**Minimizing Phosphorus Loss with 4R Stewardship and Cover Crops**

Nelson, N.O., K.L. Roozeboom, P. Tomlinson, P.L. Barnes, J.R. Williams, and G.J. Kluitenberg

Project dates: October 2014 to September 2019

**Annual Report – February 15, 2018**

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. We have established a replicated small watershed study to achieve this objective. The study site is at the Kansas Agricultural Watershed (KAW) Field Laboratory near Manhattan, KS. The KAW field lab consists of 18 small watersheds (1.2 to 1.5 ac in size) equipped with automated runoff monitoring equipment. The following treatments have been applied to the watersheds (replicated 3 times):

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

**Field activities during the reporting period (Jan. 1, 2017 to Dec. 31 2017)**

Cover crop biomass was harvested on April 17, prior to corn planting on April 24 and cover crop termination on April 25th. Spring injected P was supplied at planting. The corn biomass was harvested on Sept. 9th and grain was harvested on Sept. 21st. A cover crop mix of Rye and triticale was planted on Sept. 21st and 22nd. Fall broadcast fertilizer treatments were applied on November 28, 2017.

The 2016-2017 water year was dryer than prior years, with only 3 inches of total runoff occurring in 14 runoff events, only seven of which had enough runoff to analyze. Dates and methods of collection are contained in the methods sections of the attached conference proceedings along with additional details on field operations.

**Summary of results**

Please refer to the attached conference proceedings for a summary of the results during the reporting period.

**Presentation of results**

Results from the second and third years of the study were presented at the conferences listed below. Copies of these presentations are available on the project web site, http://www.ksu.edu/kaw.

Carver, R.E., N.O. Nelson, G.J. Kluitenberg, K.L. Roozeboom, and P.J. Tomlinson. 2017. Fertilizer management and cover crop effects on phosphorus use efficiency, environmental efficiency and crop yield. North Central Extension-Industry Soil Fertility Conference. Nov. 15-16, 2017. Des Moines, IA.

Nelson, N.O., R.E. Carver, K. Roozeboom, P. Tomlinson, and G. Kluitenberg. 2017. Improving water quality with cover crops and fertilizer management during transition to no-till production.Governor's Conference on the Future of Water in Kansas. Nov. 8-9, 2017. Manhattan, KS.

Nelson, N.O., R.E. Carver, K. Roozeboom, G. Kluitenberg, P. Tomlinson, and J.R. Williams. 2017. Cover Crop Impacts on Runoff Hydrographs and Edge-of-Field Surface Water Quality. ASA-CSSA-SSSA International Annual Meeting. Oct. 22-25, 2017. Tampa, FL.

Carver,R.E., N.O. Nelson, G. Kluitenberg, K. Roozeboom, P. Tomlinson, and J.R. Williams. 2017. Environmental and Agronomic Efficiency of Phosphorus in No-Tillage Corn-Soybean Rotation with Cover Crops. ASA-CSSA-SSSA International Annual Meeting. Oct. 22-25, 2017. Tampa, FL.

Nelson, N.O., R.E. Carver, K. Roozeboom, G. Kluitenberg, P. Tomlinson, J. Williams, and D. Able. 2017. Phosphorus management and cover crop impacts on water quality and environmental efficiency in no-till soybean. 4R Nutrient Stewardship Summit, June 12-13, 2017, Minneapolis, MN.

Nelson, N.O. 2017. 4Rs of N and P (Right Source, Rate, Time, Placement). 2017 Agricultural Equipment Technology Conference, American Society of Agricultural and Biological Engineers. February 13-15, 2017. Louisville, KY.

Nelson, N.O., K. Roozeboom, G. Kluitenberg, P. Tomlinson, J. Williams, D. Able, and R.E. Carver. 2017. Exploring Management Options for Reducing Phosphorus Loss. The Fertilizer Institute Annual Meeting. February 6-8, 2017. Scottsdale, AZ.

**Plans for the 2018 Growing Season**

Soybean will be planted following cover crop termination in May 2018, at which time the remaining fertilizer treatments will be applied. Cover crop biomass and nutrient uptake will be measured at the time of termination. Soybean growth will be monitored throughout the 2018 growing season. Runoff measurement and sampling will continue throughout the season as was done for 2017. Soybean biomass will be measured at maturity along with grain yield, nutrient uptake, and nutrient removal. The fifth and final year of the study will begin following soybean harvest when cover crops will be direct seeded into soybean residue.

**Attachments**

The following conference proceedings are attached to this report. These proceedings summarize the water quality, nutrient uptake and removal, and nutrient use efficiency data from the 2015-16 and 2016-17 water years (second and third years of the study).

Nelson, N.O., R.E. Carver, K.L. Roozeboom, P.J. Tomlinson , and G.J. Kluitenberg. 2018. Fertilizer management effects on phosphorus concentrations in runoff from no-till corn and soybean. In Proc. of the Great Plains Soil Fertility Conf., Denver, CO. March 6-7, 2018. International Plant Nutrition Institute (IPNI), Brookings, SD.

Carver, R.E., N.O. Nelson, G.J. Kluitenberg, K.L. Roozeboom, and P.J. Tomlinson. 2018. Impacts of cover crops on phosphorus loss. In Proc. of the Great Plains Soil Fertility Conf., Denver, CO. March 6-7, 2018. International Plant Nutrition Institute (IPNI), Brookings, SD.

Carver, R.E., N.O. Nelson, G.J. Kluitenberg, K.L. Roozeboom, and P.J. Tomlinson. 2017. Fertilizer management and cover crop effects on phosphorus use efficiency, environmental efficiency and crop yield. North Central Extension-Industry Soil Fertility Conference. Nov. 15-16, 2017. Des Moines, IA.

# FERTILIZER MANAGEMENT EFFECTS ON PHOSPHORUS CONCENTRATIONS IN RUNOFF FROM NO-TILL CORN AND SOYBEAN

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## ABSTRACT

Elevated P concentrations in runoff water from agricultural fields can induce algal blooms, eutrophication, and associated water quality degradation. Fertilizer management, such as timing and placement of P fertilizers, can influence the P concentration in runoff water, but additional information is needed from field-scale experiments to determine effects of fertilizer management systems on P loss. The objective of this study was to determine the effects of fall broadcast and spring injected fertilizer management systems on P concentrations in runoff water from a no-till corn-soybean cropping system. Natural runoff was monitored from 18 1.2-ac watersheds managed in a no-till corn-soybean cropping system at the Kansas Agricultural Watershed (KAW) field laboratory during the 2015/16 and 2016/17 water years. Treatments were applied in a 3x2 factorial with three levels of P fertilizer management (no P, fall broadcast P, spring injected P; CN, FB, and SI respectively) and two levels of cover crop (no cover and with cover). Flow-weighted composite water samples were collected from each runoff event and analyzed for total P, dissolved reactive P, and particulate P concentrations. Spring injected fertilizer management reduced dissolved P and total P concentrations by 70% and 40% respectively during the months prior to SI fertilizer application. Following SI fertilizer application, the dissolved P and total P concentrations in runoff from SI and FB treatments were relatively similar up until FB fertilizer application. Runoff from the CN treatment had the lowest dissolved P and total P concentrations. Results from this study indicate that subsurface P fertilizer application remains the best fertilizer management option for minimizing P concentrations in agricultural runoff.

## INTRODUCTION

Minimizing phosphorus (P) loss from agricultural lands is essential to developing sustainable agricultural systems. Phosphorus is an essential nutrient for plant production as well as being critical for human and animal health. However, P inputs to surface waters promote algae growth, eutrophication, and harmful algal blooms. These water quality problems can decrease dissolved oxygen, release toxic compounds, trigger fish kills, and increase drinking water treatment costs (Correll, 1998; Hudnell, 2010; Paerl, 2008).

The timing and placement of P fertilizer, which can be used to reduce P loss from agriculture, are critical components of 4R nutrient management (selecting the Right source, Right rate, Right time, and Right place. Several studies have found that subsurface placement of P fertilizer reduces P loss in runoff water compared to surface broadcast fertilizer (Baker and Laflen, 1982; Mostaghimi et al., 1988; Kimmell et al., 2001; Zeimen et al., 2006). These studies all compare changes in placement at the same time, generally in the spring prior to planting. The timing of fertilizer application relative to intense rainfall and runoff has a strong influence on P loss from surface-applied fertilizers. Therefore, the general recommendation is to plan surface P fertilizer applications for times of the year when rainfall, and hence runoff, is not likely. For much of the Great Plains, the time of highest likelihood for runoff is in the spring and the lowest chance for runoff is in late fall. Therefore, surface broadcast P applications should be made during the fall.

The objective of this study was to determine the effects of fall broadcast and spring injected fertilizer management systems on P concentrations in runoff water from a no-till corn-soybean cropping system.

## MATERIALS AND METHODS

The experiment was conducted at the Kansas Agricultural Watersheds (KAW) field laboratory located near Manhattan, KS. The KAW field lab consists of 18 watersheds, with average area of 1.2-ac, equipped with 1.5-ft H-flumes and ISCO 6700 series automated water samplers to monitor edge-of-field runoff. The soils are mapped as eroded Smolan silty clay loams with 3 to 7% slopes. The treatment structure is a 3×2 factorial with three levels of P fertilizer management (control, fall broadcast, and spring injected; CN, FB, and SI respectively) each with two levels of cover crop (no cover crop and with cover crop) arranged in a randomized complete block design with three replicates. The site was under conventional till management until the study was initiated in November 2014 and planted to corn in April 2015. Because the first water year (October 2014 to September 2015 was a transition from conventional till to no-till, we present results from only the second and third years of the study (2015/16 and 2016/17 water years).

A winter wheat cover crop was seeded in cover crop treatments with a no-till drill on 22 September, 2015 following corn harvest. Diammonium phosphate was applied to FB treatments with a tractor-mounted drop spreader on 12 November, 2015 at 54 lb $P_2O_5$ $ac^{-1}$. Cover crop was terminated with herbicide on 6 May, 2016 and soybean was planted with a no-till planter on 6 June, 2016. All SI treatments received 56 lb $P_2O_5$ $ac^{-1}$ as ammonium poly-phosphate in a 2x2 placement at planting. The CN treatment did not receive P fertilizer.

A triticale and rapeseed mix cover crop was seeded in cover crop treatments with a no-till drill on 16 October, 2016 immediately following soybean harvest. Diammonium phosphate was applied to FB treatments with a tractor-mounted drop spreader on December 2, 2016 at 56 lb $P_2O_5$ $ac^{-1}$. Corn was planted with a no-till planter on 24 April, 2017 and cover crops were terminated with herbicide within two days following corn planting. All SI treatments received 53 lb $P_2O_5$ $ac^{-1}$ as ammonium poly-phosphate in a 2x2 placement at planting. Nitrogen was balanced between all treatments at 155 lb N $ac^{-1}$ with UAN applied with a disk-coulter injection unit within 3 days following planting. An additional 40 lb N $ac^{-1}$ was applied to all treatments on 12 June, 2017 (V8) with streamers. Although the target P application rates were the same for both FB and SI treatments, limitations in equipment calibration and operation caused slight differences in actual application rates between treatments as indicated above.

Water depth within the flumes was continuously monitored throughout the study with ISCO 730 series bubbler units. Event-based flow-weighted composite water samples were collected for each runoff event throughout the study, with one sub-sample collected for every 0.04 inches of runoff. Water samples were removed from the field within 24 hours after the end of the precipitation event and analyzed for total suspended sediment, total P, and dissolved P. Particulate P was determined as total P minus dissolved P.

Events with mean runoff less than 0.06 and 0.08 inches for the 2015/16 and 2016/17 water years respectively had an excessively high quantity of missing water samples and were therefore excluded from statistical analysis. Runoff and concentration data were transformed prior to statistical analysis with either log or square-root transformations as appropriate to satisfy the assumptions of normality of residuals. Statistical analysis was computed with SAS proc glimmix and the least square means were back-transformed for presentation in results. Data for this study were averaged across cover crop treatments because interactions between cover crop and fertilizer management were rarely significant.

## RESULTS AND DISCUSSION

Total P concentrations were greater in runoff leaving the FB fertilized treatment compared to the SI treatment prior to soybean planting in the 2015/16 water year (Figure 1). During this same time period, P concentrations in runoff from SI and CN treatments were similar for seven of the eight events. The total P concentration in runoff from the SI treatment increased significantly following the planting operation in June (i.e., the time of P application). Thereafter, the total P concentration in runoff water from the SI treatment was greater than or equal to that from the FB treatment. This trend continued into the 2016/17 water year until fertilizer was applied to the FB treatment in November 2016 (Figure 1). Total P concentrations in runoff from the FB treatment were greater than other treatments from November 2016 through mid April 2017. Following fertilizer application to the SI treatment on 20 April, 2017, the total P concentration in runoff water from the SI increased to nearly the same as from the FB treatment and remained similar to that of the FB treatment for the remainder of the year.

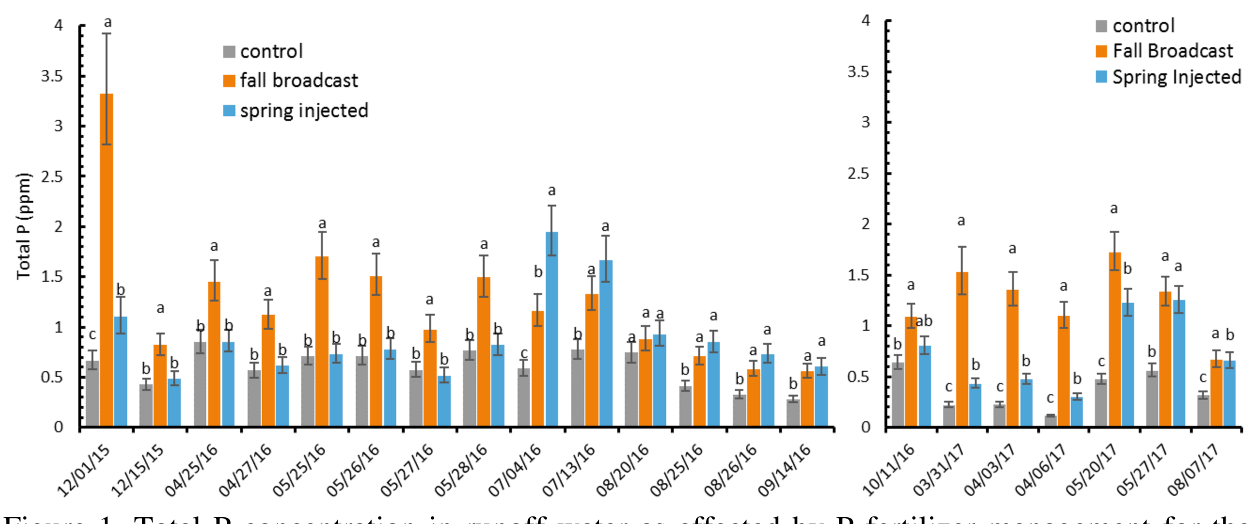


Figure 1. Total P concentration in runoff water as affected by P fertilizer management for the 2015/16 (left) and 2016/17 (right) water years. Letters above bars indicate significant differences within runoff event. Data are averaged across cover crop treatment.

Effects of fertilizer management on dissolved P concentrations in runoff were similar to what was observed for total P (Figure 2). However, treatment differences were typically greater. For example, prior to soybean planting in June 2016, the total P concentrations of runoff from the SI treatment were about 40% less than in runoff from the FB treatment whereas dissolved P concentrations in runoff from SI treatment were 70% less than from the FB treatment during the same time priod.

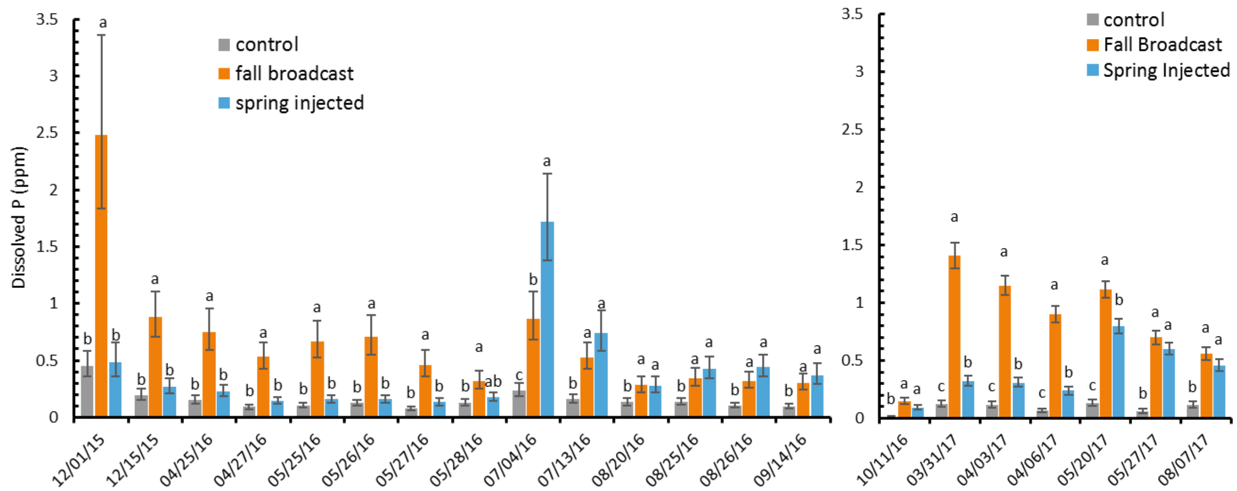


Figure 2. Dissolved P concentration in runoff water as affected by P fertilizer management for the 2015/16 (left) and 2016/17 (right) water years. . Letters above bars indicate significant differences within runoff event. Data are averaged across cover crop treatment.

Fertilizer management did not impact particulate P concentrations in runoff to the same extent that it impacted total P and dissolved P concentrations. Particulate P concentrations in runoff from the CN treatment were significantly less than the other treatments in only five of the 21 runoff events (12/01/15, 05/25/16, 03/31/17, 04/03/17, and 04/06/17; Figure 3).

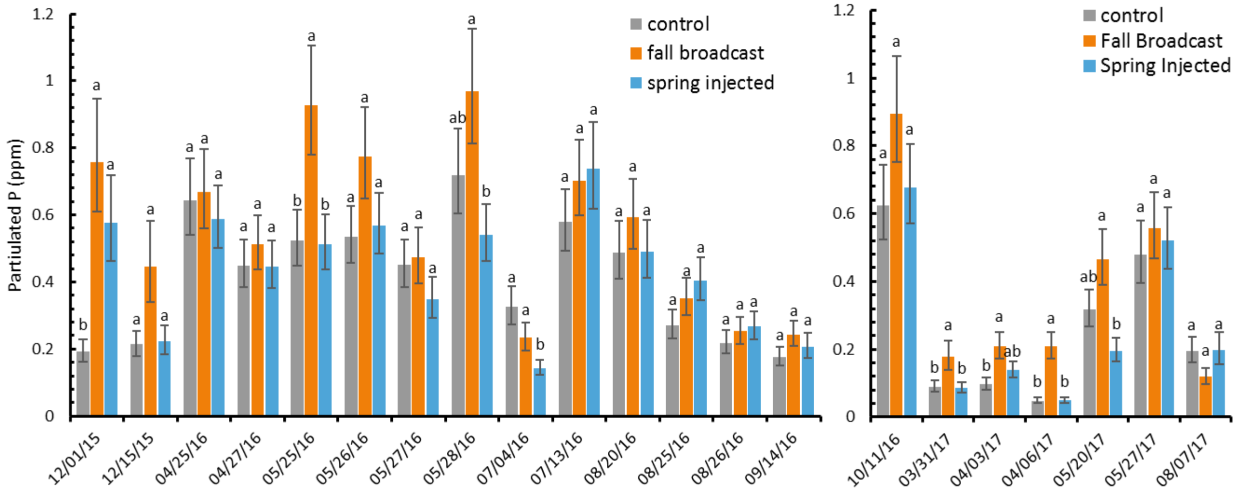

Figure 3. Particulate P concentration in runoff water as affected by P fertilizer management for the 2015/16 (left) and 2016/17 (right) water years. . Letters above bars indicate significant differences within runoff event. Data are averaged across cover crop treatment.

The primary effects of fertilizer application and fertilizer management were to increase dissolved P concentration in runoff events following the application of fertilizer. Fall broadcast fertilizer application tended to increase the dissolved P concentration in runoff more than the SI application and the effects tended to persist for a longer duration. Following SI fertilizer application there were fewer differences between P concentrations in runoff from the FB and SI treatments.

## Conclusions

These results indicate that spring subsurface placement of P fertilizer maintains lower dissolved P concentrations in runoff water compared to fall broadcast fertilizer application, which led to lower total P concentrations in runoff water. Therefore, subsurface P placement remains the best management practice for reducing P loss from agricultural fields, even if broadcast applications are made at times when runoff is reduced. This study will continue through one more rotation cycle to confirm trends observed thus far.

## ACKNOWLEDGEMENTS

This research is supported by the 4R Research Fund, Kansas Soybean Commission, Kansas Corn Commission, USDA-NRCS Grant #69-3A-75-17-32, the Kansas Agricultural Experiment Station, and the Kansas State University Department of Agronomy.

## REFERENCES

Baker, J., and J. Laflen. 1982. Effects of corn residue and fertilizer management on soluble nutrient runoff losses. Trans. ASAE 25:344-348.

Correll, D. 1998. The role of phosphorus in the eutrophication of receiving waters: A review. J. Environ. Qual. 27:261-266.

Hudnell, H.K. 2010. The state of US freshwater harmful algal blooms assessments, policy and legislation. Toxicon 55:1024-1034.

Kimmell, R.J., G.M. Pierzynski, K.A. Janssen, and P.L. Barnes. 2001. Effects of tillage and phosphorus placement on phosphorus runoff losses in a grain sorghum-soybean rotation. J. Environ. Qual. 30:1324-1330.

Mostaghimi, S., J. Flagg, T. Dillaha, and V. Shanholtz. 1988. Phosphorus losses from cropland as affected by tillage system and fertilizer application method. Water Resour Bull 24:735-742.

Paerl, H.W. 2008. Nutrient and other environmental controls of harmful cyanobacterial blooms along the freshwater-marine continuum. In: H.K. Hundell, editor, Cyanobacterial harmful algal blooms: State of the science and research needs. Springer Press, New York. p. 218-237.

Zeimen, M.B., K.A. Janssen, D.W. Sweeney, G.M. Pierzynski, K.R. Mankin, D.L. Devlin, D.L. Regehr, M.R. Langemeier, and K.A. Mcvay. 2006. Combining management practices to reduce sediment, nutrients, and herbicides in runoff. J. Soil Water Conserv. 61:258-267.

# Impacts of cover crops on phosphorus loss

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## ABSTRACT

Non-point source phosphorus (P) loss in surface runoff from agriculture is a major contaminant of surface waters. Therefore, agricultural management strategies that reduce P loss in surface runoff must be identified. The aim of this study was to determine the impacts of winter cover crops on total P, dissolved P, and total suspended solids concentration of surface runoff from a no-tillage corn-soybean rotation. This study was conducted in the Central Great Plains (Manhattan, KS) on a Smolan silty clay loam (fine, smectitic, mesic Pachic Argiustoll), and consisted of a 2x3 factorial structure arranged in randomized complete block design replicated in triplicate. Treatments included two cover cropping methods (cover crop and no cover crop) each implemented with three phosphorus fertilizer management systems (no P, fall broadcast P, and spring sub-surface injected P). Flow-weighted composite samples were collected from natural runoff for precipitation events resulting in greater than equal to 0.08 inches of runoff from October 1, 2015 through September 30, 2017 and analyzed for total phosphorus, dissolved phosphorus, and total suspended solids concentrations. The present analysis only examines cover crop effects (examined over fertilizer management systems) There was an event by cover crop interaction for total phosphorus, dissolved phosphorus, and total suspended solids concentrations in surface runoff across both water years. Cover crops increased dissolved P concentration compared to no cover crops in both water years. However, cover crops dramatically reduced total suspended solid concentrations in surface runoff for both 2015-2016 and 2016-2017. Data collected for this study represents one cycle through the crop rotation. An additional cycle through the crop rotation needs to be completed to confirm these findings.

## INTRODUCTION

Phosphorus (P) loss from agricultural production is a known contributor to the degradation of surface water quality. Excess P inputs to surface waters can lead to eutrophication, potentially causing an increase in aquatic plant and algal growth resulting in an overall drop in ecosystem health and water quality (Correll, 1998; Carpenter et al., 1998). The degradation of surface waters caused by P loss has created the need for new agricultural best management practices (BMP) to help decrease P loss through surface runoff.

Among many factors, cropping system selection can influence nutrient loss from an agricultural system (Liu et al., 2014). A popular approach to controlling nutrient loss from agricultural fields is though the utilization of a cover crop during traditionally fallow periods (DeBaets et al., 2011). Hartwig and Ammon (2002) define a cover crop as any living ground cover sown prior to, during, or after a cash crop but is terminated before planting the subsequent crop. Cover crops can reduce erosion, decrease nutrient loss/leaching, and suppress weeds all while providing greater water infiltration, slower surface runoff, and improved soil properties (Dabney et al., 2001). However, there is inconclusive evidence quantifying the effects of cover crops on P concentration in natural runoff from no-till cropping systems (Christianson et al., 2017).

This study aims to quantify the impacts of cover crops as a BMP on the concentration of P in surface runoff from a no-tillage corn soybean rotation on a precipitation event basis.

## MATERIALS AND METHODS

This study was conducted near Manhattan, Kansas, at the Kansas Agricultural Watershed (KAW) field laboratory. The KAW facility has eighteen small-scale watersheds (plots). Plots averaged 1.2 acres in size and were equipped with a 1.5 ft H-flume and automated water sampling equipment. All plots were under a no-tillage corn-soybean rotation.

A total of six management practices were utilized in this study. Three P fertilizer application practices were used: fall broadcast (FB), spring injected (SI), and a no P fertilizer control (CN). Each P application method is expressed both without a winter cover crop (NC) and with a winter cover crop (CC). Each management practice (treatment) was replicated in triplicate and arranged in randomized complete block design. Treatments were structured in a 2x3 factorial.

A flow-weighted composite surface runoff sample was collected for each precipitation event. Samples were analyzed for total P, dissolved P, and total suspended solids (TSS). Events with runoff averaging less than 0.08 inches were omitted from analysis due to the high number of missing data points for small events. Omitted events account for less than 7% of total runoff for 2015-2016 and less than 8% for 2016-2017. A water year runs from October 1 through September 30 of the following year.

### 2015-2016 Water Year

On September 22, 2015, a cover crop mixture of winter wheat and rapeseed was planted. The FB treatments received a surface application of 60 lb $P_2O_5$ $a^{-1}$ applied as diammonium phosphate (DAP, 18-46-0) on November 12, 2015. On May 6, 2016, prior to planting soybeans, the CC was terminated with herbicide. Soybean was sown on June 6, 2016, approximately one month after termination of the CC. The SI treatments received 60 lb $P_2O_5$ $a^{-1}$ as ammonium polyphosphate (APP, 10-34-0) applied at planting in a 2x2 band. All P fertilizer rates were based on the Kansas State University build and maintain fertilizer recommendation system using initial soil test P levels (Leikam et al., 2003).

### 2016-2017 Water Year

On October 19 & 20, 2016, a CC mixture of triticale and rapeseed was sown immediately following soybean harvest. The FB treatment received 56 lb $P_2O_5$ $a^{-1}$ as DAP on December 2, 2016 and the SI treatment received 53 lb $P_2O_5$ $a^{-1}$ as APP on April 24, 2016. The NC treatment received an early spring burndown application of herbicide on March 8, 2017. The CC was terminated with herbicide on April 24 and 25, 2017. Termination of the cover crop corresponded with the timing of corn planting for all plots. Nitrogen (N) was applied to all treatments, for a total N rate of 155 lb N $ac^{-}1$, as urea ammonium nitrate (UAN, 28-0-0) utilizing a disk-coulter injection unit within 3 days following planting. All treatments received an additional 40 lb N $ac^{-1}$ on June 12, 2017 (V8) with streamer bars.

**Statistical Analysis**

SAS version 9.4 was used to analyze all data. A proc glimmix procedure with repeated measures analysis of variance was utilized to examine treatment effects. All data required transformation to satisfy the assumption of normal variance. Figures depict back-transformed least-square means estimates.

## RESULTS AND DISCUSSION

There was a precipitation event by cover crop interaction for total P concentration in surface runoff for both 2015-2016 and 2016-2017 water years. For both 2015-2016 and 2016-2017, there was an inconsistent influence of CC on total P concentration, where runoff from the CC treatment had greater total P concentrations for some events and less total P for other events (Figure 1). Main effect of cover crop on total P concentration was not significant for either water year.

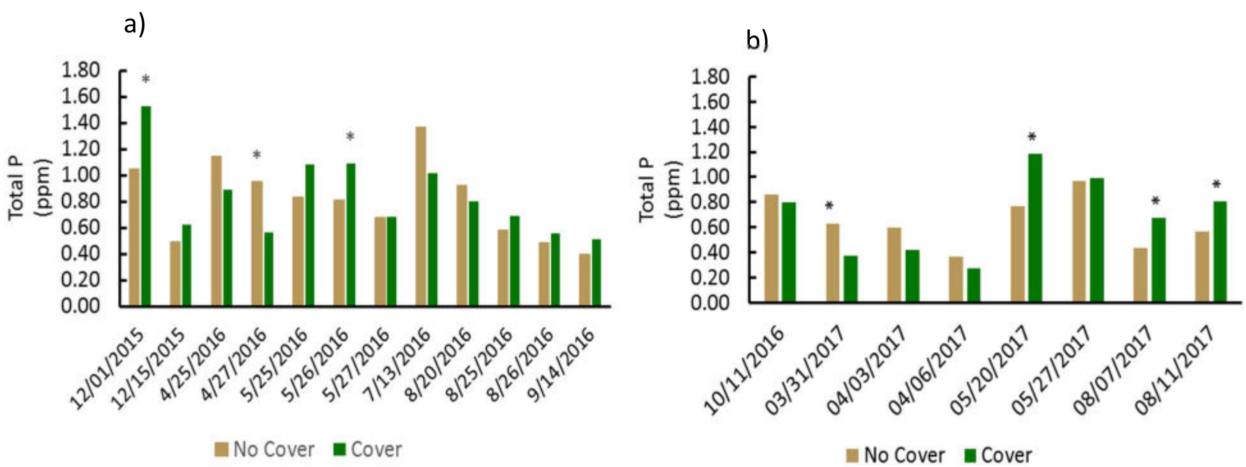


Figure 1. Winter cover crop effects on total P concentration in surface runoff for events with greater than 0.08 inches of runoff during the 2015-2016 (a) and 2016-2017 (b) water years (averaged across fertility treatments). ). Asterisks indicate a significant difference between treatments within an event at $p<0.05$.

There was a significant event by cover crop interaction on dissolve P concentration in surface runoff for both 2015-2016 and 2016-2017 water years. In the 2015-2016 water year, the CC treatment has greater dissolved P concentrations in the runoff compared to the NC treatment for 75% of the runoff events. In the 2016-2017 water year, the dissolved P concentration was higher in CC treatment for 50% of runoff events. No significant differences were seen between CC and NC for the remaining events in both 2015-2016 and 2016-2017. Increases in dissolved P concentration in surface runoff from the CC treatment occurred after termination of the cover crop for both water years.

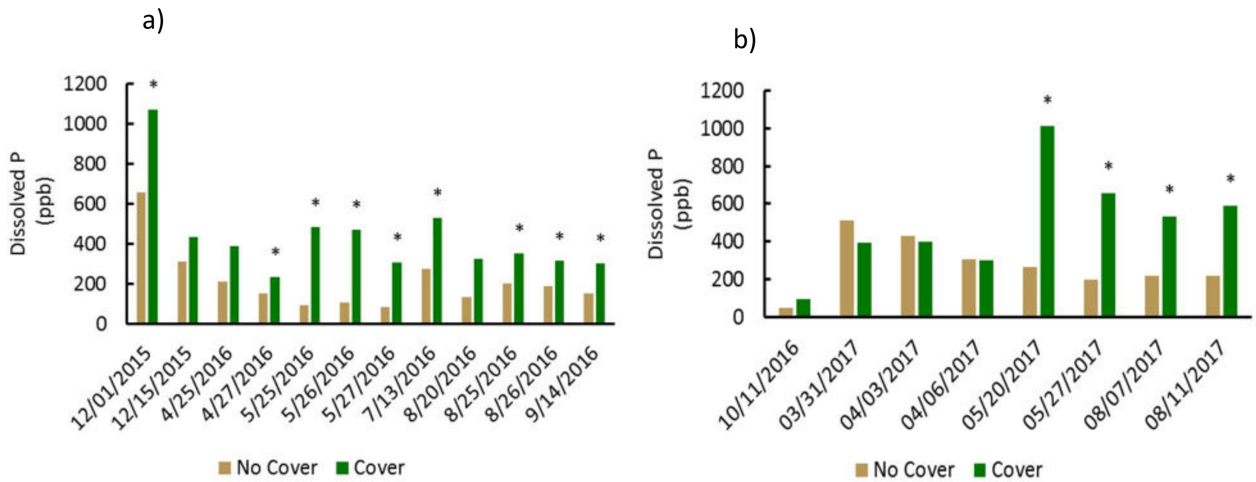


Figure 2. Effect of winter cover crop on dissolved P concentration in surface runoff for events with greater than 0.08 inches of runoff during the 2015-2106 (a) and 2016-2017 (b) water years (averaged across fertility treatments). ). Asterisks indicate a significant difference between treatments within an event at $p<0.05$.

The cover crop main effect significantly influenced dissolved P concentration in runoff for both water years (Figures 3). This increase runs counter to the often touted benefits of cover crops pertaining to nutrient loss. Miller et al. (1994) stated that cover crops could potentially increase the quantity of nutrients lost in surface runoff from the agricultural system due to plant tissue leaching during rainfall events. This phenomenon, in conjunction with the no-tillage management system used in this study, could contribute to the increase in dissolve P concentration of surface runoff. For 65% of observed runoff events across both water years examined in this study, the CC treatment had higher dissolved P concentration comparted to NC. In both water years, he CC treatment never had lower dissolved P concentrations than the NC treatment.

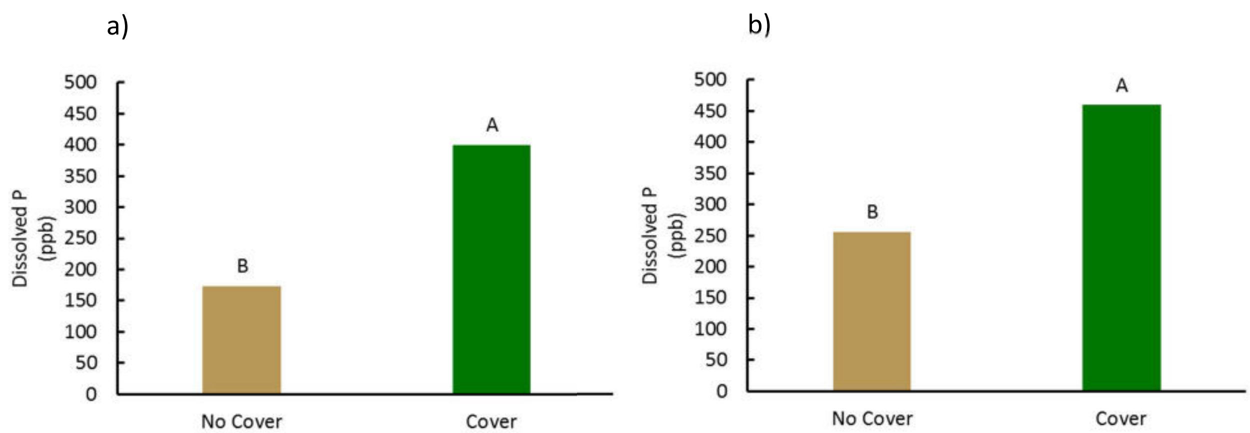


Figure 3. Effect of winter cover crop on dissolved P concentration for 2015-2016 (a) and 2016-2017 (b) water years. Bars with same letters are not differnt at $p<0.05$.

Although cover crops increased dissolved P concentration in surface runoff, cover crops dramatically reduced the TSS in surface runoff for both water years. A main effect of cover crop as well as an event by cover interaction were observed in both water years. The NC treatment had greater TSS concentration in surface runoff for 85% of all observed runoff events occurring in 2015-2016 and 2016-2017 (Figure 4). The NC treatment had over 50% greater TSS concentration for 2015-2016 and over 70% greater TSS concentration for 2016-2017 (Figure 5).

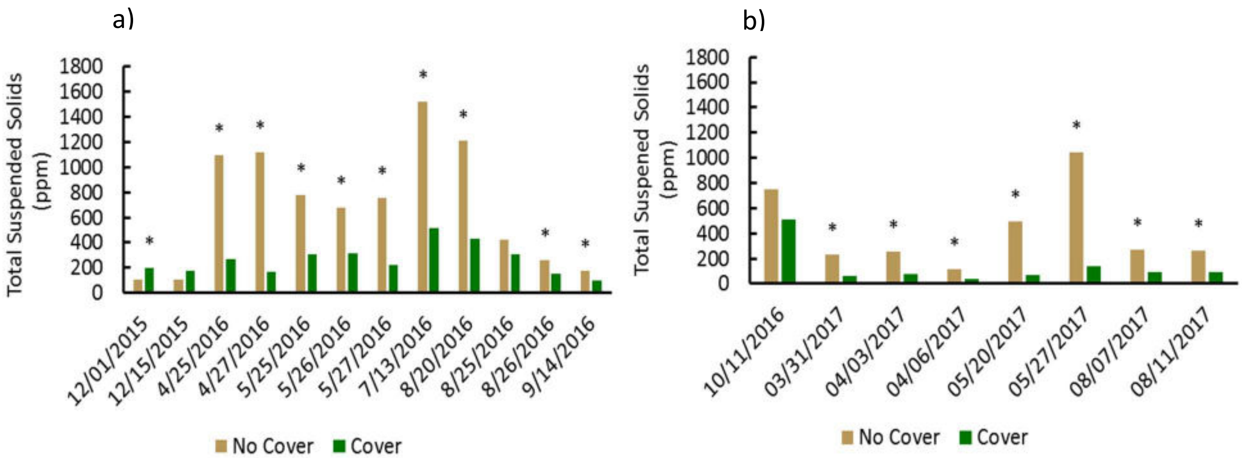


Figure 4. Impact of winter cover crops on TSS concentration in surface run off for events with greater than 0.08 inches of runoff during the 2015-2016 (a) and 2016-2017 (b) water years (averaged across fertility treatments). Asterisks indicate a significant difference between treatments within an event at *p*<0.05.

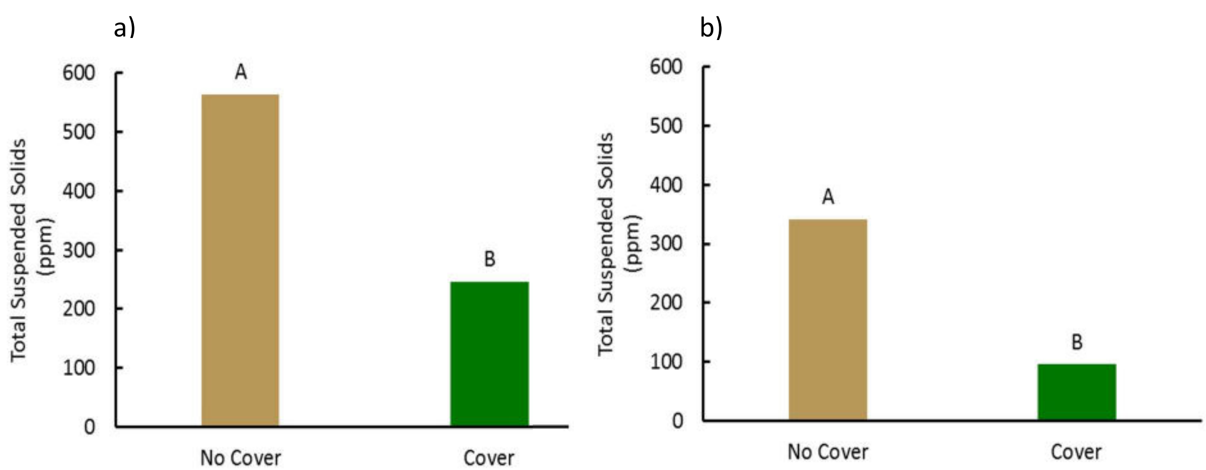


Figure 5. Effect of winter cover crops on TSS concentration in surface runoff= for 2015-2016 (a) and 2016-2017 (b) water years. ). Asterisks indicate a significant difference between treatments within an event at *p*<0.05.

## SUMMARY

This study found an event by cover crop interaction for total P, dissolved P, and TSS concentrations in surface runoff for both water years. The CC treatment had greater dissolved P concentration in surface runoff compared to the NC treatment. However, the CC treatment drastically reduced TSS concentration in surface runoff compared to the NC treatment for both observed water years. A second cycle through the cropping rotation will be examined to confirm these findings.

## ACKNOWLEDGEMENTS

This research is supported by the 4R Research Fund, Kansas Soybean Commission, Kansas Corn Commission, USDA-NRCS Grant #69-3A-75-17-32, the Kansas Agricultural Experiment Station, and the Kansas State University Department of Agronomy.

## REFERENCES

Carpenter, S.R., N.F. Caraco, D.L. Correll, R.W. Howarth, A.N. Sharpley and V.H. Smith. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Applications. 8:559-568.

Correll, David L. 1998. The role of phosphorus in the eutrophication of receiving water: A review. J. Environ. Qual. 27:261-266.

Christianson R., J. Fox, C. Wong, D. Caraco, A. Daniels, N. Law, B. Stack. 2017. Literature Review and Synthesis of the Effectiveness of Cover Crops for Water Quality Management in the Upper Mississippi River Basin (White Paper). Center for Watershed Protection, Inc., Ellicott City, Maryland. https://owl.cwp.org/?mdocs-file=8834.

Dabney, S., J. Delgado and D. Reeves. 2001. Using winter cover crops to improve soil and water quality. Commun. Soil Sci. Plant Anal. 32:1221-1250.

De Baets, S., J. Poesen, J. Keersmans and L. Serlet. 2011. Cover crops and their erosion-reducing effects during concentrated flow erosion. Catena. 85:237-244.

Hartwig, N. and H. Ammon. 2002. 50th anniversary - invited article - cover crops and living mulches. Weed Sci. 50:688-699.

Leikam, D.F., Lamond, R.E., Mengel, D.B. 2003. Soil test interpretation and fertilizer recommendations. Kansas State University Agricultural Experiment State and Cooperative Extension Service, MF-2586.

Liu, J., B. Ulen, G. Bergkvist and H. Aronsson. 2014. Freezing-thawing effects on phosphorus leaching from catch crops. Nutri. Cycl. Agro. 99:17-30.

Miller, M., E. Beauchamp and J. Lauzon. 1994. Leaching of nitrogen and phosphorus from the biomass of 3 cover crop species. J. Environ. Qual. 23:267-272.

# Fertilizer management and cover crop effects on phosphorus use efficiency, environmental efficiency and crop yield

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## ABSTRACT

Phosphorus loss from agricultural production is a significant contributor to the degradation and contamination of surface and ground waters. To help protect these waters, it is vital to maximize agronomic and environmental efficiency of phosphorus in the cropping system. The objective of this study was to quantify the effects of cover crops and different phosphorus fertilizer management practices on nutrient use efficiency, environmental efficiency and yield in a no-tillage corn-soybean rotation. This study utilized six different management practices. Three phosphorus management treatments (0 lb $P_2O_5$/acre, 55 lb $P_2O_5$/acre fall broadcast, 55 lb $P_2O_5$/ac spring sub-surface injected) were examined. All three phosphorus management methods were examined both with and without a winter cover crop. Treatments were arranged in a 3x2 factorial, randomized complete block design with three replications. This study was conducted from 2014-2017 and occurred in the Central Great Plains (Manhattan, KS) on a Smolan silty clay loam (fine, smectitic, mesic Pachic Argiustoll). Total phosphorus uptake, phosphorus removal and yield were measured for each treatment. In addition, agronomic nutrient use efficiency, partial productivity factor, fertilizer recovery efficiency, partial nutrient balance, and environmental efficiency were examined. Results from 2016 show application method of phosphorus fertilizer statistically influenced environmental efficiency and soybean yield increased with the application of $P_2O_5$ fertilizer. The goal of this study is to provide producers with flexible nutrient management options which maximize yield, protect water quality and increase profitability. Findings from the 2017 growing season will be presented as available.

## INTRODCUTION

The loss of phosphorus (P) from agricultural production is a key contributor to the decrease in quality of surface and ground waters and has created a need for new best agricultural management practices to help mitigate P loss. When P is lost from the agricultural system via surface runoff, it can lead to a mineral enrichment of surface waters known as eutrophication (Correll, 1998). The increase in nutrient levels within surface waters can lead to enhanced algal and aquatic plant growth which ultimately lead to an overall reduction in water quality and ecosystem health (Carpenter et al., 1998).

Liu et al. (2014) state the extent of nutrient lost is directly influenced by several factors: variety of crops being grown, cropping rotation, and soil management practices. A common management practice to decrease nutrient loss by erosion is the planting of cover crop during a normally fallow period (De Baets et al., 2011). Defined as any living ground cover sown before, during or after a main crop and terminated prior to planting the next crop (Hartwig & Ammon, 2002), cover crops are known to provide increased levels of water infiltration, improved soil properties, and decreased nutrient loss (Dabney et al., 2001).

In addition to cover crops, tillage and fertilizer management practices can also influence P loss from the agricultural system. In a no-tillage management system, crop residue is left on the soil surface. This increase in surface cover leads to decreased runoff, improved soil structure, and increased soil organic matter (Unger & Vigil, 1998). The implementation of no-tillage has also allowed producers to individually manage greater quantities of land (Triplett and Dick, 2008). While there are several benefits of no-tillage, the implementation of no-tillage creates a potential source of nutrient loss when dealing with surface-applied (broadcast) P fertilizers. Since no-tillage does not incorporate any surface material, broadcast P fertilizer is exposed to a greater risk of loss through surface runoff. To help reduce the risk of P loss from broadcast applied P fertilizers, some producers have chosen to sub-surface inject P fertilizer. Placement of P fertilizer below the soil surface has shown reduction in soluble, bioavailable, and total P loss from the soil system (Kimmell et al., 2001).

Since 2014, this study has aimed to quantify the effects P fertilizer management and cover crops on P use efficiency from a no-tillage corn-soybean rotation. To better quantify P use efficiency, this study examined the impact of phosphorus fertilizer placement (broadcast and sub-surface injected) both with and without cover crops on P uptake, P removal, and crop yield.

## MATERIALS AND METHODS

This study was performed at the Kansas Agricultural Watershed Field Research Facility (KAW) located in Manhattan, Kansas. The KAW consists of eighteen watersheds/plots varying in size from 1.2-1.6 acres. Each plot outlet was equipped with a 1.5 $ft^3$ H-flume (manufactured by Plasti-Fab) along with automated water sampling equipment (Teledyne ISCO 6700 or 6712 paired with a 730 bubbler module).

Six unique management practices are expressed in this study. Three P management practices are expressed: fall broadcast (FB application of P fertilizer, spring injected (SI) application of P fertilizer, and no P fertilizer (CN). Each of these three fertilizer management practices were examined with a winter cover crop (CC) and without a winter cover crop (NC). Treatments were arranged in a 3x2 factorial with three replicates and placed in randomized complete block orientation. Within each plot, three sub-plot located were marked using a GPS. Sub-plot locations were recorded and utilized for both biomass and grain harvest

### 2016 Growing Season

During September 2015, a winter wheat cover crop was sown for the 2016 growing season. In November 2015, the FB plots received 55 lb $P_2O_5$/a applied as diammonium phosphate (DAP, 18-46-0). In May 2016, prior to planting soybean, the cover crop was terminated with herbicide. Approximately one month after cover crop termination (June 2016), soybean were planted. SI plots received 55 lb $P_2O_5$/a of ammonium polyphosphate (APP, 10-34-0). The APP was applied in a 2x2 band at planting. All fertilizer application rates were based on a build and maintain nutrient recommendation system.

Biomass was harvested when soybeans were at R7. To perform the biomass harvest, entire soybean plants were collected from 3 feet of planted row at each sub-plot location. Biomass samples were then dried, ground, and submitted to the Kansas State Soil Testing Lab for total nutrient analysis.

At R8, soybean grain was harvested from 2 rows across the entire plot using a plot combine. Three times during the 2-row pass, distance travelled by the combine and grain weight harvested was recorded. This data was then utilized to determine 3 sub-sample yield estimates for the plot as a whole.

**2017 Growing Season**

A triticale and rapeseed mixture was sown as a winter cover crop in October 2016 for the 2017 growing season. In December 2016, the FB plots received 55 lb $P_2O_5$/a of DAP. An early spring burndown of the NC plots occurred in March 2017. In mid-April 2017, CC plots were terminated with herbicide and all plots were planted to corn at the time of termination. The SI plots received 55 lb $P_2O_5$/a applied in 2x2 placement as APP. Nitrogen (N) was surface applied as UAN (28-0-0) at a rate of 150 lb N/a. N applications were adjusted on a per plot basis based on quantity of N supplied through application of P fertilizer (i.e. all plots receive same amount of N).

Corn ears were handed harvested from two 30 foot sections of planted row at each sub-plot location. Corn ears were removed from the stalk, leaving the husk still attached. The ears were placed into burlap sacks and weighed. The sacks of ears were then placed in a storage shed until the grain could be shelled. One week after hand harvest, corn grain was shelled. The shelled grain was then ground and submitted for nutrient analysis. Yield for the entire plot was then estimated using the grain harvested from each respective sub-plot location.

Biomass was harvested from 3 sub-plot locations within each plot. To perform the biomass harvest, 10 random plants (ears had previously been harvested) were selected from 30 feet of planted row at each sub-plot location. Whole plant biomass samples were then weighed and passed through a wood chipper. A sub-sample of chipped stalk was then collected and weighed. Chipped samples were then dried, ground and analyzed by the Kansas State Soil Test Lab for nutrient analysis.

**Efficiency Calculations**

Table 1. Efficiency terms and calculations used. Y: fertilized yield; $Y_0$: non-fertilized yield; F: amount of fertilizer applied (Dobermann, 2007).

| Term | Calculation |
|---|---|
| P Uptake | $P_{uptake} = \text{biomass} \times \%P_{biomass}$ |
| P Removal | $P_{removal} = Y \times \%P_{grain}$ |
| Agronomic Nutrient Use Efficiency | $ANUE = (Y-Y_0) / F$ |
| Partial Productivity Factor | $PPF = Y / F$ |
| Fertilizer Recovery Efficiency | $FRE = (P_{uptake} - P_{uptake,control}) / F$ |
| Partial Nutrient Balance | $PNB = P_{removal} / F$ |
| Environmental Efficiency | $EE = P_{removal} / P_{loss}$ |

Table 1 contains a summary of efficiency calculations utilized in this study. These terms, as described by Dobermann (2007), enable the measurement of potential for P loss from the cropping system. While these terms are not a quantification of P loss, they do provide an index into the overall efficiency of the cropping system being examined.

**Agronomic Nutrient Use Efficiency (ANUE)**

ANUE is determined based on the amount of yield increase due to application of fertilizer per unit of fertilizer applied. Calculation of ANUE provides insight into the yield trends when applying fertilizer. This parameter was only measured on the FB-CC, FB-NC, SI-CC and SI-NC plots

**Partial Productivity Factor (PPF)**

PPF is similar to ANUE in that it examines yield versus fertilizer application rate. The benefit of using PPF in conjunction with ANUE is that ANUE requires the use of yield without nutrient input. For this study, PPF was measured for only the P fertilized plots.

**Fertilizer Recovery Efficiency (FRE)**

FRE provides insight into the quantity of the applied nutrient that was taken up by the plant. By examining the difference in P uptake of fertilized versus non-fertilized plants, this measurement can supply a potential efficiency of the P application method and identify P loss potential from the given cropping system. Like ANUE, FRE can only be determined if a plot without nutrients (CN-CC, CN-NC) are included in the study.

**Partial Nutrient Balance (PNB)**

The most basic form of P efficiency calculated in this study is PNB. A relationship of the quantity of P removed to the amount of P applied, PNB provides insight into what may be occurring with soil fertility levels. A PNB of approximately 1 would indicated that soil nutrient test levels should be maintained at a steady state. However, as the name implies, this calculation is only partial and does not include potential nutrient losses via erosion or leaching.

**Environmental Efficiency (EE)**

For this study, EE is defined as the quantity of P removed by the crop versus the amount of P lost in runoff. To measure the amount of P lost in runoff, water samples were collect during rain events using the automated sampling units and H-flumes described earlier. Runoff samples were analyzed for total P, dissolved P and total suspended solids. Total P and dissolved P loss for the entire year was calculated and used to determine EE. Calculations for EE were performed on both a total P and dissolved P basis.

## RESULTS AND DISCUSSION

All data were analyzed statistically using SAS version 9.4. Treatment effects were examined using proc glimmix with repeated measures analysis of variance. For all graphs, letters indicate significant difference at $\alpha = 0.05$.

P fertilization statistically increased soybean yield (Figure 1) in the 2016 growing season. The FB plots showed a 12 % yield increase compared to the control and the SI plots showed a 7.5% yield increase compared to the control. Soil test P levels for the FB and SI plots where 24 and 23 ppm, respectively. Control plot soil test P levels were at 12 ppm. No cover nor cover by fertilizer effect was seen on yield.

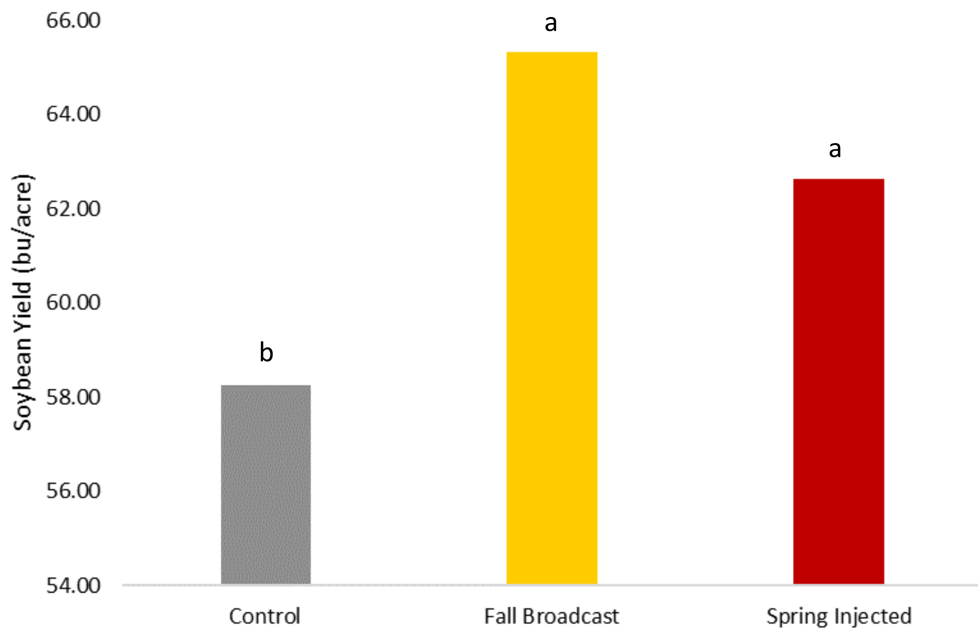


Figure 1. Impact of P fertilization application method on soybean yield in the 2016 growing season

As seen in Figure 2, the application method of P fertilizer application influenced total P uptake in soybean tissue. Both FB and SI application methods had statistically higher total P uptake. The FB plots saw a 30.5% increase in total P uptake and the SI plots saw a 23.5% increase in P uptake. Increase in P uptake for plots receiving applications of P fertilizer is not unexpected

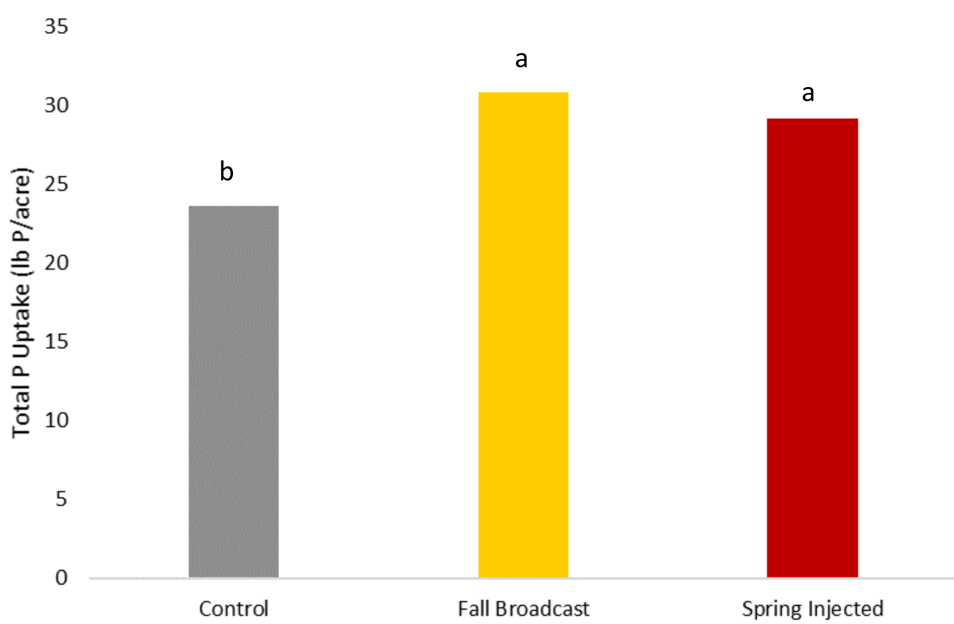


Figure 2. Effects of P fertilization method on total P uptake in soybean for 2016 growing season

The application of P fertilizer also statistically increased the total P removed from the system (Figure 3). FB and SI plots had an increase of 28% and 23%, respectively. The statistical increase in total P removal can be correlated to the statistically higher yields of the FB and SI plots and higher concentrations of P in the grain. The greater the quantity of grain produced, the greater the amount of P removed.

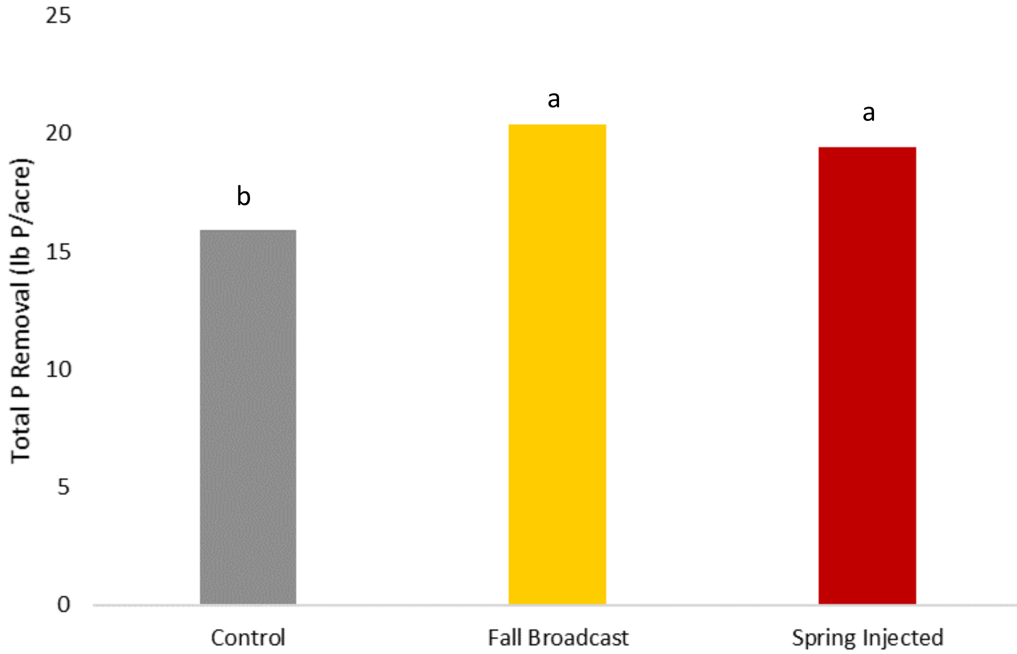


Figure 3. P fertilization method effects on total P removal

Figure 4 shows a statistically higher PNB for FB application of P compared to the SI application method. The FB application of P fertilizer had a 4.75% higher PNB compared to the SI application method.

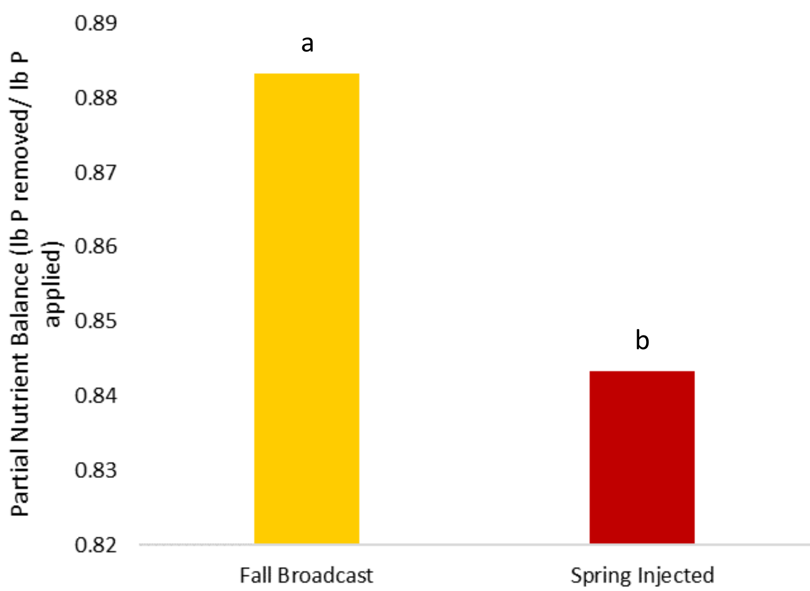


Figure 4. Partial nutrient balance for FB and SI applications methods of P fertilizer

Total P loss (Figure 5) was statically higher for FB method of P fertilizer application compared to CN. The FB had 55.5% high amount of total P loss compared to the CN. The SI was statistically similar to both the FB and CN with an increase in total P loss of 17% compared to CN.

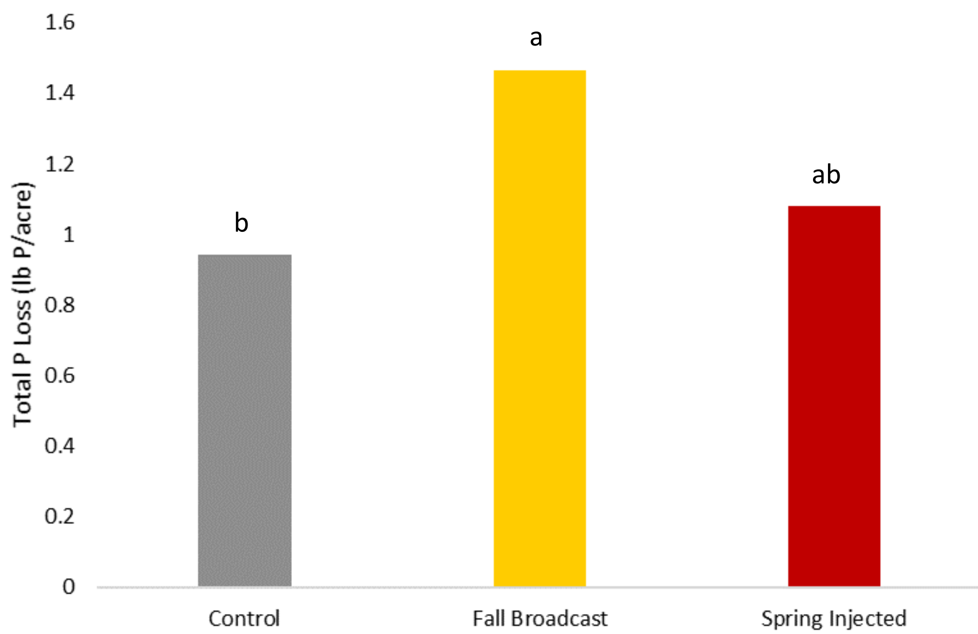


Figure 5. Difference in total P loss based on fertilizer application method.

Dissolved P loss was also statically varied across both fertilizer application method and cover. As seen in Figure 6, the FB treatment had a 206% higher level of dissolved P loss and the SI treatment had a 62% higher level of dissolved P loss.

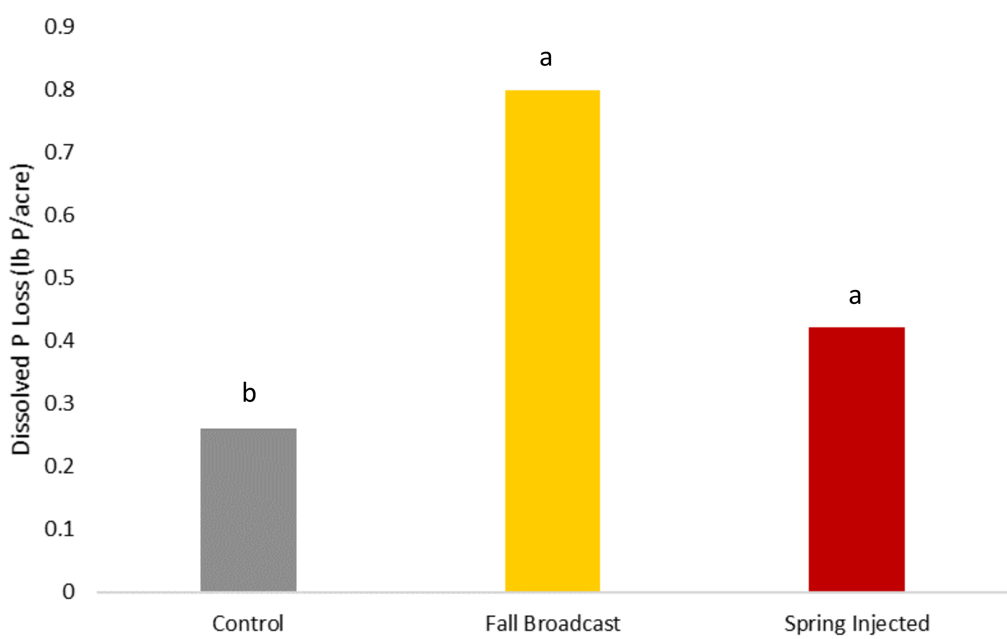

Figure 6. Effect of P fertilizer management practice on dissolve P loss

Figure 7 shows that the CC plots had statistically higher dissolved P loss compared to the NC. A possible source of this increase in dissolved P loss for the cover cropped plots could be related to the winter cover crop's exposure to freeze-that conditions. In 2014, Liu et al. showed that exposure of cover crop to freeze-that conditions can lead to an increase in phosphorus loss from the tissue. Miller et al. (1994) also showed when cover crop tissue is exposed to rainfall, the likelihood of nutrient loss from plant tissue into surface runoff is increased. Further research is ongoing to determine what role cover crop management plays in phosphorus loss form plant tissue.

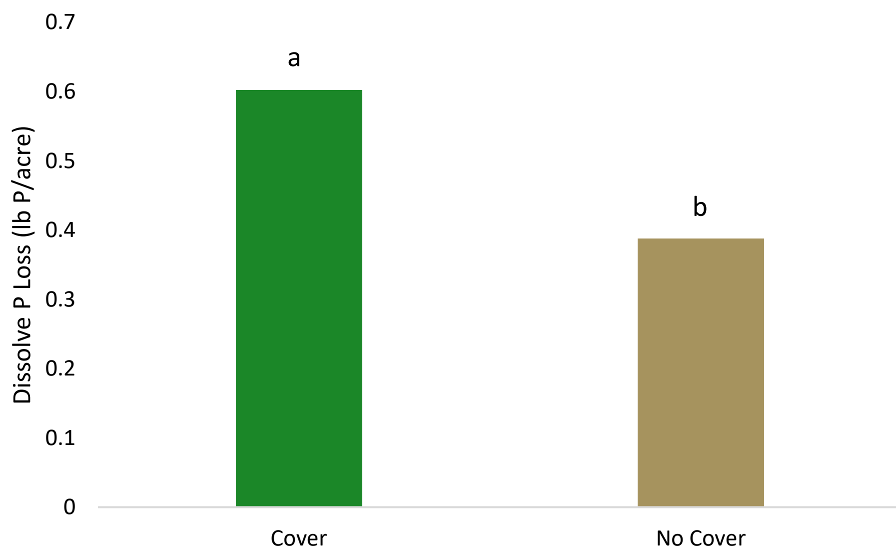


Figure 7. Effect of cover crop on dissolved P loss

Cover statistically impacted sediment loss from the plot. As shown in Figure 8, the NC plots had a 67% higher amount of sediment loss compared to the CC plots. It is interesting to that that while the CC plots had a statistically lower level of sediment loss, the amount of dissolve P (Figure 7) lost from the CC plots was statistically higher than that lost from the NC plots.

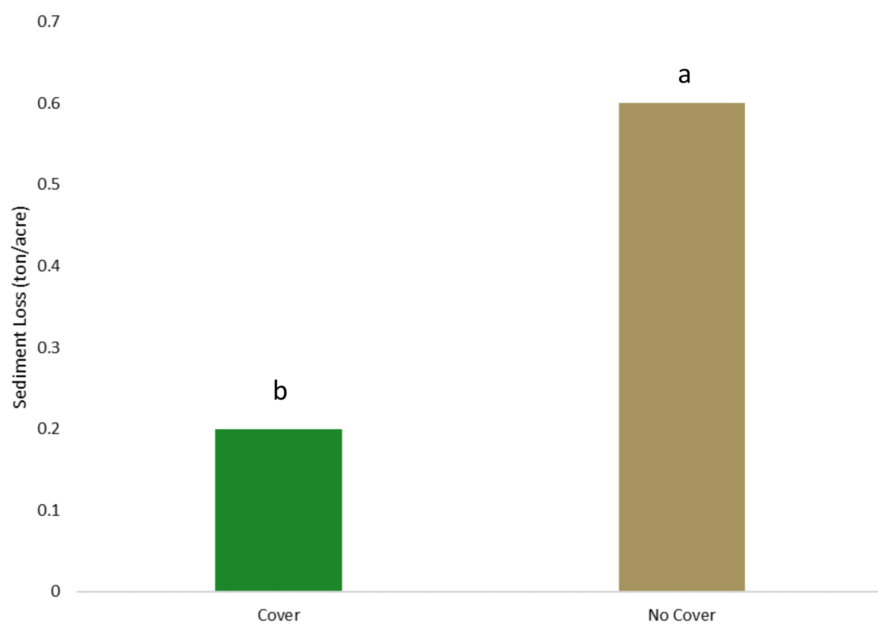


Figure 8. Impact of cover on sediment loss

When calculated on a dissolved P basis (Figure 9), the EE of the CN (0 lb $P_2O_5$/a) application of P was statistically higher than both FB and SI application methods. However, when calculated on a total P basis (Figure 10) the EE of the CN and SI are both statistically higher than the EE of the FB.

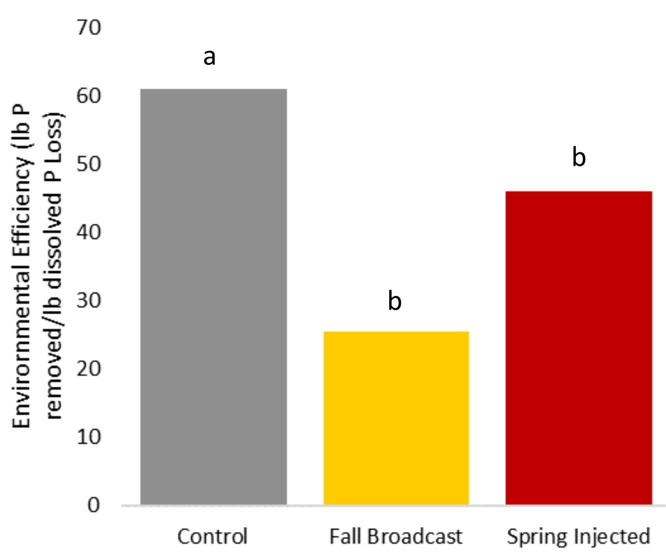


Figure 9. Impact of P fertilizer application method on environmental efficiency on a dissolved P loss basis.

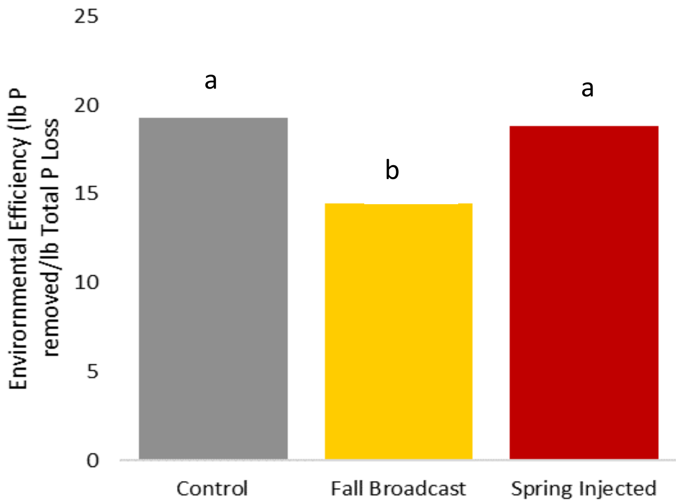


Figure 10. Impact of P fertilization application method on environmental efficiency on a total P loss basis

For the 2016 growing season, no statistical differences were observed for ANUE, PPF, and FRE. Since no statistical differences in these parameters were observed, data pertaining to them have been omitted.

## SUMMARY

This study found that the application of P fertilizer statistically increased the yield of soybean, regardless of application method and statistically increases the uptake of P into the plant tissue. CC where shown to statistically decrease sediment loss. However, for the 2016 growing season, CC statistically increased dissolved P loss. Findings from the 2017 growing season should be analyzed and compared to 2016 to establish trends in measured parameters.

## REFERENCES

Carpenter, S.R., N.F. Caraco, D.L. Correll, R.W. Howarth, A.N. Sharpley and V.H. Smith. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Applications. 8:559-568.

Correll, David L. 1998. The role of phosphorus in the eutrophication of receiving water: A review. J. Environ. Qual. 27:261-266.

Dabney, S., J. Delgado and D. Reeves. 2001. Using winter cover crops to improve soil and water quality. Commun. Soil Sci. Plant Anal. 32:1221-1250.

De Baets, S., J. Poesen, J. Keersmans and L. Serlet. 2011. Cover crops and their erosion-reducing effects during concentrated flow erosion. Catena. 85:237-244.

Dobermann, A. 2007. Nutrient use efficiency – measurement and management. In "IFA International Workshop on Fertilizer Best Management Practices", Brussels, Belgium, p1-28.

Hartwig, N. and H. Ammon. 2002. 50th anniversary - invited article - cover crops and living mulches. Weed Sci. 50:688-699.

Kimmell, R., G. Pierzynski, K. Janssen and P. Barnes. 2001. Effects of tillage and phosphorus placement on phosphorus runoff losses in a grain sorghum-soybean rotation. J. Environ. Qual. 30:1324-1330.

Liu, J., B. Ulen, G. Bergkvist and H. Aronsson. 2014. Freezing-thawing effects on phosphorus leaching from catch crops. Nutri. Cycl. Agro. 99:17-30.

Miller, M., E. Beauchamp and J. Lauzon. 1994. Leaching of nitrogen and phosphorus from the biomass of 3 cover crop species. J. Environ. Qual. 23:267-272.

Triplett, G. B. and W. A. Dick. 2008. No-tillage crop production: A revolution in agriculture!. Agron. J. 100:S-153-S-165.

Unger, P. and M. Vigil. 1998. Cover crop effects on soil water relationships. J. Soil Water Conserv. 53:200-207.