Cover Crops and Phosphorus Management to Protect Water Quality in Corn-Soybean Rotations

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<u>Major goals of the project</u>

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.

We 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 edge-of-field 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

<u>What was accomplished under these goals?</u>

IMPACT: The major impact of this research was an increase in knowledge about how cover crop and fertilizer management practices affect water quality. We found that cover crops are excellent conservation tools to reduce sediment loss and decrease runoff intensity. However, cover crops increased the edge of field dissolved P loss and had variable effects on total P loss. Spring sub-surface placement of P fertilizer decreased dissolved and total P loss. Conservation management systems that use cover crops need to have P fertilizer applied at the right rate, time, and place to control P losses from the field.

ACCOMPLISHMENTS

We measured runoff volume and sediment, total P, and dissolved P concentrations in runoff from three fertilizer management systems (no P fertilizer, fall broadcast P fertilizer, spring injected P fertilizer) both with cover crops and without cover crops for 5 years in a no-till corn soybean rotation. These data were used to compute the mass of sediment, total P, and dissolved P lost for each year of the study. Biomass production, grain yield, and nutrient concentrations in tissue were measured for the main crop each year, and biomass production and nutrient concentrations in the cover crop were measured annually. Treatment effects on soil chemical, physical, and biological properties were also measured throughout the study. We recorded all input costs for each treatment system and computed treatment effects on gross return, total costs, and net returns. Although data were collected for 5 growing seasons, results are summarized for the final 4 seasons because the cropping system was converting from conventional till to no-till during the first season.

Cover crop treatments had minor effects on crop yield except in 2017 when the cover crop decreased corn yield by 27% (Figure 1a). Phosphorus fertilizer application increased crop yield by 10% to 18%, although the increase was significant in only 2 of the 4 years (Figure 1b). Fall broadcast P fertilizer (as diammonium phosphate) increased total cover crop growth and P uptake over the 4 years by 38% and 70% respectively (Table 1).

Phosphorus fertilization increased the Mehlich 3 soil test P in the 0 to 2-inch surface soil from 30 ppm to about 70 ppm for the Fall Broadcast and Spring Injected treatments (Figure 2). The Mehlich 3 soil test P in the control dropped from 30 ppm to 12 ppm at the 0 to 2 inch depth. Fertilizer treatments had similar effects on total P concentration in soils. The cover crop treatments did not have any consistent effects on Mehlich 3 or total P concentrations in soils. However, the cover crop increased the total C and total N content by nearly 10% compared with the no cover treatments (Figure 3).

We found that cover crops had variable effects on runoff volume, which was highly dependent on the rainfall event. For some events, the cover crop treatments had less runoff, but for other events the cover crop treatments had more runoff. Although the cover crops typically reduced runoff during dry periods and increased runoff during wet periods, this tendency was not consistent. Cover crops decreased annual runoff in one of the 4 years (Figure 4). Cover crops consistently reduced the peak runoff rate (Figure 5) and increased the duration of the runoff (Figure 6). Therefore, cover crops decreased runoff intensity.

Cover crops consistently decreased sediment concentration in runoff water and annual sediment loss by 60 to 70% (Figure 7). Cover crop effect on total P concentration in runoff water was variable but cover crops consistently increased the dissolved P concentration in runoff water (Figure 8). During wet periods, or years with substantial sediment loss, the cover crops tended to decrease the total P concentration and loss. During periods with less sediment loss, corresponding to drier years, cover crops tended to increase total P concentration and loss. Over the 4-year period, cover crops increased annual dissolved P loss between 0 and 76%, with an average annual increase of 28% (Figure 9). Cover crop effects on annual total P loss ranged from a 38% increase (2018) to a 43% decrease (2019) with an average annual decrease of 28% (Figure 9).

Fall broadcast fertilizer application tended to have the greatest P loss of the P fertilizer management systems, but this was affected by the time of year and the weather patterns. During the cropping season the P loss from fall broadcast tended to be similar to P loss from spring injected P, particularly during the latter years of the project. Between the time of fall broadcast application and spring injected P fertilizer application, the P loss from the fall broadcast was greater than from the spring injected. After the first two years of the study, the no-fertilizer treatment (Control) consistently had lower P concentrations in runoff and less P loss than the treatments receiving fertilizer. The flow-weighted annual dissolved P concentration from the spring-injected P treatment was consistently less than that from the fall broadcast treatment (Figure 10). Over the 4 years of data collection (2016-2019), spring injected fertilizer decreased dissolved and total P loss by 33% and 16% respectively compared to fall broadcast (Figure 11). Decreasing the P fertilizer rate to 0 lb P_2O_5/acre/yr reduced dissolved and total P loss by 235% and 93% respectively compared to fall broadcast P fertilizer.

Fall broadcast P without a cover crop had the highest net returns of all systems (Figure 12). The cost of moving to a sub-surface P fertilizer application at planting was $8.71/ac compared to fall broadcast fertilizer application. This would reduce the P loss by an average of 0.74 lb P_2O_5/ac, which reduced P loss at the cost of $11.75/lb P_2O_5 removed from runoff. Converting from the most profitable system (fall broadcast P without cover crop) to the system with the least P loss (no P fertilizer with cover crop) cost $68.21/ac and reduced P loss by 2.74 lbs P_2O_5/ac/yr, which would cost $24.93/lb P_2O_5 removed from the runoff. The system conversion with the greatest reduction per lb of P_2O_5 removed from runoff is converting from fall broadcast P without cover crop to no P applied without cover crop, which cost $23/ac, removed 2.41 lbs P_2O_5/ac/yr, and would cost $9.54/lb of P_2O_5 removed. The treatments with P application of 0 lb P_2O_5/ac resulted in substantial declines in soil test P (Figure 2) and future crop yield may decline more, which could make these options unsustainable in the long-term.

Cover crops resulted in lower net returns than the non-cover crop practices. To adopt a cover crop, a significant incentive payment to cover the per acre opportunity cost is needed and ranges from $43.40/acre for no P control, $52.48/acre for spring injected P, and $67.90/acre for fall broadcast treatment. These incentives would result in P removal costs of $137.30, $47.46, and $48.56 per pound of P_2O_5 removed from runoff respectively. Based strictly on economics, an incentive to use a cover crop may be needed to encourage cover crop systems.

There are several possible explanations for the role that cover crops played in causing increased dissolved P loss. Cover crop tissue can release dissolved P in the runoff water. The release of dissolved P occurs shortly after termination and then increases for a few weeks. Additional information is needed to determine the pattern of P release from the tissue over the entire season and under field conditions. The cover crops also increase the contact time between the soil and the water; this increase in contact time could increase the dissolved P release from soil. Additional information is needed on short-term kinetics of P release to fully understand the effects of these processes. Finally, cover crop effects on erosion processes could affect the P enrichment ratio in sediments. For example, cover crops could reduce ephemeral gully erosion.

Spring injected fertilizer tended to decrease P loss by reducing the presence of highly available P in soil during the spring months, when runoff was highest. The P concentration in the surface soil of the spring injected P treatment was also slightly less than in the Fall Broadcast treatment. These factors reduced the dissolved P concentrations in runoff and reduced overall dissolved P and total P loss.

The results support the recommendation that producers use cover crops to decrease runoff intensity and soil erosion. Cover crops will decrease total P loss in situations where there is excessive soil loss (> 2 ton/ac) due to soil, management, or climate conditions. When soil losses are minimal (< 0.5 ton/ac), cover crops will not decrease total P loss and may even increase total P loss. Cover crops increase the dissolved P concentration and loss in surface runoff; therefore, additional fertilizer management practices should be used in combination with cover crops to effectively control P loss from agricultural fields. Sub-surface placement of P fertilizer or reducing P fertilizer application rate should be used to reduce both dissolved and total P loss from agriculture. Although subsurface placement had no effect on P loss in some years, depending on weather patterns, sub-surface placement never increased dissolved P or total P loss; therefore, the net effect of this practice over time will be a reduction in P loss. Reducing P fertilizer application to 0 lb P_2O_5/ac consistently had the least P loss, but also reduced crop yield and net returns. Changes in fertilizer management, either sub-surface placement of P fertilizer or reducing the P fertilizer rate, were the most economical methods of reducing P loss from agriculture.

Table 1. Phosphorus fertilizer management effects on cumulative cover crop biomass and nutrient uptake from 2015 through 2019 cropping years at the Kansas Agricultural Watershed Field Laboratory. Control = 0 lb P_2O_5/ac/yr; Fall Broadcast = 55 lb P_2O_5/ac/yr broadcast as diammonium phosphate between Nov 15 and Jan 15, Spring Injected = 55 lb P_2O_5/ac/yr applied as ammonium polyphosphate in a 2x2 placement at planting. Different letters indicate significant difference at α=0.05.

	Biomass	N uptake	P uptake	K uptake
	lb/ac	lb/ac	lb P_2O_5/ac	lb K_2O/ac
Control	5,002 B	67 B	28 B	121 B
Fall Broadcast	6,896 A	90 A	48 A	162 A
Spring Injected	5,616 AB	74 AB	34 AB	131 B
p-value from F-test	0.045	0.028	0.002	0.047

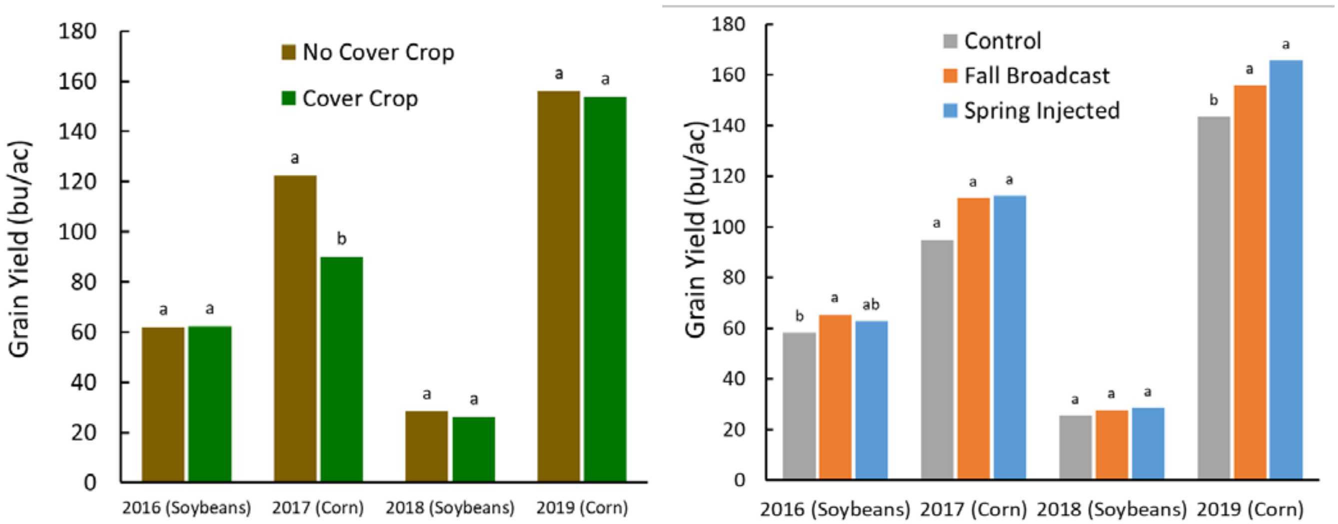

Figure 1. Cover crop and P fertilizer management effects on soybean and corn yield at the Kansas Agricultural Watershed Field Laboratory. Control = 0 lb P_2O_5/ac/yr; Fall Broadcast = 55 lb P_2O_5/ac/yr broadcast as diammonium phosphate between Nov 15 and Jan 15, Spring Injected = 55 lb P_2O_5/ac/yr applied as ammonium polyphosphate in a 2x2 placement at planting. Different letters indicate significant difference within a year at α=0.05.

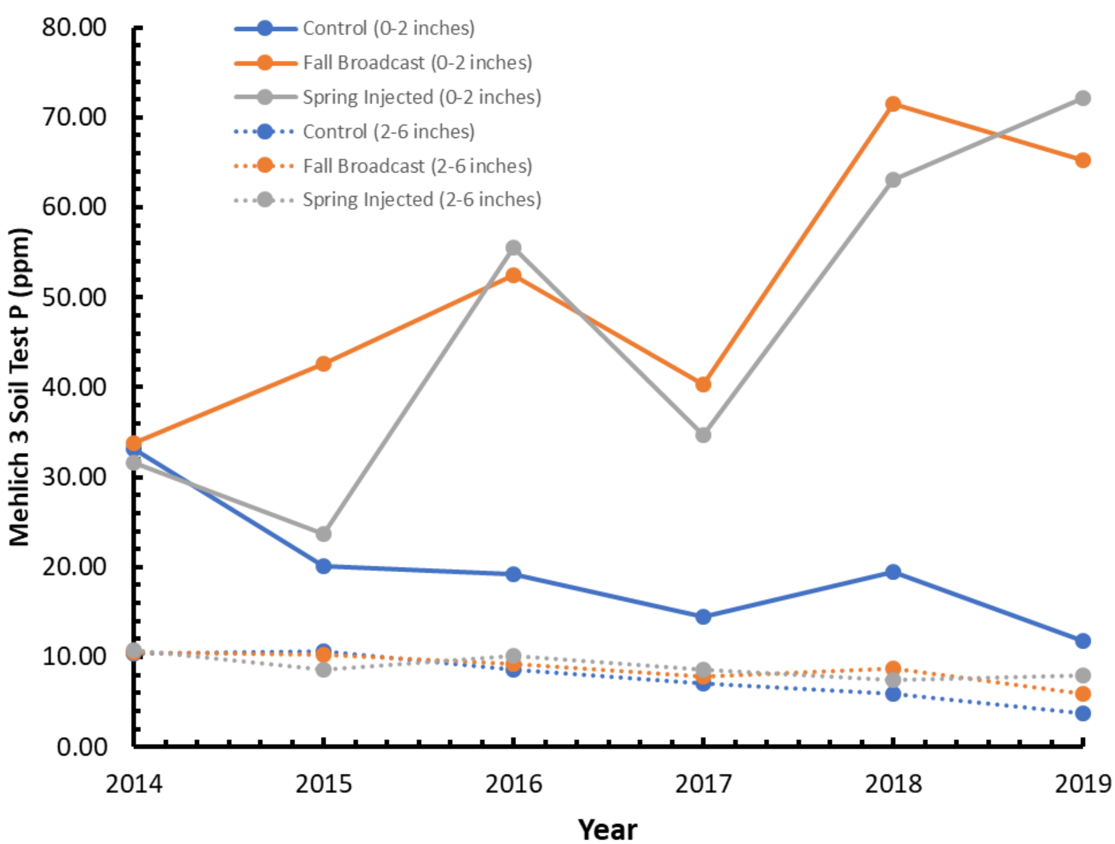

Figure 2. Phosphorus fertilizer management effects on Mehlich 3 soil test P at the Kansas Agricultural Watershed Field Laboratory. Control = 0 lb P_2O_5/ac/yr; Fall Broadcast = 55 lb P_2O_5/ac/yr broadcast as diammonium phosphate between Nov 15 and Jan 15, Spring Injected = 55 lb P_2O_5/ac/yr applied as ammonium polyphosphate in a 2x2 placement at planting.

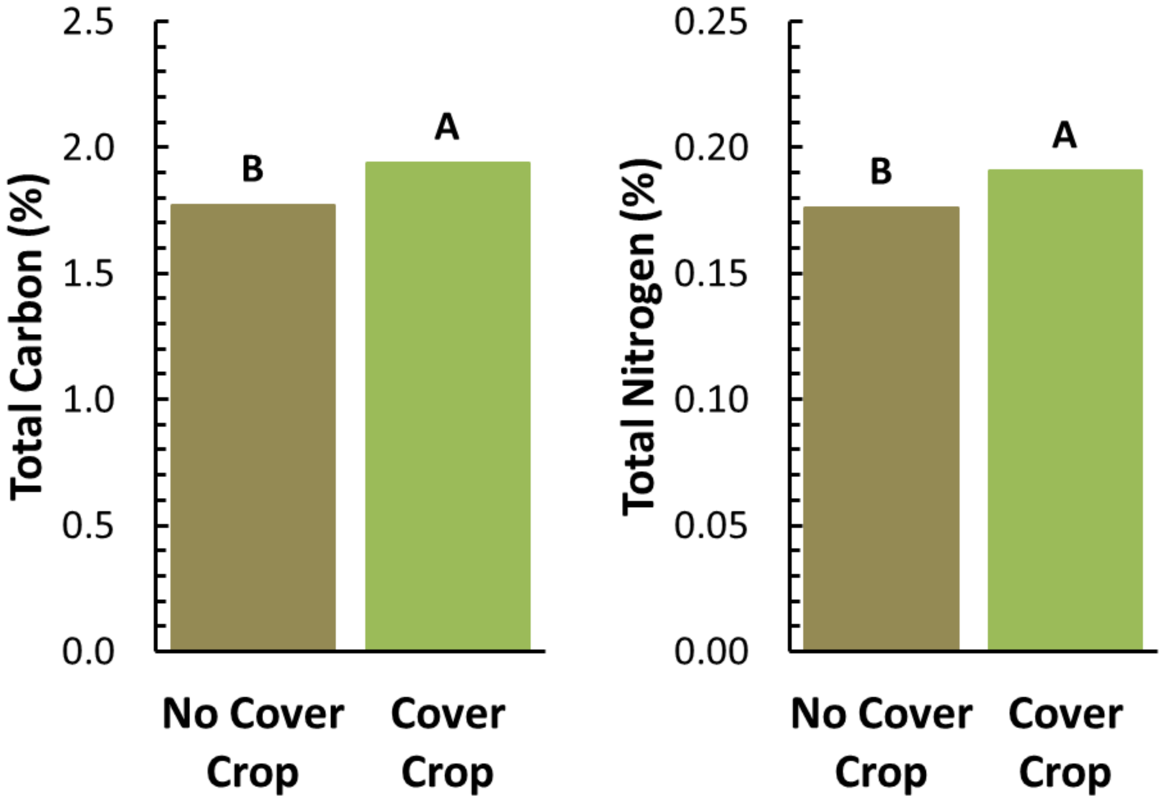

Figure 3. Cover crop effects on soil C and soil N content in soils (0 to 1-inch depth) at the Kansas Agricultural Watershed Field Laboratory. Different letters indicate significant difference within a year at α=0.05.

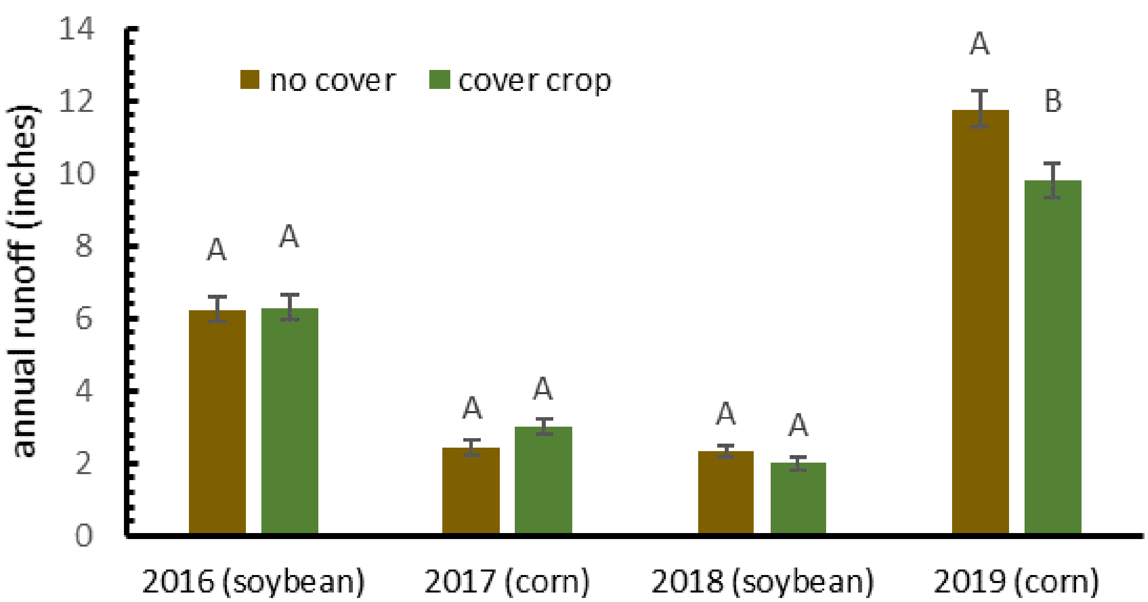

Figure 4. Cover crop effects on annual runoff volume at the Kansas Agricultural Watershed Field Laboratory (different letters indicate significant difference within a year at α=0.05).

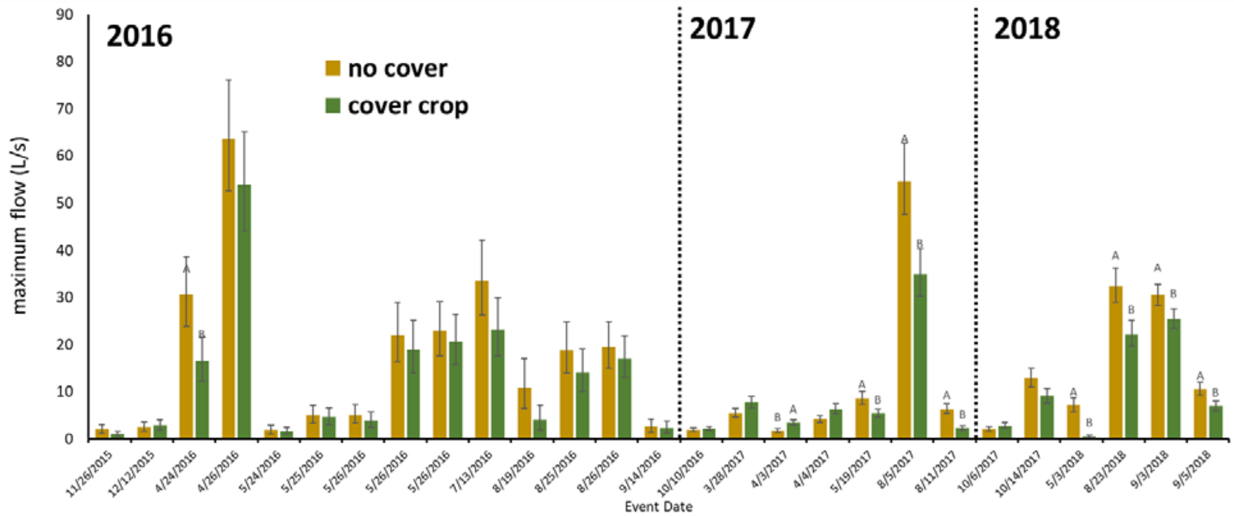

Figure 5. cover crop effects on the peak flow rate of runoff for individual runoff events at the Kansas Agricultural Watershed Field Laboratory (different letters indicate significant difference within a runoff event at α=0.05).

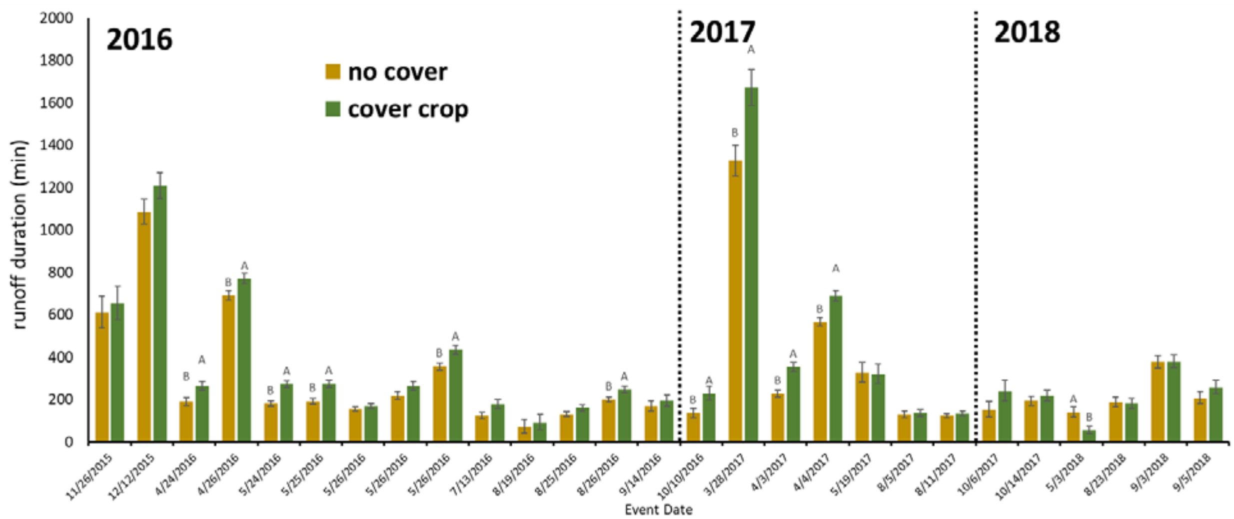

Figure 6. Cover crop effects on the runoff duration (time from initiation to cessation of runoff) for individual runoff events at the Kansas Agricultural Watershed Field Laboratory (different letters indicate significant difference within a runoff event at α=0.05).

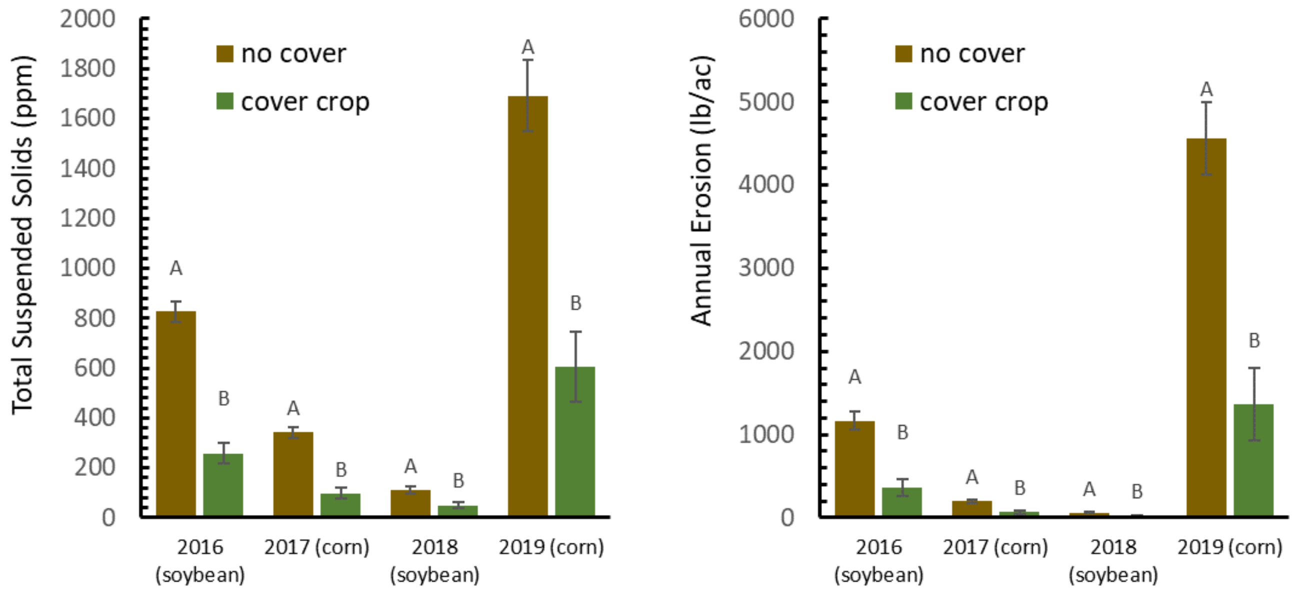

Figure 7. Cover crop effects on the flow-weighted annual sediment concentration and annual sediment loss in runoff at the Kansas Agricultural Watershed Field Laboratory (different letters indicate significant difference within a year at α=0.05).

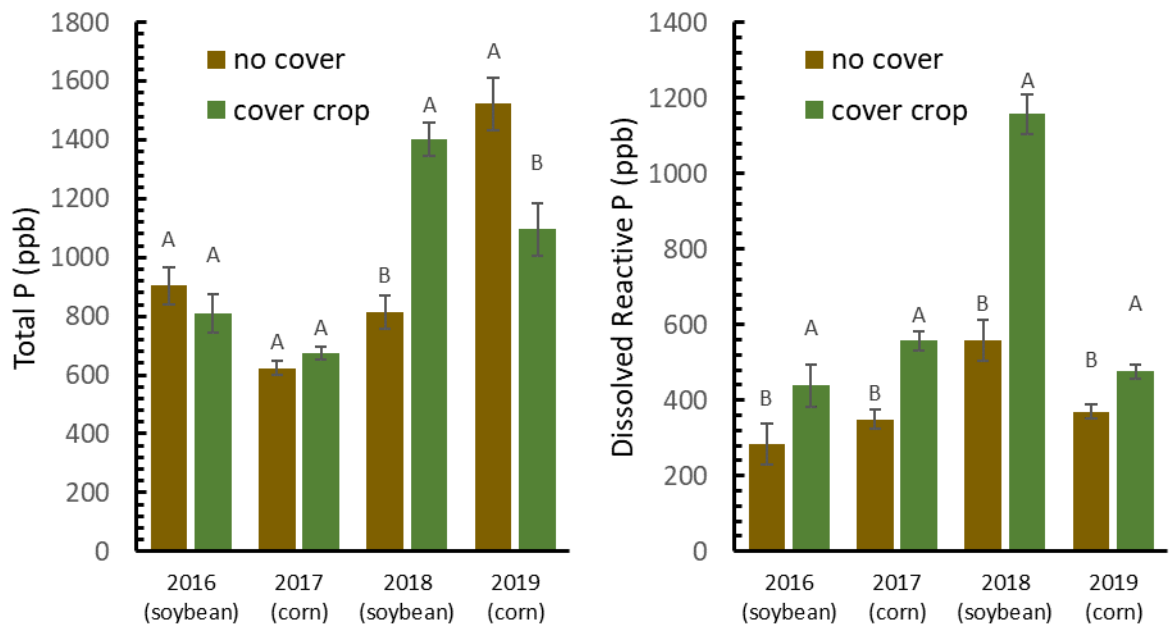

Figure 8. Cover crop effects on the flow-weighted annual total P and dissolved P concentrations in runoff at the Kansas Agricultural Watershed Field Laboratory (different letters indicate significant difference within a year at α=0.05).

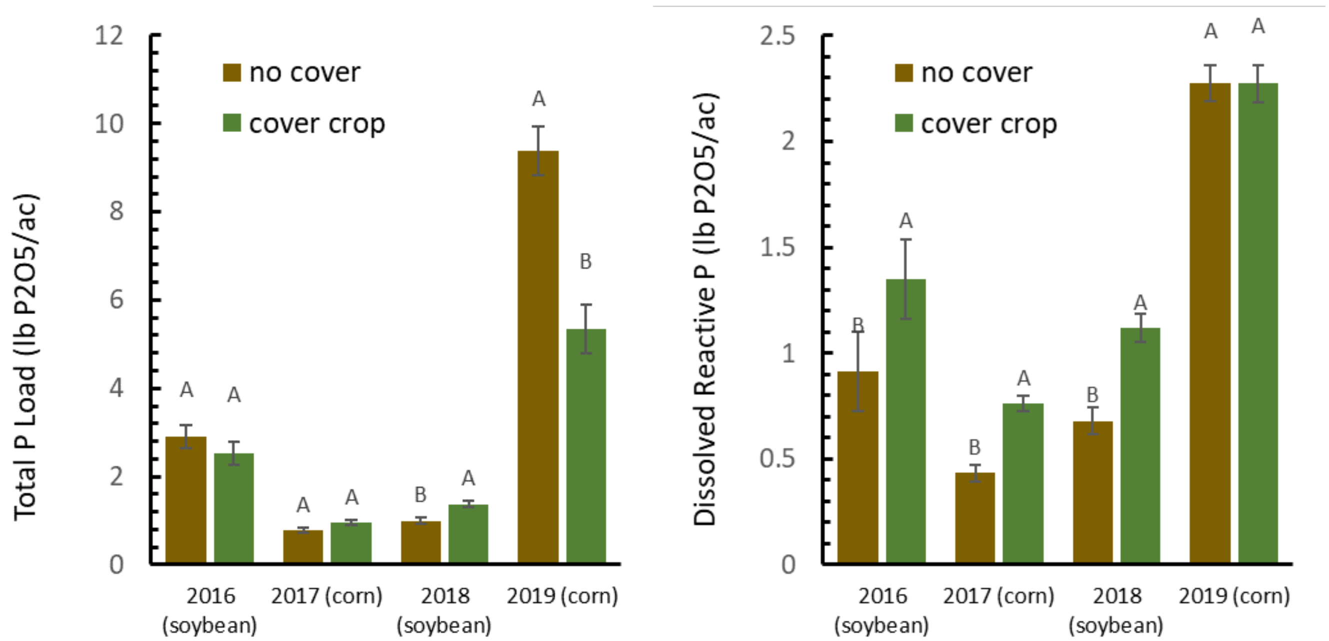

Figure 9. Cover crop effects on the annual total P and dissolved P loss in runoff at the Kansas Agricultural Watershed Field Laboratory (different letters indicate significant difference within a year at α=0.05).

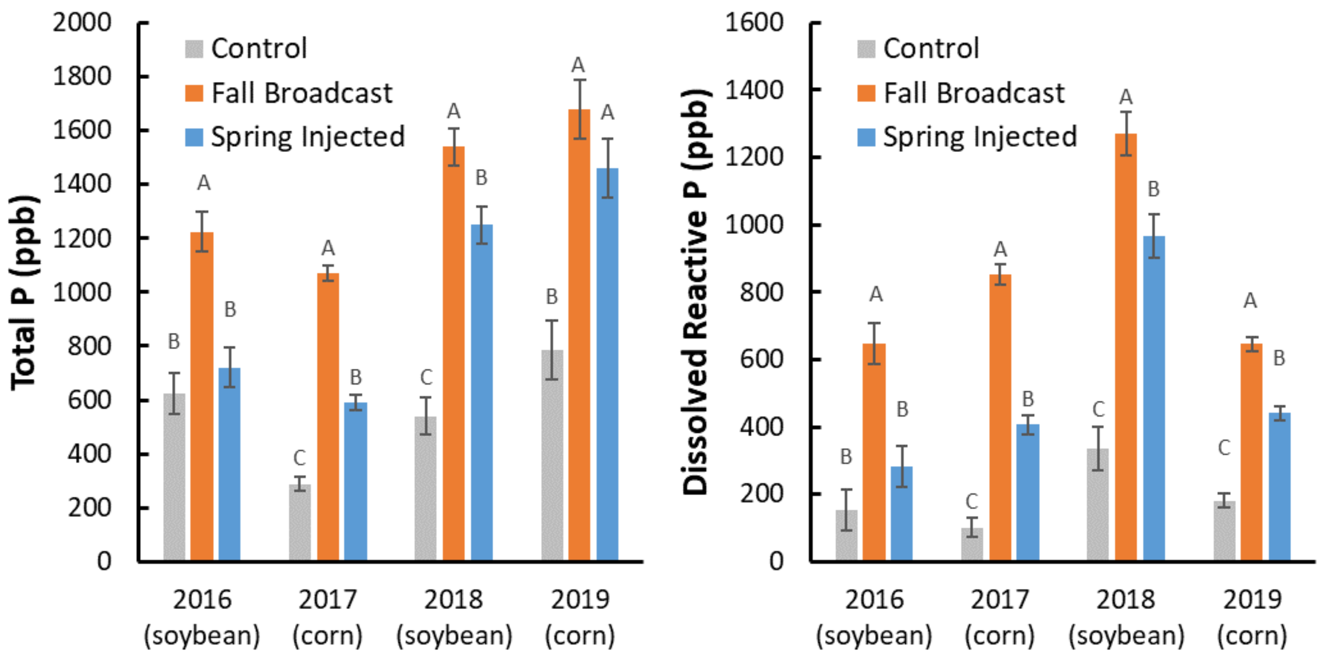

Figure 10. Phosphorus fertilizer management effects the flow-weighted annual total P and dissolved reactive P concentrations in runoff at the Kansas Agricultural Watershed Field Laboratory. Control = 0 lb P_2O_5/ac/yr; Fall Broadcast = 55 lb P_2O_5/ac/yr broadcast as diammonium phosphate between Nov 15 and Jan 15, Spring Injected = 55 lb P_2O_5/ac/yr applied as ammonium polyphosphate in a 2x2 placement at planting. Different letters indicate significant difference within a year at α=0.05.

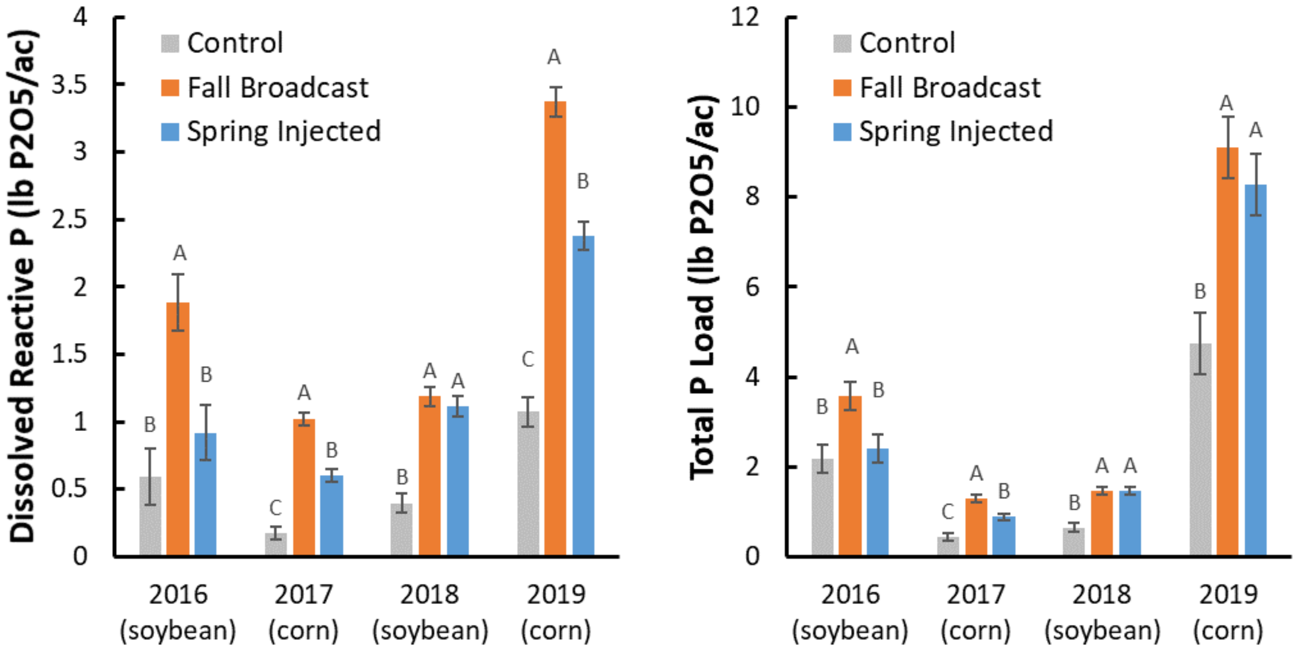

Figure 11. Phosphorus fertilizer management effects the flow-weighted annual dissolved P and total P concentrations in runoff at the Kansas Agricultural Watershed Field Laboratory. Control = 0 lb P_2O_5/ac/yr; Fall Broadcast = 55 lb P_2O_5/ac/yr broadcast as diammonium phosphate between Nov 15 and Jan 15, Spring Injected = 55 lb P_2O_5/ac/yr applied as ammonium polyphosphate in a 2x2 placement at planting. Different letters indicate significant difference within a year at α=0.05.

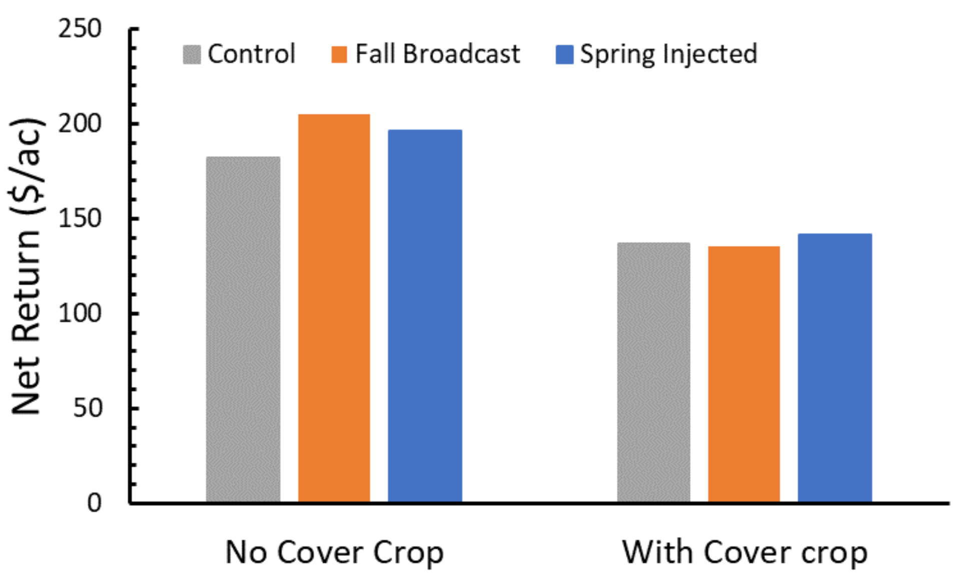

Figure 12. Net return for corn-soybean production for cropping systems with different P fertilizer management and cover crop systems at the Kansas Agricultural Watershed Field Laboratory. Control = 0 lb P_2O_5/ac/yr; Fall Broadcast = 55 lb P_2O_5/ac/yr broadcast as diammonium phosphate between Nov 15 and Jan 15, Spring Injected = 55 lb P_2O_5/ac/yr applied as ammonium polyphosphate in a 2x2 placement at planting.