Minimizing Phosphorus Loss with 4R Stewardship and Cover Crops

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Project Goal

The goal of this project is to protect water quality and maximize nutrient use efficiency while simultaneously providing producers with flexible management options for phosphorus (P) fertilizers. We will attain this goal through integration of the 4R nutrient stewardship with cover crop use in corn-soybean production systems. **The overall objective of this research is to determine how interactions between cover crops and P fertilizer management impact P loss, P use efficiency, crop yield, and net return.** The addition of a cover crop and changes in P fertilizer management can also influence N uptake, cycling, and loss. Therefore, **the secondary objective of this research is to determine how interactions of cover crop use and P fertilizer management impact N loss and N use efficiency.** This research will improve our understanding of how cover crop use impacts the 4R stewardship recommendations for P fertilizer.

Introduction and Justification

A key component of the 4R stewardship for P is minimizing P loss to surface water. Phosphorus inputs to surface waters promote algae growth, which can in turn decrease dissolved oxygen, trigger fish kills, and increase drinking water treatment costs (Correll, 1998). Furthermore, excess P inputs to surface water are cited as a primary cause of harmful algal blooms (HABs) (Hudnell, 2010; Pearl, 2008). Unfortunately, effects of P loss to surface water are not uncommon and can impact human health. From 2010 through 2013, there were 67 lakes in the state of Kansas with HABs, impacting over 20% of the state waters. In 2011 and 2012, there were 17 cases of human illness related to HABs in Kansas, two of which resulted in hospitalization (KDHE, 2013). These examples highlight the importance of developing P management practices that minimize loss to surface water.

Effects of P placement and timing on P loss and crop yield

Research studies have shown that placing fertilizer below the soil surface can reduce P loss. Kimmell et al (2001) found that subsurface placement of P fertilizer in no-till systems reduced dissolved and total P losses by 75 and 30% respectively. In a larger field-scale study, Zeimen et al. (2009) found that P losses from subsurface placement of P fertilizer were less than or equal to surface broadcast fertilizer depending on the year and location of the study. Similar results have been found in numerous rainfall simulation studies, showing that when fertilizer is applied at the same time, subsurface placement of P fertilizer reduces P loss compared to surface

broadcast (Baker and Laflen, 1982; Mostaghimi et al., 1988). Decreased contact between runoff and the fertilizer source is a primary factor contributing to the reduced P loss from sub-surface P applications.

The timing of fertilizer application relative to intense rainfall and runoff has a strong influence on P loss from surface-applied fertilizers. Recent summaries of literature have found that P applications during times of the year when runoff is likely will increase the risk of P loss (Vadas et al., 2011; Vadas et al., 2008; Sims and Kleinman 2005). Increased P losses from surface applied fertilizers during periods of high rainfall have also been observed in large watershed-scale studies (Richards et al., 2010). The general recommendation is to plan fertilizer applications for times of the year when rainfall, and hence runoff, is not likely.

Although the timing and placement of P fertilizer can have significant impacts on P loss, the impacts on crop growth are less substantial. Several studies show that placement of P fertilizer does not influence soybean yield (Borges and Mallarino, 2000; Schawb et al., 2006; Edwards et al., 2013). Effects of P fertilizer placement for no-till corn production are less consistent, with a few studies showing some advantage to starter (2 in. to the side and 2 in. below the seed) placement when soil test is low (Schawb et al., 2006; Edwards et al., 2013) and other studies showing no difference in corn yield for broadcast vs sub-surface placement (Bordoli and Mallarino, 2000; Fernandez and White, 2012). Furthermore, fall-broadcast P is equally effective for increasing corn and soybean growth compared to spring broadcast (Mallarino et al., 2009; Bundy et al., 2005).

Because of the lack of consistent yield response to differences in placement and timing of P fertilizer, producers often select their placement and timing methods based on economic or management factors. Fall broadcast P fertilization is particularly advantageous because fertilizer prices tend to be lower, labor and equipment are more available, and it does not interfere with the timeliness of planting (Mallarino et al., 2009). In general, fall broadcast P applications are faster and simpler compared to a spring sub-surface P application.

The seasonal trend in rainfall for the central plains region is generally high in spring and summer, with less precipitation in fall and winter months (Figure 1). Based on this rainfall pattern, the optimal time to surface-apply P fertilizer would be in fall (e.g., November), prior to when soils freeze and when there is a relatively low risk of P loss directly from the fertilizer. **However, this method and timing has not been compared to the currently recommended BMP of sub-surface P application in spring.** It is essential to determine the difference in P loss between these methods if the primary reason for recommending one over the other is to reduce P loss.

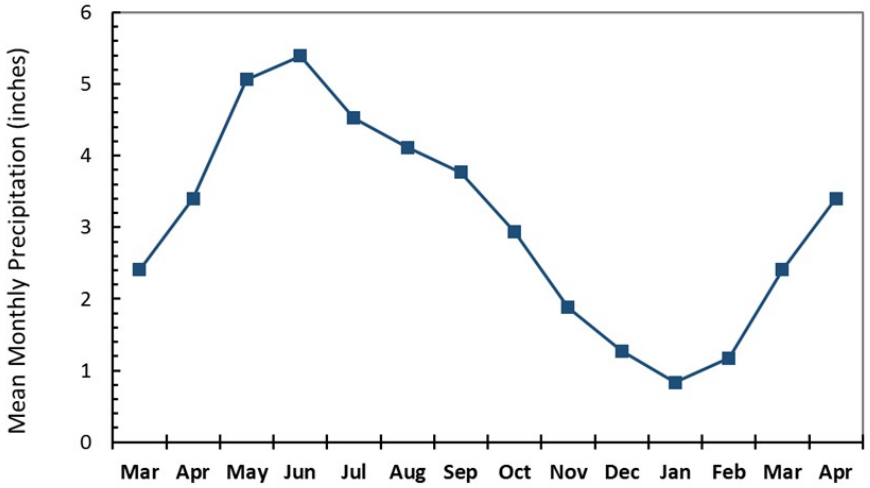

Figure 1. Thirty-year (1981-2010) mean monthly precipitation for North East Kansas. Seasonal trend is typical for precipitation patterns in the Central Plains region of the US.

Although shifting the time of fertilizer application to periods of low rainfall may decrease P loss from surface applied fertilizers, the fertilizer still remains on the soil surface where it is more susceptible to loss than sub-surface applied fertilizers. Furthermore, surface-applied fertilizers increase the stratification of P in no-till soils, thereby increasing the soil test P concentration in the surface soil (Fernandez and Schaefer, 2013). The increased soil test P could result in increased concentrations of dissolved and particulate P transported in runoff (Sharpley, 1995). Therefore, additional BMPs may still be needed to control P losses from fall broadcast P fertilizer applications.

Effects of cover crops on P loss and crop yield

The use of winter cover crops is a promising method to reduce P loss from fall, surface-applied P fertilizers. Cover crops can potentially increase infiltration, and hence reduce runoff and nutrient loss as a result of decreased soil moisture, improved soil structure, and increased residue cover (Danby 1998; Blanco-Canqui et al., 2011, 2012). Although reduced P loss is an often cited advantage to cover crop use (Sharpley and Smith, 1991; Danby et al., 2001), few studies have been conducted to quantify cover crop impacts on P loss. The few studies that have measured cover crop impacts on P loss have been conducted with rainfall simulation shortly following manure applications (Kleinman et al., 2005; Kovar et al., 2011; Adeli et al., 2013). Results from these studies can indicate trends for P loss from manure applied-soils, but are difficult, if not impossible, to extrapolate to field scale conditions using fertilizer applications due to limitation of the experimental methodology. Comprehensive cover crop effects on P loss must be studied using multi-year, field scale projects with natural rainfall because cover crop effects on runoff and P loss will change throughout the year as a function of the cover crop growth. **We need field-scale data to document the impact of cover crops on P loss before we can make recommendations for their use as a BMP.**

Although cover crops may have a positive impact on water quality, their impact on crop yield, and therefore nutrient uptake and fertilizer use efficiency, can be variable. Cover crops can

have a negative impact on crop yield due to excessive water use. Cover crop impact on grain yield is minimal during years with adequate moisture (Arnett, 2010), however, we have documented a 27% reduction in soybean yield after a rye cover crop during drought years (Roozeboom, 2013, unpublished data). The impact of cover crops on water availability can be controlled by proper timing of cover crop termination (NRCS 2013).

Cover crops can also impact crop yield due to changes in nutrient cycling and availability. Although cover crops that produce high C:N residues can be planted ahead of soybean without negative effects on yield, they can decrease corn or grain sorghum yields unless additional N fertilizer is supplied (Reinbott et al., 2004; Vyn et al., 2000). Therefore, cover crops that producer lower C:N residues are generally preferred prior to corn. A meta-analysis of 36 peer-reviewed papers indicated that corn yields following cover crops were on average equal to or greater than without cover crops (Miguez and Bollero, 2005). Although cover crops can provide N to the subsequent corn crop (Miguez and Bollero, 2005), yield advantages for corn following cover crops have also been attributed to a rotational effect (Andraski and Bundy, 2005). Similar results have been recorded for grain sorghum after summer and winter cover crops in a multi-year experiment located less than one mile from the proposed experimental site (Roozeboom, unpublished data).

Summary of justification

As discussed above, both fertilizer timing and placement can have large impacts on P loss. Currently recommended BMPs have focused on sub-surface fertilizer placement as the recommended method for reducing P loss. In contrast, economic and farm management factors may encourage producers to use surface-broadcast P applications in the fall. Weather patterns typical of the Great Plains indicate that a shift to fall applications may also reduce P loss from surface applied P fertilizer compared to spring surface applications. **We need field-scale data comparing P loss from fall surface-applied P fertilizer to sub-surface spring-applied P fertilizer so we can make accurate recommendations for the right timing and placement combinations to minimize P loss.**

Furthermore, cover crop use may protect against potential increased P loss associated with fall surface-applied fertilizers, thereby allowing producers wider flexibility in fertilizer management while maintaining minimal P loss. However, **we need more information about the effects of cover crops on P loss and the interaction between cover crops and P fertilizer management.** Because cover crops can also impact crop yields, we need comprehensive analysis that includes cover crop and fertilizer management impact on multiple agronomic, environmental, and economic factors, including grain yield, N uptake and use, and P uptake and use, input costs, gross return, net return, N and P loss, sediment loss, and runoff volume. Producers and fertilizer dealers recognize the value in this information, as indicated in the accompanying letters of support from the Kansas Soybean Commission and the Kansas Agribusiness Retailer's Association (attached).

Research Objectives

Our specific research objectives are as follows:

1. Determine the agronomic, environmental, and economic impacts of fall surface-applied P fertilizer compared to currently recommended BMPs for P fertilizer (spring injected P) and no P fertilizer application in corn-soybean rotations.
2. Determine the agronomic, environmental, and economic effects of winter cover crops in corn-soybean rotations.
3. Determine the interaction of fertilizer management and cover crop use on agronomic, environmental, and economic measures in corn-soybean rotations.

We will accomplish these objectives by measuring the effects of the following treatments on crop yield, runoff, sediment loss, N and P loss, P uptake, P fertilizer use efficiency, N uptake, N fertilizer use efficiency, costs, gross returns, and net returns:

1. No P fertilizer applied, no cover crop
2. No P fertilizer applied, with cover crop
3. Fall broadcast P fertilizer, no cover crop
4. Fall broadcast P fertilizer, with cover crop
5. Spring injected P fertilizer, no cover crop
6. Spring injected P fertilizer, with cover crop

Due to site limitations, we are restricted to only six treatments. Therefore we have selected these treatments as systems representing low-cost conventional production practices (fall broadcast P fertilizer) contrasted with currently the recommended BMP (spring injected P fertilizer) and a potentially recommended BMP (cover crop use). The control will provide essential information on crop response to P fertilizer and P losses in the absence of P fertilization.

Procedure

The study will be conducted at the Kansas Agricultural Watershed (KAW) Field Laboratory, located on the KSU Agronomy Department's Ashland Bottoms research farm near Manhattan, Kansas. The KAW Field Lab is a set of 18 watersheds ranging from 1.1 to 2 acres in size that we are developing to study effects of agricultural management on water quality and quantity (Figure 2). Each watershed will be delineated by a combination of terraces, soil berms, and grassed waterways.

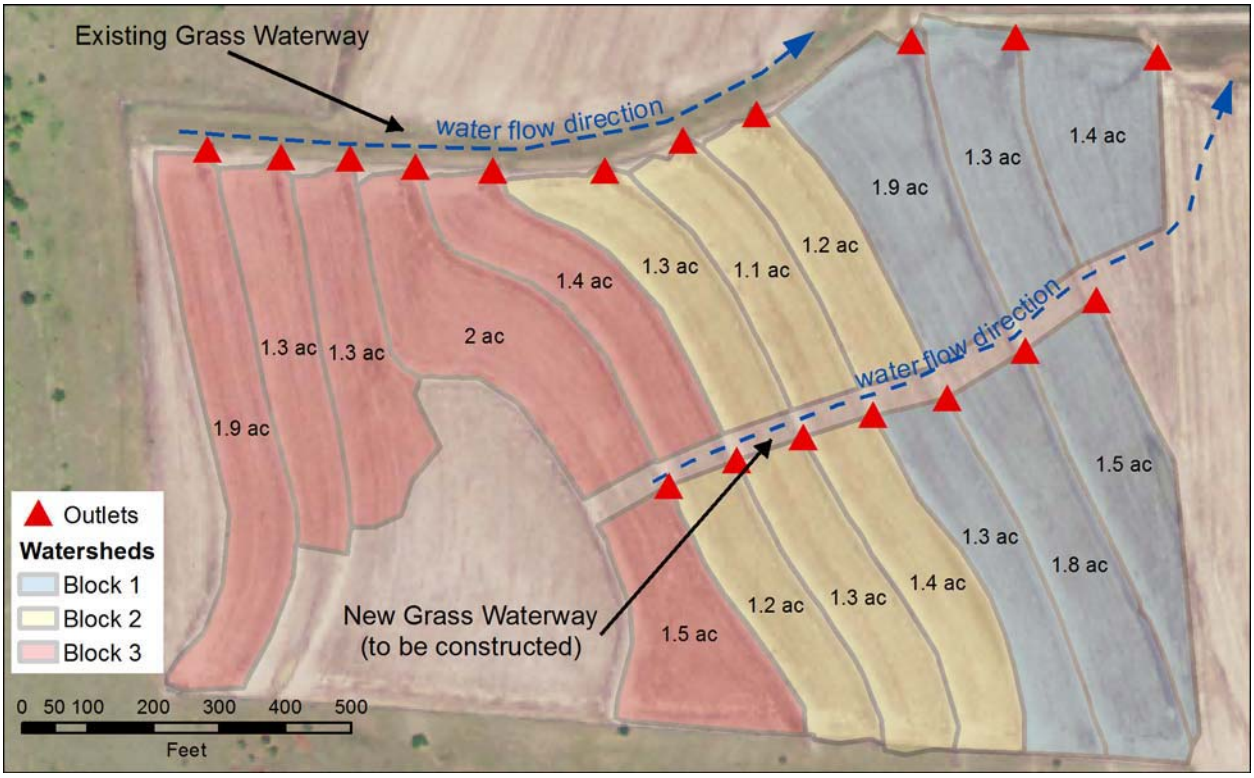

Figure 2. Watershed map for proposed study. Watershed boundaries will be defined by terrace ridges, soil berms, and natural changes in slope that direct flow toward terrace outlets.

Cover crop and P fertilizer treatments will be applied to the watersheds in a 2 x 3 factorial with three replications. The cover crop treatment will have two levels (with and without cover crop) and P fertilizer treatments will have three levels (no P fertilizer, fall surface-applied P fertilizer, and spring injected P fertilizer).

The cropping system will be no-till with soil disturbance only during planting or fertilizer application. Phosphorus fertilizer application rates will be 50 lbs P_2O_5/ac/yr for all treatments receiving P. This is the rate recommended by the KSU build and maintain fertilizer recommendations for this site (Table 1). Phosphorus will be applied to treatments 3 and 4 (fall broadcast) as diammonium phosphate, surface broadcast with a calibrated drop spreader (Barber spreader). Application timing will be what we consider the best possible management for fall applied fertilizer for this region, which is application after November 1 with greater than 3 days before the next forecasted precipitation. Phosphorus will be applied to treatments 5 and 6 (spring injected) as ammonium polyphosphate applied at the time of planting in a 2x2 placement with the planter. Urea ammonium nitrate (UAN) will applied sub-surface with a shallow minimal-disturbance disk applicator on 15 inch centers to all plots prior to planting corn to equal 130 lbs N/ac based on KSU soil fertility recommendations (Table 1). Treatments 1 and 2 will receive 130 lb N/ac as UAN, treatments 3 and 4 will receive 110 lbs N/ac as UAN, and treatments 5 and 6 will receive 115 lb N/ac as UAN. Standard, uniform herbicide, insecticide, and fungicide treatments will be applied during grain crop production. Corn and soybean will be no-till planted on the contour in 30-inch rows. Prior to harvest, whole plant samples will be

collected from three ten-foot row lengths evenly distributed in each plot (30 row-feet total) for determination of total nutrient uptake. Crop yield for each plot will be measured with a well-calibrated yield monitor on a combine. Sub-samples of grain will be collected to determine nutrient content and nutrient removal.

Table 1. Soil analysis, yield goals, and fertilizer recommendations. Numbers in parenthesis represent 95% confidence intervals (*n*=4). Nutrient applications are based on KSU nutrient recommendations (Leikam et al., 2003).

	Yield	Soil Analysis				Nutrient Application	
Crop	Goal (bu ac^{-1})	OM (%)	pH	M3 P (mg kg^{-1})	K (mg kg^{-1})	N (lb ac^{-1})	P_2O_5 (lb ac^{-1})
Corn	120	1.9 (±0.1)	5.7 (±0.1)	16 (±5)	375 (±23)	130	50
Soybean	45	1.9 (±0.1)	5.7 (±0.1)	16 (±5)	375 (±23)	0	50

Cover crop will differ depending on crop sequence. Cereal rye has been documented to suppress winter annual weeds and provides a layer of weed-suppressing and moisture conserving mulch when grown before soybeans. Rye will be no-till drilled into the corn stubble as soon as possible after corn harvest. A multi-species cover crop mixture consisting of brassica and legume species will be over-seeded into standing soybeans in late August or early September (in the early stages of senescence). Cover crops will be terminated with herbicide prior to planting the next crop according to NRCS and RMA guidelines (NRCS 2013). Prior to herbicide application, cover crop biomass will be harvested from each plot in three quadrants (3 ft x 3 ft areas) to determine total growth and nutrient uptake. Non-cover crop treatments will be maintained weed-free during the non-cropping season with the use of standard herbicide treatments.

Runoff from each plot will be measured with a 1.5 ft H-flume equipped with a 4.5 ft level confined approach. Water depth in the H-flume will be continuously measured with an automated bubble-type pressure transducer attached to an ISCO 6700 series automated water sampler and integrated data logger. This instrumentation is the most accurate method for measuring field runoff and can measure flows between 0.001 and 5.33 ft^3/s (CFS). The automated water sampler will be set to collect flow-weighted composite water samples during runoff events. Runoff will be collected from each sampler within 24 hours following the end of precipitation events. This method of runoff collection and sampling has been successfully used for nutrient load calculations on similar studies (Zeimen et al., 2009; Sweeney et al., 2012). Three automated tipping bucket rain gauges will be set up to collect precipitation data across the 30 ac site. In addition to the rain gauges on site, a fully-equipped Kansas Mesonet weather station is located approximately 2000 ft. from the site and records air temperature, soil temperature, solar radiation, relative humidity, wind speed, wind direction, and precipitation.

Two composite soil samples will be collected annually at 0-2 and 2-6 inches from each plot. Soil samples will be analyzed for NO_3-N, Mehlich 3 P, ammonium acetate extractable K, pH, lime requirement, total N, total C, and total P. Total N and total C will be determined by combustion. Total P will be determined by salicylic-sulfuric acid digestion. Other parameters will be determined by standard soil testing procedures. Water samples will be analyzed for total suspended solids (determined by filtration); nitrate, ammonium, and dissolved P

(determined colorimetrically following filtration through a 0.45 μm filter); and total N and total P (determined by persulfate digestion). Grain and plant tissue samples will be analyzed for N, P, and K by sulfuric acid/hydrogen peroxide digest and for Ca, Mg, Zn, Fe, Cu, Mn, and SO_4 by the nitric-perchloric digest method. All analysis of soil, plant, and water samples will be conducted by the KSU Soil Testing Laboratory.

Crop uptake and removal of N and P will be computed for each crop (including cover crops) within each treatment. Phosphorus and N use efficiency will be calculated by methods listed below depending on the nutrient in question. All five methods will be used to assess P use efficiency. However, because we will not have a treatment without N application, only methods 3 through 5 will be used to assess N use efficiency.

1. Fertilizer recovery efficiency - (increase in P removal)/(fertilizer application rate), where P removal is grain yield multiplied by P concentration in grain and the increase is the P removal of the fertilized treatment minus the control (no fertilizer).
2. Agronomic nutrient use efficiency – (increase in crop yield)/(fertilizer application) where the increase in yield is the yield of the fertilized treatment minus the control yield.
3. Partial nutrient balance – (nutrient removal)/(nutrient application rate).
4. Partial productivity factor – (grain yield)/(fertilizer application rate)
5. Environmental efficiency – (nutrient removal by crop)/(nutrient loss in runoff)

Loss of total P, dissolved P, total N, nitrate, ammonium, and sediment will be computed by multiplying the flow-weighted event-based concentration by the total volume of runoff for the event.

Treatment effects on crop yield, nutrient uptake, nutrient removal, nutrient use efficiencies, nutrient loss, sediment loss, and runoff volume will be analyzed by analysis of variance using α=0.05. Treatment comparisons will be made using contrast statements for planned comparisons. Event-based nutrient loss will be analyzed using repeated measures ANOVA.

Costs, gross returns and net returns will be calculated using experimental input levels and resulting yields, and commodity prices for each of the each of the watershed treatments using an enterprise budgeting format. The cost associated with each treatment that reduces total sediment, nitrogen and phosphorus will also be calculated to determine the economic feasibility of each treatment as well as the cost of reducing environmental runoff. This analysis will help select cost-effective watershed management practices to reduce soil, nitrogen, and phosphorus losses from cropland.

Project Duration

The proposed project will begin in October 2014 with the planting of the first cover crop and will continue for five monitoring seasons until September of 2019 with harvest of the final grain crop.

Facilities and Equipment

The KSU Agronomy department owns the land required for the research project at the Ashland Bottoms research farm. The farm also owns the required tractors and implements for planting,

harvesting, and other field operations. Soil, plant tissue, and water samples will be analyzed in-house at the Agronomy Dept. Soil Testing Lab.

Collaboration with On-going Activities and Industry Involvement

The Kansas State Agricultural Experiment Station (KAES) is providing $110,000 to purchase additional equipment (e.g., H-flumes), make necessary site preparations (e.g., terrace maintenance and grading, water way maintenance and construction, etc.), and install field equipment during the spring and summer of 2014 (see attached letter of support). The Agronomy Department owns 18 automated water samplers (valued at approximately $90,000) that will be used to collect the water samples from each watershed. We have submitted requests for support from the Kansas Fertilizer Research Fund and the Kansas Corn Commission to leverage the 4R funds (see budget section). We will collaborate with industry on our extension and outreach plan (see letters of support from Kansas Agribusiness Retailer's Association and the Kansas Soybean Commission).

Expected Outcome

This project will help producers understand the impact of cover crops and fertilizer management on crop yield, water quality, and net return. We expect that winter cover crops will reduce the runoff and P loss from corn-soybean cropping systems. Cover crops will have a minimal impact on water availability for the succeeding corn or soybean crop because the increased water use will be compensated by the reduced water loss in runoff. We expect that fall-broadcast P fertilizer applications will have higher P loss compared to P fertilizer injected into the soil at planting. However, we expect that the fertilizer management will not impact P loss when winter cover crops are planted.

Extension and Outreach

Outreach efforts are key to the successful adoption of any new technology, cultivar, or production practice. Growers are profit driven and will adopt new practices and technology only if there is sufficient evidence that they are cost effective and profitable. Towards this goal, research findings from this project will be showcased at field days, workshops and other grower meetings.

Multiple delivery methods will be employed to disseminate the findings of this project. Annual results will be made available to the public in the form of hand-outs, articles, news releases E-newsletters and on the project web site. These materials will also be disseminated through the Kansas Agribusiness Retailer's Association, Kansas Corn Commission, and the Kansas Soybean Commission. Summary data will be used to prepare traditional extension publications in year 5. Peer-reviewed publications and presentations at national and international conferences will provide open access to our data.

Each year the research site will be used for public field tours and demonstration purposes. Participating researchers will cooperatively design and deliver presentations during these events. Potential topics include terrace maintenance, cover crops, and nutrient management. Producers will be able to engage in interactive discussion at on-site visits. Presentations will also be prepared as requested for county extension and NRCS programs.

List of Deliverables

1. Research publication discussing cover crop impacts on runoff, sediment, and nutrient losses (Year 3).
2. Research publication describing cover crop and fertilizer management impacts on crop yield, nutrient uptake, and nutrient use efficiency (Year 4).
3. Research publication describing the impact of cover crops and fertilizer management interactions on nutrient loss and environmental nutrient use efficiency (Year 5).
4. Research publication describing the economic feasibility of each treatment and the cost of reducing P loss associated with each BMP (Year 5).
5. Extension publication describing the effects of cover crops on runoff, sediment, P and N loss (Year 3).
6. Extension publication describing the optimal timing and placement options for P fertilizers in no-till agriculture (Year 5).
7. Extension publication describing the costs of cover crop and fertilizer management BMPs relative to the expected impacts on runoff, sediment, P, and N loss (Year 5).
8. Five years of research data submitted to the 4R database, including information on nutrient loss, nutrient uptake, crop yield, and nutrient use efficiency for corn-soybean cropping systems.

Project Management

Nathan Nelson will be the lead PI overseeing all aspects of the project. He will manage budgets, supervise and mentor the research assistant, coordinate data collection and organization, and ensure quality control on data. He will lead quarterly project meetings and report results to IPNI (deliverable 8). Kraig Roozeboom will assist with crop and cover crop planting, management, and harvest. Phil Barnes will provide technical expertise and assist with water quality monitoring. Peter Tomlinson will coordinate extension activities and take the lead on extension publications (deliverable 5, 6, and 7). Jeffery Williams will conduct the economic analysis and be responsible for related publications (deliverable 4). Gerard Kluitenberg will assist with instrumentation of the site and provide expertise related to site hydrology. The research assistant will conduct field activities, collect water, soil, and plant samples, and supervise the hourly workers assisting with these activities. The research assistant will be enrolled as a graduate student and use the project as the primary focus of his/her thesis. The research assistant will collect and organize data, analyze data, present data and develop research publications under the mentorship of Dr. Nelson and the co-PIs on the project (deliverables 1, 2, and 3).

Time Line and Milestones

Table 3. Time line and milestones during the project (Q1, Q2, etc. represent the quarter of each year in which the milestone will be accomplished. P represents a publication).

	2014				2015				2016				2017				2018				2019			
Milestone	1Q	2Q	3Q	4Q	1Q	2Q	3Q	4Q	1Q	2Q	3Q	4Q	1Q	2Q	3Q	4Q	1Q	2Q	3Q	4Q	1Q	2Q	3Q	4Q
Finialize plans for site	X	X																						
Modify site to define watershed boundaries		X	X																					
Install runoff monitoring			X																					
START OF PROJECT FUNDING				**X**																				
Monitor runoff and nutrient loss				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Plant and grow cover crops				X	X			X	X			X	X			X	X			X	X			
Plant and grow soybean						X	X							X	X							X	X	
Plant and grow corn										X	X							X	X					
Prepare and submit annual								X				X				X				X				X
Host annual field day at location							X				X			X				X					X	
Present data at winter extension									X				X				X				X			
Develop extension fact-sheets												X				X				X				
Extension Publication - Cover																P								
Extension Publication - P																							P	
Prelim. Economic Analysis																			X					
Final Economic Analysis																							P	
Extension publication - economic analysis of BMPs																							P	
Present nutrient loss and								X	X			X				X	X			X			X	
Research Publication - cover crop impacts on water quality.																P								
Research Publication - treatment impacts on Yield and nutrient																				P				
Research publication - fertilizer and cover crop impacts on water quality and environmental NUE																							P	
END OF PROJECT FUNDING																							X	
Submit final report																								X

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