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} = biomass x %$P_{biomass}$
P Removal	$P_{removal}$ = Y x %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.

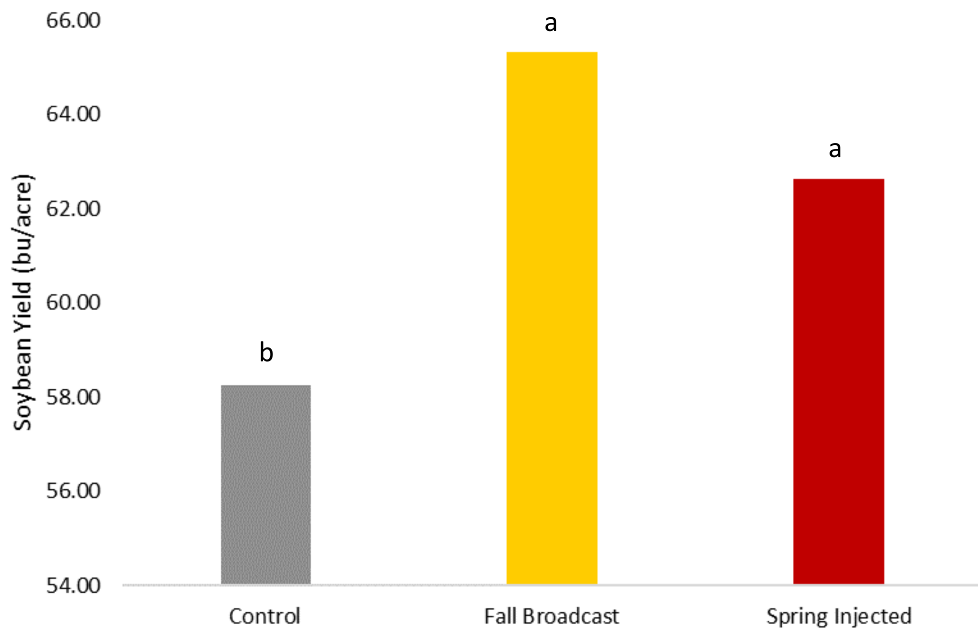

Figure 1. Impact of P fertilization application method on soybean yield in the 2016 growing season

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

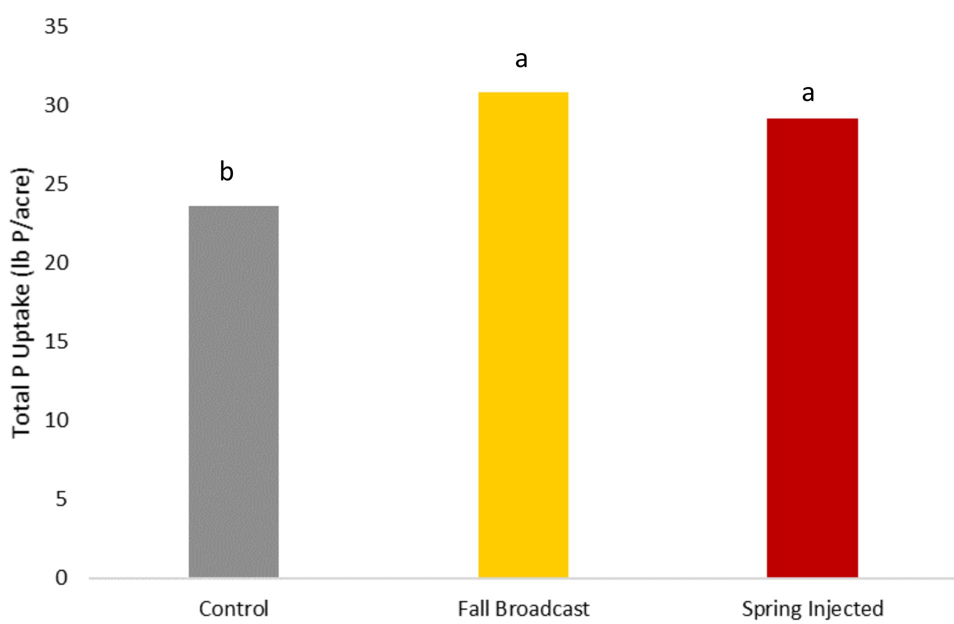

Figure 2. Effects of P fertilization method on total P uptake in soybean for 2016 growing season

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.

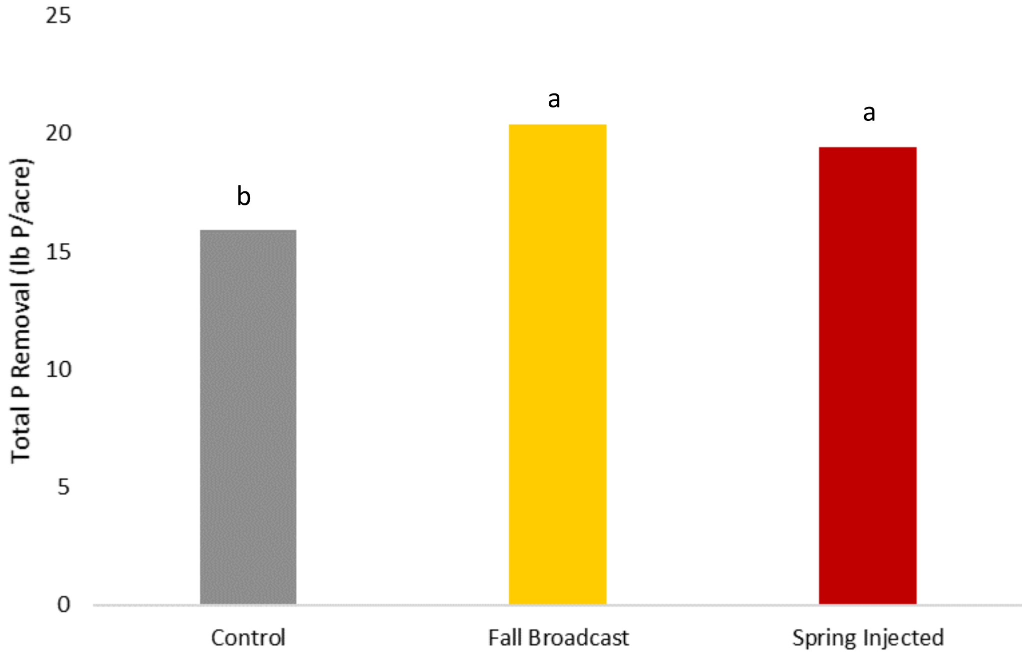

Figure 3. P fertilization method effects on total P removal

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.

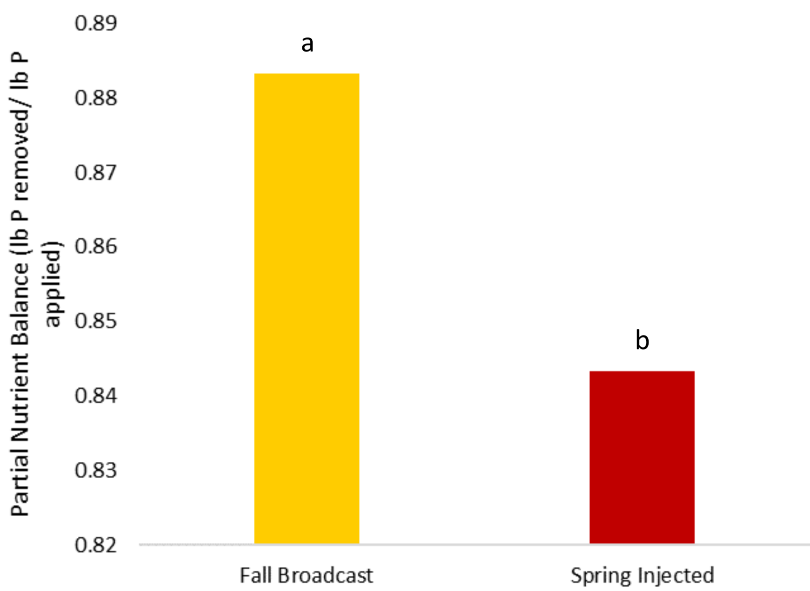

Figure 4. Partial nutrient balance for FB and SI applications methods of P fertilizer

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.

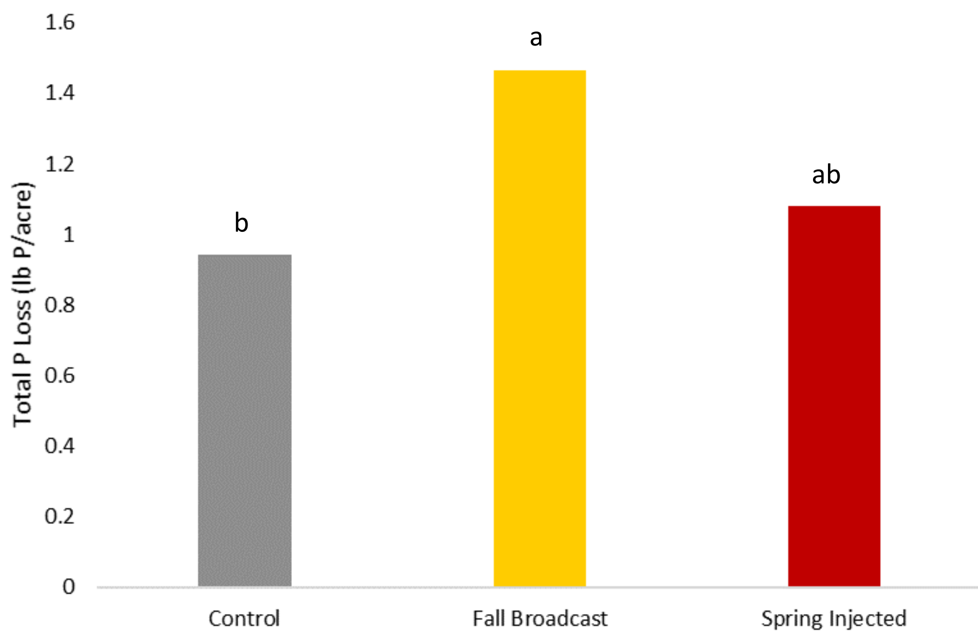

Figure 5. Difference in total P loss based on fertilizer application method.

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.

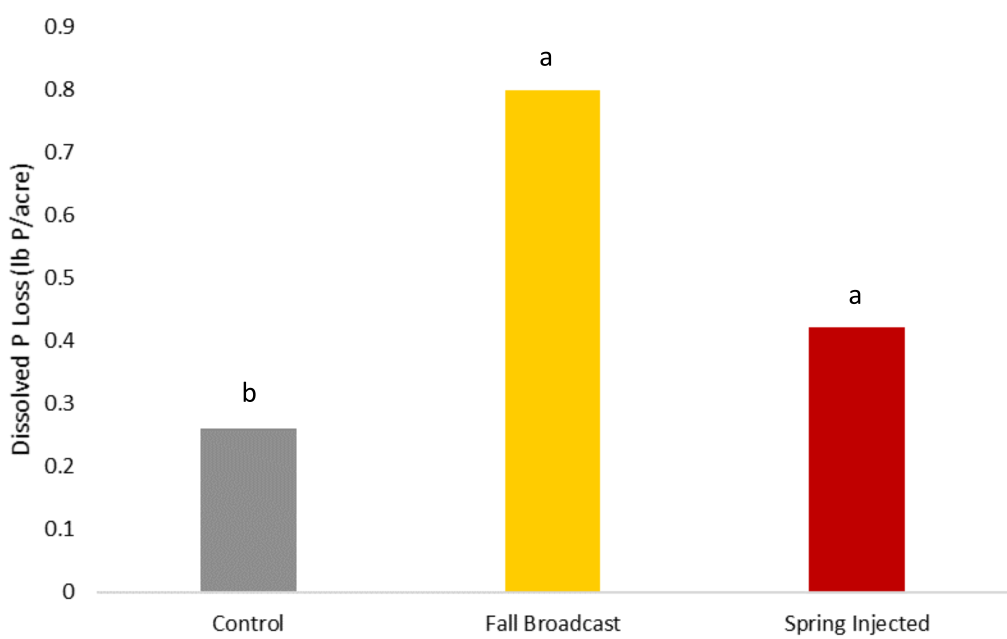

Figure 6. Effect of P fertilizer management practice on dissolve P loss

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.

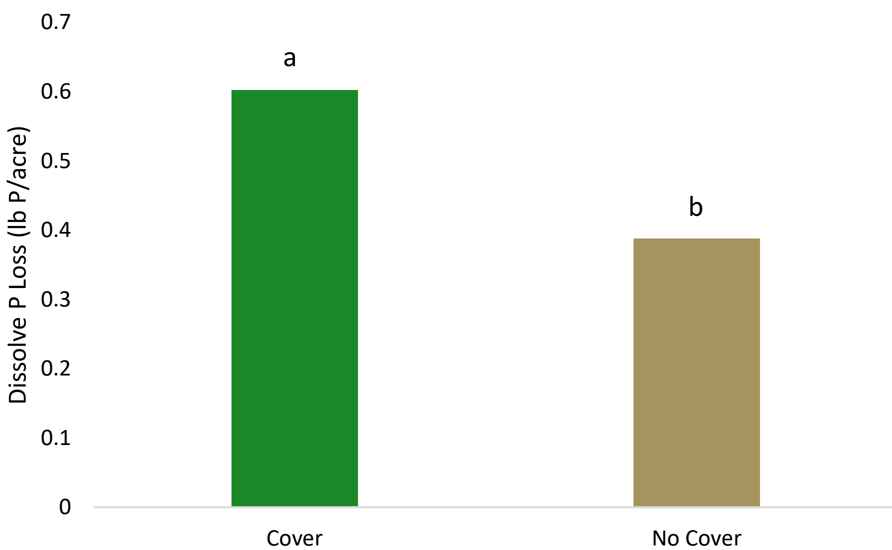

Figure 7. Effect of cover crop on dissolved P loss

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.

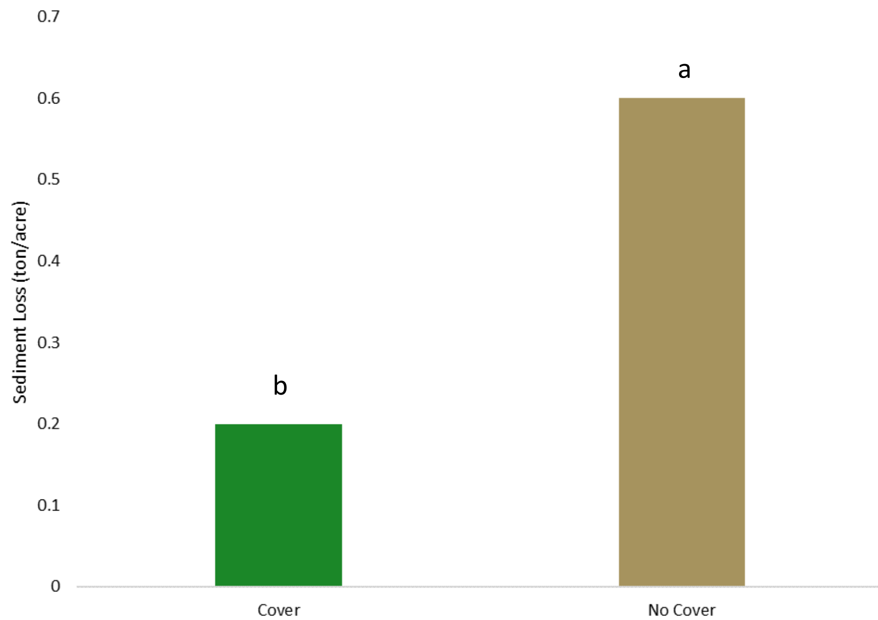

Figure 8. Impact of cover on sediment loss

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.

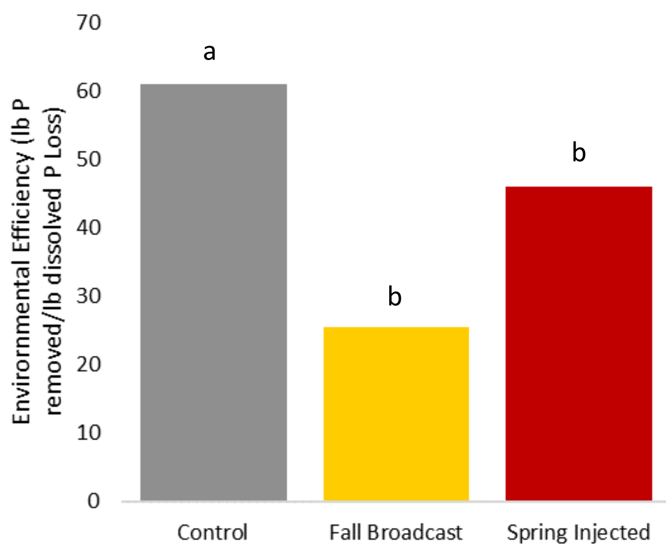

Figure 9. Impact of P fertilizer application method on environmental efficiency on a dissolved P loss basis.

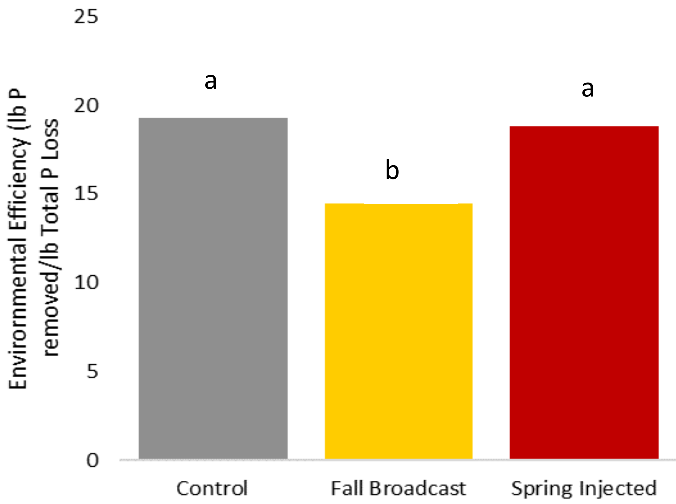

Figure 10. Impact of P fertilization application method on environmental efficiency on a total P loss basis

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.

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