, 2012.
Hoover, R. and Duiker, S.	Spring 2012 on-farm cover crop plots: spring pre-burndown biomass yields.	Field Crop News Sept 4, 2012.
Duiker, S.	Conservation message continues to be relevant.	Field Crop News Sept 11, 2012.
Duiker, S.W., Hoover, R.J., and Myers, J.C.	Calibration of grain/seed drills.	Agronomy Factsheet 75. Penn State College of Agricultural Sciences, University Park, PA.
Duiker, S.	Is it still worth establishing cover crops?	Field Crop News November 6th, 2012.
Hoover, R.	Fall 2012 on-farm cover crops field days: Coming to 10 farms near you!	Field Crop News October 16th, 2012.
Duiker, S.	Voluntary conservation approaches work in the Chesapeake Bay .	Field Crop News January 8th, 2013.
Duiker, S.	Get ready for red or sweet clover frost-seeding..	Field Crop News February 5th, 2013
Duiker, S.	Time for planter maintenance.	Field Crop News February 5th, 2013.
Teresa McMinn	Extension shows off cover crop study. Report of field day in Lancaster.	Lancaster Farming 4/20/2013. http://www.lancasterfarming.com/-Extension-Shows-Off-Cover-Crop-Study-#.UmrZNSRQ36I
Carol Ann Gregg.	Butler County dairy farmer still learning from cover crop study. Report of field day in Butler, PA.	Lancaster Farming 5/4/2013. http://www.lancasterfarming.com/-Butler-County-Dairy-Farmer-Still-Learning-From-Cover-Crop-Study-

Author	Title	Series name
		#.UmrYrCRQ36I
Duiker, S.	NRCS cover crop termination guidelines for non-irrigated cropland show cover crops can be terminated up to crop emergence in PA.	Field Crop News June 11, 2013.
Duiker, S.	Protecting our soils from erosion remains a priority.	Field Crop News July 23, 2013.
Duiker, S.	Getting ready for cover crops after corn silage.	Field Crop News, July 30, 2013.
Duiker, S.	Cover crop countdown has begun!	Field Crop News, August 20, 2013.
Duiker, S.	The 2014 planting season begins now with proper residue spreading.	Field Crop News, September 24, 2013.
Hoover, R.	More results from 2012/13 cover crop project: late 2012 accumulations of aboveground biomass.	Field Crop News, April 15, 2013.
Hoover, R.	Cover crops and alternative summer forages to complement corn silage.	Field Crop News, September 17, 2013
Duiker, S.	Keeping your fields covered.	Field Crop News October 15, 2013.

Research results

Cover crop species & establishment

Cover crop biomass averaged across all sites in spring 2011 was 2800 for crimson/ryegrass to 4500 lbs/A for rye (Fig. 1). Biomass for a particular site ranged from 1200 lbs/A for crimson clover/ryegrass to 7500 lbs/A for rye in 2011. Cover crop biomass averaged across all sites in spring 2012 was 2700 for oat/ryegrass - 4900 lbs/A for rye (Fig. 2). The range of biomass for any particular site in 2012 was from 1700 lbs/A for oat/ryegrass to 7400 lbs/A for the radish/vetch/rye mix. Cover crop biomass averaged across all sites in spring 2013 was 1300 for oat/ryegrass - 4000 lbs/A for rye (Fig. 3). The range of biomass was from 120 lbs/A for oat/ryegrass to 6900 lbs/A for rye in 2013. Cover crop biomass varies depending on weather conditions in the fall, winter and spring. It is clear that the winter of 2012/13 did not favor cover crop growth as much as the previous two years. The wide range in biomass reflects differences in climatic zones – cover crop biomass was much higher in southern than northern locations due to milder winter conditions. It also reflects soil fertility and soil health – sites with higher fertility and better soil health had higher biomass as well. The data show that cereal rye or mixtures with cereal rye (which were usually dominated by rye in the spring) produce the most biomass of all the mixes tested. Because we wanted to learn more about different species we reduced the number of entries with rye in 2011/12 and 2012/13. All mixtures with oats and forage radish did not have oat or radish in them in the spring because of winterkill, so these values reflect the biomass of the companion species. Although we thought these species could be of interest in mixtures because of rapid fall growth we did discover that after corn silage their fall growth potential is quite limited (especially of forage radish), while they are not growing in the spring when nutrient leaching potential is high. We also observed that when these species grew rapidly in the fall, they tended to suppress the companion cover crop resulting in a poor stand of that cover in the spring. Hairy vetch and rape were among the cover crops that did not do very well in our trials, perhaps due to the late establishment date or perhaps herbicide residues from the corn. The crimson clover/ryegrass mixture captured the imagination of the farmers, particularly in the southern parts of the state. The two species grow very well together, produce reasonable biomass yield in the south, which has milder winter conditions than the north, and have high forage quality (not reflected in total biomass) and low seed cost. Triticale/crimson clover is another good combination of a very winterhardy cereal with a legume. Because triticale stays lower in the fall and spring than rye it combines well with crimson clover. Huron rye has a phenology that is very similar to that of triticale and can be an alternative for this cover crop. We often use the rule of thumb that 1500 lbs/A of dry matter means acceptable ground cover for erosion protection. With most mixtures we achieved this threshold in the spring, although in some northern sites this was not always the case, particularly with the species that were not that winter hardy.

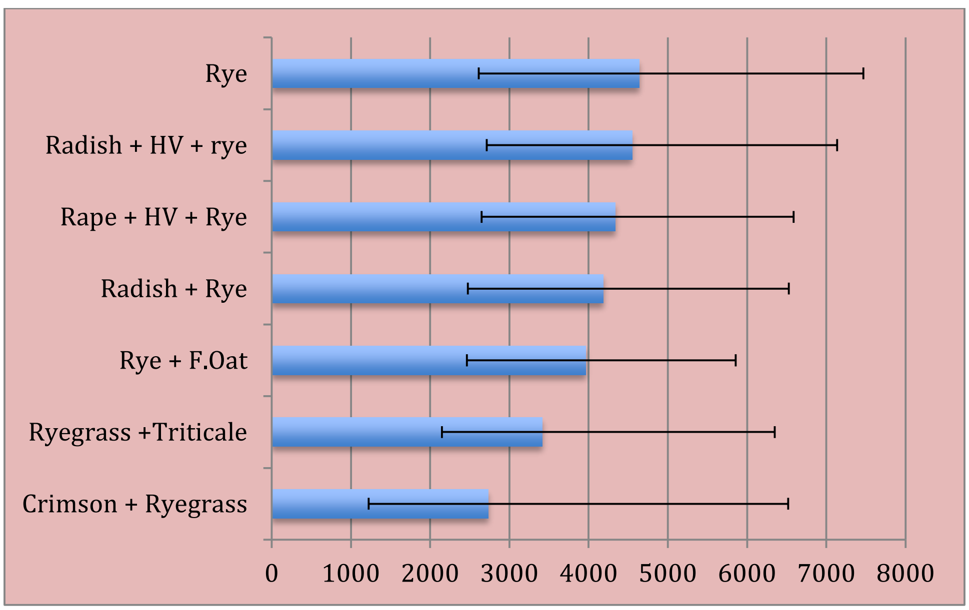


Figure 1. Average cover crop biomass of cover crops in spring of 2011 is shown in the bars, with the line respresenting the range of biomass over all the sites. (HV = hairy vetch, F.Oat = forage oat)

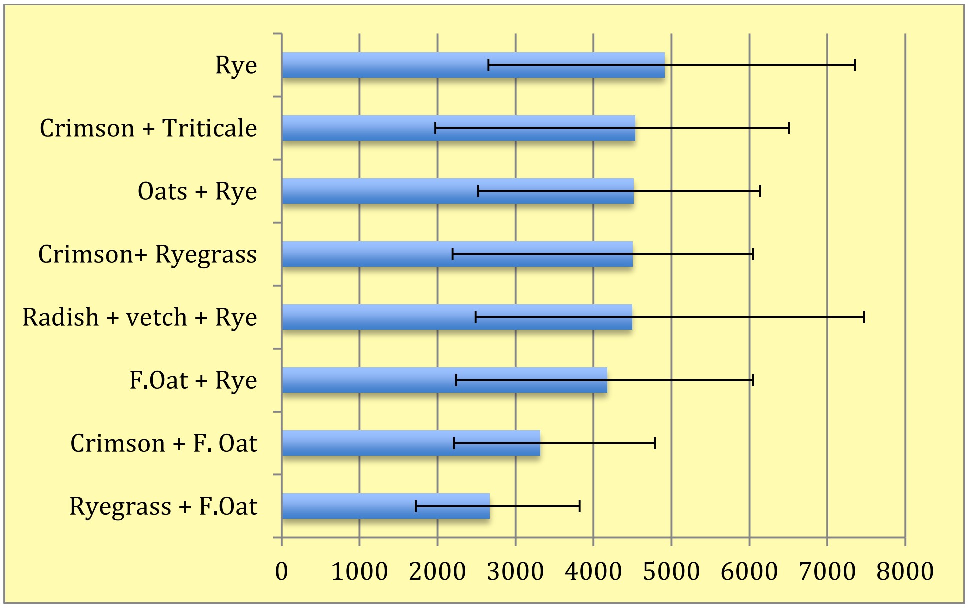


Figure 2. Average cover crop biomass of cover crops in spring of 2012 is shown in the bars, with the line respresenting the range of biomass over all the sites. (F.Oat = forage oat)

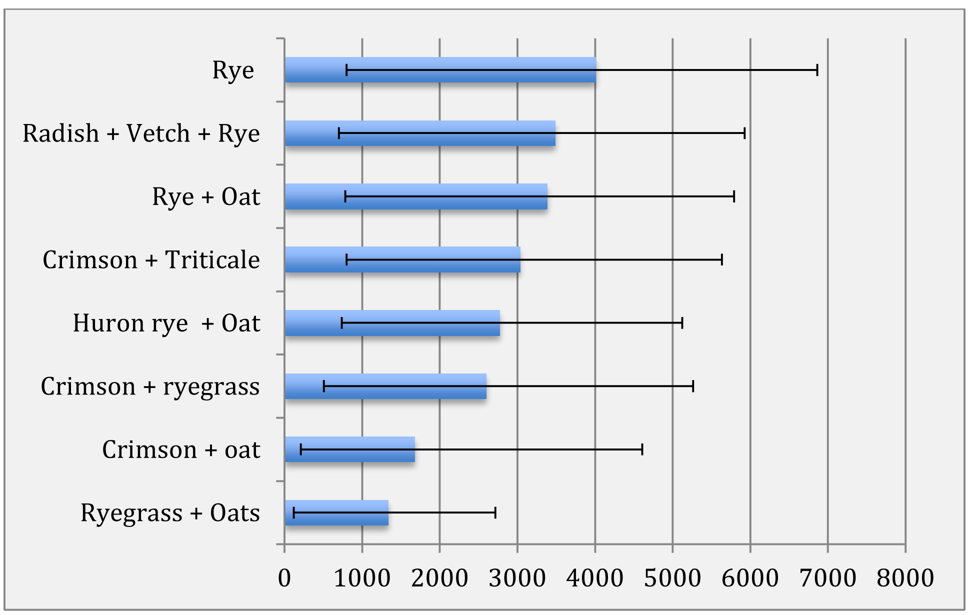


Figure 3. Average cover crop biomass of cover crops in spring of 2013 is shown in the bars, with the line respresenting the range of biomass over all the sites.

Nitrogen content in the above ground biomass in spring averaged from 31-112 lbs N/A (Table 7). In some cases nitrogen in above-ground biomass was up to 180 lbs/A. This shows the potential of these cover crops to absorb nitrogen that is then protected from loss by leaching.

Table 7. Average, maximum and minimum nitrogen content in above-ground biomass in small-plot cover crop trials in spring of 2011, 2012 and 2013.

		Average	Minimum lbs/A	Maximum
	Crimson + Ryegrass	70	21	104
	Ryegrass +Triticale	73	41	126
	Rye + F.Oat	76	44	139
2011	Radish + Rye	82	49	161
	Rape + HV + Rye	87	50	169
	Radish + HV + rye	89	52	164
	Rye	93	47	182
	Ryegrass + F.Oat	52	21	74
	F.Oat + Rye	69	26	107
	Oats + Rye	73	34	97
	Radish + vetch + Rye	82	39	120
2012	Rye	84	35	120
	Crimson + F. Oat	103	57	144
	Crimson+ Ryegrass	106	63	140
	Crimson + Triticale	112	65	147
	Ryegrass + Oats	31	5	72
	Crimson + oat	54	7	135
	Huron rye + Oat	66	16	125
2013	Rye + Oat	66	17	122
	Crimson + ryegrass	70	18	125
	Radish + Vetch + Rye	79	16	158
	Rye	82	16	176
	Crimson + Triticale	83	23	130

These are just a sample of the data collected in this project. We are still working on analysis and publication of the results which will be forthcoming in the future.

The change in cover crop adoption over the project period

The most important aspect of this project is the impact on adoption of the technologies promoted. In figures 4-7 we present the results of the remote sensing analysis of cover crop adoption in Berks, Lancaster, Lebanon and York, respectively. These counties were chosen based on the size of corn fields and the remote sensing imagery available for our time period. The data are for cover crop use after all types of corn because the database did not allow us to distinguish between corn silage and corn grain acres. The figures show corn acres with minimal, low, medium and high cover. Figure 4 shows that, between spring 2010 and 2013 the percentage corn acres with minimal green cover (representing fields without cover crop) in Berks decreased from 65 to 34%. This percentage decreased from 49 to 26% in Lancaster (Fig. 5), 60% to 36% in Lebanon (Fig. 6), and 76% to 52% in York (Fig. 7). These results suggest, that from 2009 to 2013, cover crop use after corn increased from 35 to 66% in Berks, from 51 to 74% in Lancaster, from 40 to 64% in Lebanon, and from 24 to 48% in York. The results also show that the percentage acres with high cover (indicating heavy cover crop in the spring) increased, confirming the trend of increasing use of cover crops. The reason for lower percentage cover crop in York is possibly because this county has more grain corn than the other three counties, where corn silage is more prevalent. Because of earlier harvest it is easier to establish cover crops after corn silage than it is after corn grain. Unfortunately, the crop database did not allow us to distinguish between corn grain and corn silage acres. Although the increased adoption of cover crops after corn cannot be solely attributed to our project, we believe that our activities did contribute significantly to the trend, showing the effectiveness of this approach for this technology.

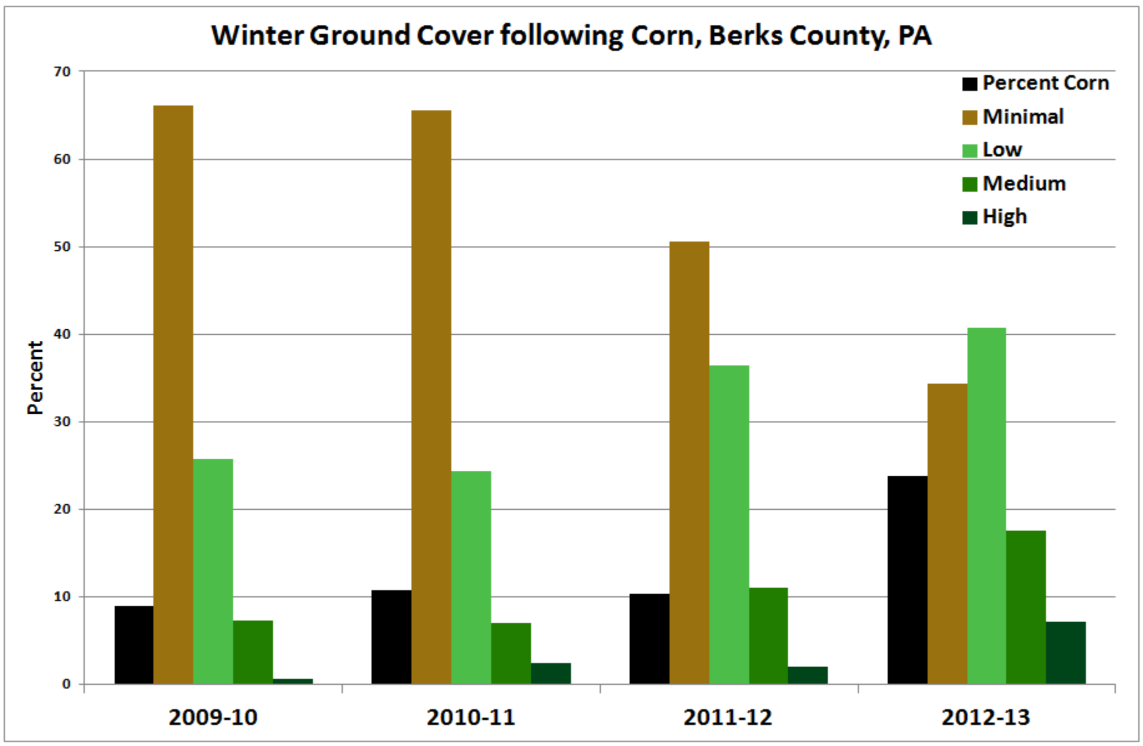


Figure 4. Percent corn and green winter ground cover following corn in Berks County measured using remote sensing analysis using images in Feb-Mar of 2010 to 2013.

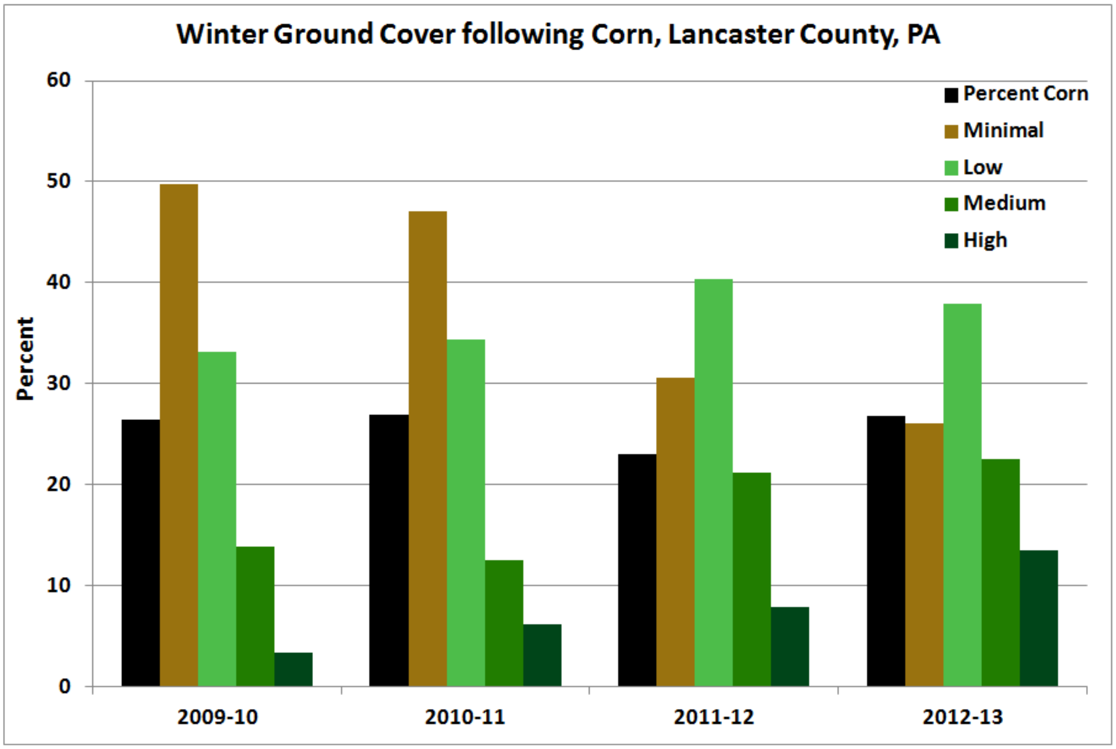


Figure 5. Percent corn and green winter ground cover following corn in Lancaster County measured using remote sensing analysis using images in Feb-Mar of 2010 to 2013.

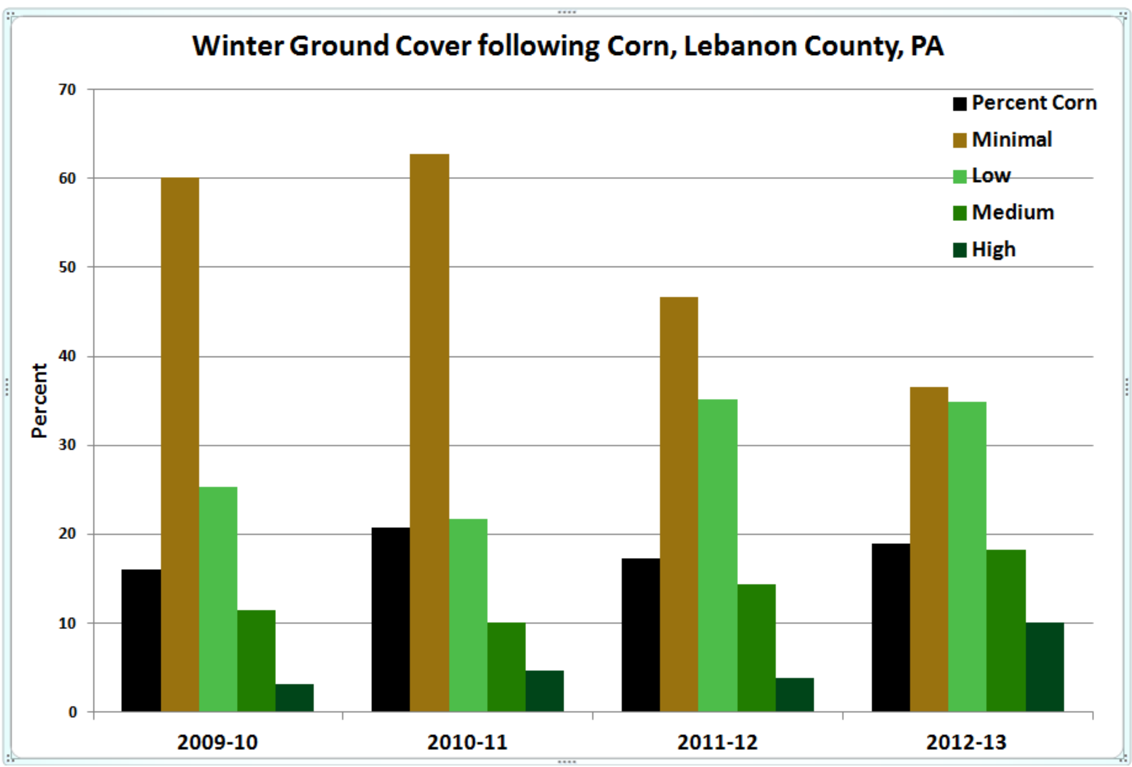


Figure 6. Percent corn and green winter ground cover following corn in Lebanon County measured using remote sensing analysis using images in Feb-Mar of 2010 to 2013.

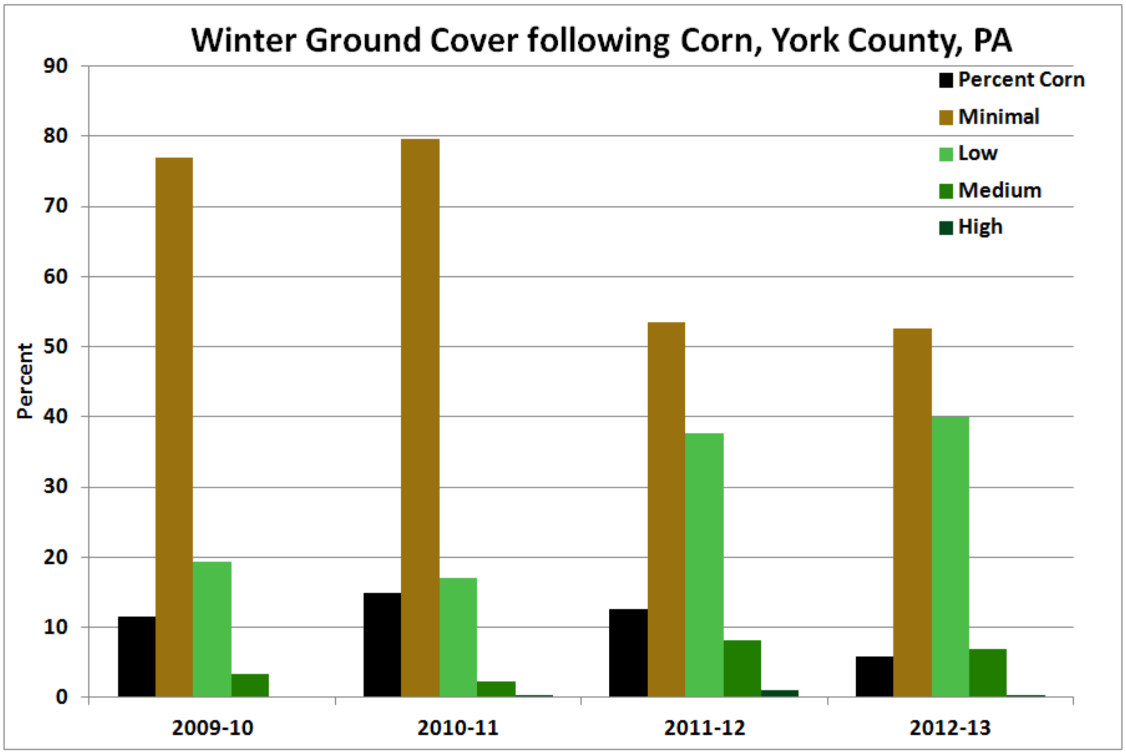


Figure 7. Percent corn and green winter ground cover following corn in York County measured using remote sensing analysis using images in Feb-Mar of 2010 to 2013.

Conclusions and Recommendations

The primary goal of this project was to expand the use of cover crops and manure injection because the environmental benefits of these technologies are already well-accepted.

1. Reliance on extension and education instead of subsidies or enforcement to stimulate cover crop adoption to achieve a reduction of sediment, nitrogen, and phosphorus losses to the Chesapeake Bay. Over the three year project period, we held 52 cover crop field walks and gave 27 in-door presentations, attended by 1700 persons. Therefore, we exceeded our objective to reach 1000 people in meetings and field days. We produced 5 videos viewed more than 5000 times. We therefore think it is reasonable to suggest we met our goal to reach 2000 farmers with the videos. Finally, we produced 21 articles in Field Crop News, the weekly electronic newsletter produced by the Field and Forage Team of PSU with 1800 subscribers, one fact sheet, and had 2 articles in Lancaster Farming (56,000 subscribers). We therefore expect we reached our goal of 5000 famers with these written publications.
2. We hypothesized that the educational approach would be more cost-effective than enforcement or subsidies. Assuming our estimate of new cover crop acres in

Pennsylvania is correct, we can compare the cost of our approach with that of alternatives. We estimated that use of cover crops increased on 360,000 acres over the project period in Pennsylvania. If a subsidy of $40 was paid per acre (a very modest subsidy compared to, for example the Maryland cover crop program that pays $80 or more per acre), this would have represented $14.4 million per year, excluding administration costs, or $43.2 million over the 3-yr project period. Enforcement of this program would have been costly as well. If we assume 4 new staff persons to administer and enforce cover crop use on such a large area at a cost of $100,000 per staff person (salary+benefits, office and equipment, vehicle, mileage etc.), the cost would have been $400,000 per year or $1.2 million over the project period. In comparison, the costs of this educational program to the government were $256,950 over the entire project period. In addition, the effects of this project will continue without expense to the government in contrast to subsidy or enforcement programs. The enforcement approach would have been almost 5 times as expensive and the subsidy approach 170 times as expensive as the educational approach used here.

3. A combination of researcher-established cover crops in on-farm small-plot trials and farmer-managed large fields with cover crops of their choice proved to be a great way to collect high-quality data while engaging the farmers. To use either one approach in isolation would have led to a lack of credibility to farmers or a lack of credibility to researchers, service providers and policy makers.
4. The use of remote sensing to monitor the increase in adoption of cover crops. Transect surveys have been used to monitor adoption of observable practices such as no-tillage or cover crops. This is labor intensive and is limited to observations along roads. By using remote sensing we were able to gauge cover crop adoption across the entire footprint of the imagery, which usually covered most of the 4 counties we focused on. Like any methodology, remote sensing has its shortcomings too. For example, sometimes no usable image could be found at the desired dates due to cloudiness or snow cover. Narrow strips or small fields also represented a challenge for remote sensing because one unit of observation (pixel) could have bare fallow, cover crop and perennial vegetation in it making it difficult to use this method in areas where fields were small or stripcropping was common.
5. Cover crop mixtures versus single cover crop plantings. Cereal rye was the most reliable cover crop due to greatest winterhardiness among all cover crops tested. However, it also has its shortcomings such as limited growth in the fall and very fast growth in the spring when stem elongation starts, making it challenging to manage this cover crop. Among the many different species evaluated in this project after corn silage there were cover crops such as oats, annual ryegrass, hairy vetch, crimson clover, and triticale, which showed promise for increased fall forage production (oats), high-quality feed in the spring (annual ryegrass, crimson clover and triticale), and nitrogen fixation (hairy vetch and crimson clover). When cover crops produced large quantities of biomass, large quantities of nutrients were absorbed from the soil and protected from loss to surface or ground water, the soil was protected by the biomass, while farmers had to purchase less feed which increased on-farm nutrient cycling. By mixing and matching species

according to the desired objectives, multiple benefits could be achieved. The cost of mixtures was sometimes lower, sometimes higher primarily reflecting seeding rate. Some small-seeded cover crops such as annual ryegrass and crimson clover were very economical to plant. Some cover crops tested, particularly hairy vetch, forage radish and rape showed limited use for planting after corn silage.

6. Use of cover crops for feed. The potential to use cover crops for feed proved to be a big motivator for the farmers to spend money to purchase cover crop seed, establish the cover crop immediately after corn silage harvest, and increased nutrient recycling on the farm instead of purchase of nutrient-containing feed from outside the farm. This is a major finding of this project and we recommend it be integrated in policies and programs stimulating cover crop adoption.
7. Manure injection reduces potential of nutrient loss by volatilization (N) or runoff (P and N). However, it involves purchase of new equipment and slows down manure application. However, an added benefit is the reduction of odor which proved to be as important to the farmers as the other benefits. The project allowed us to work with a manure hauler who mounted injectors on several manure tankers and now offers this as a service to farmers so they don't have to purchase the equipment themselves.