NRCS CONSERVATION INNOVATION GRANT

Final Project Report

Grantee Entity Name	Kansas State University
Project Title	**Protecting Surface Water with Healthy Soils and Cover Crops**
Agreement Number	69-3A75-17-32
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Project Start Date	October 1, 2016
Project End Date	September 29, 2021
Period covered by report	**October 1, 2016 to September 29, 2021**
Geographic Area	Data collection in Northeast Kansas, Bluestem Hills (MLRA 76).

PROJECT SUMMARY

Reduction of phosphorus (P) loss from agricultural systems is a national concern because P inputs to surface water increases the likelihood of harmful algal blooms that deteriorate water quality. Including cover crops in agricultural systems could help reduce P loss from soils and applied fertilizers. Cover crops can reduce P loss and protect water quality by improving soil health, which can in-turn increase infiltration and reduce runoff. However, there is very little direct evidence of this in field-scale row-crop production. The goal of this project was to provide information linking soil health benefits to water quality protection because producers will be more likely to include cover crops in their cropping systems if they see direct evidence of cover crop impacts on improved soil health, reduced water loss (runoff), and increased water quality protection. Our objectives were to quantify the effects of cover crops on: i) surface runoff and P loss, ii) soil health, and ii) temporal trends of near-surface soil moisture.

We found that cover crop implementation consistently decreased soil erosion by 60 to 70% in no-till agriculture. This effect was observed at both the university research site (Kansas Agricultural Watershed Field Laboratory) and the producer demonstration site. Cover crop use also improved soil health by increasing total C, enzyme activities, microbial activity, and wet aggregate stability. Cover crop use had variable effects on runoff quantity where runoff was reduced for some events but not consistently. Analysis of cover crop effects on soil moisture revealed that, while cover crops can decrease soil moisture, the effects on soil moisture did not explain the cover crop effects on surface runoff. Therefore, cover crop effects on other soil properties, such as aggregate stability, may be responsible for differences in runoff.

We found that cover crop implementation increased dissolved reactive P loss in surface runoff and had variable effects on total P loss, with some decreases in total P loss and some increases depending on the year. Cover crop termination can result in a flush of dissolved reactive P release from the residue, which may explain in part the increased dissolved reactive P loss from fields with cover crops. Cover crops increased phosphatase enzyme activities, which could increase the cycling of organic P to more bioavailable inorganic forms; however, treatment effects on water extractable P from soils were not consistent with the increase in enzyme activities.

Because of the undesirable increase of dissolved reactive P loss with cover crop implementation, additional research is needed to more fully understand the cause of this effect and to develop crop management practices that mitigate this effect. Additional research is needed on the effects of cover crop species on dissolved reactive P loss and the interactions between P application rate and cover crop use on P availability in soils, crop growth and yield, and water quality. Long-term studies are needed to determine if cover crop effects on soil physical properties and runoff will mitigate, counteract, or exacerbate cover crop effects on dissolved reactive P loss.

Based on findings in this study, we recommend cover crop use for decreasing sediment loss and improving soil health in agricultural soils. We further recommend that producers use sub-surface P placement and other 4R management practices to reduce dissolved P loss from fields with cover crops. Following these guidelines will improve soil health and protect water quality.

DETAILS ON THE PROJECT

Background and Rationale

Reduction of phosphorus (P) loss from agricultural systems is a national concern because P 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; Paerl, 2008). Unfortunately, effects of P loss to surface water are not uncommon and can impact human health. The residents of Toledo, Ohio, could not drink water for three days in August 2014 due to a P-induced HAB (Jetoo et al., 2015). From 2010 through 2015, there were 114 confirmed HABs in 57 different lakes in the state of Kansas. 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 encouraging producers to adopt conservation practices that have documented effects on minimizing P loss to surface water.

Cover crop use is a promising conservation practice for reducing P loss and protecting surface water quality. 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 (Dabney 1998; Blanco-Canqui et al., 2011, 2012). Although reduced P loss is an often-cited advantage to cover crop use (Sharpley and Smith, 1991; Dabney et al., 2001), there is a surprising lack of field-scale data to quantify cover crop impacts on P loss, especially in no-till cropping systems.

Decreased runoff and improved water quality from cover crop use could be a result of decreased soil moisture due cover crop water use (i.e., transpiration). Cover crops could have also improved soil biological and physical characteristics that result in increased infiltration. Cover crops have been shown to increase soil health related parameters, such as glomalin and microbial biomass (Balota et al., 2014; Gispert et al., 2013). These parameters have in turn been related to improvements in aggregate stability and increased infiltration (Garcia-Orenes et al., 2012; Presley et al., 2012).

Understanding the mechanisms by which cover crops reduce runoff and protect water quality can assist in extending research findings to different environments, soils, and cropping systems. This can also help producers understand the multiple benefits arising from cover crop adoption. Furthermore, understanding cover crop impacts on soil health can help extrapolate water quality benefits from cover crops to other conservation practices that have similar impacts on soil health. Recent research found that producers were much more likely to adopt cover crops as a conservation practice if they perceived the positive benefits of the cover crop (Arbuckle and Roesch-McNally, 2015). Therefore, providing a solid link between cover crop use, improved soil health, and decreased runoff (decreased water loss) should help producers adopt this promising conservation practice.

On-farm demonstration studies can also encourage producers to adopt conservation practices because they are less skeptical of data generated on their own farm or in a full-scale production environment. The additional data can be used to verify results from other environments and soils. This is particularly important with respect to cover crop impacts on water quality and soil health because there is very little data available.

We need more information linking soil health benefits to water quality protection because producers will be more likely to include cover crops in their cropping systems if they see direct evidence of cover crop impacts on soil health, water loss (runoff), and water quality protection.

Project Objectives

The goal of this project was to use edge-of-field monitoring data paired with soil analysis to demonstrate that adoption of cover crop conservation systems will improve soil health, reduce P loss, and protect water quality. Specific project objectives supporting this goal were as follows:

1. Quantify the effects of cover crop implementation on runoff, sediment, and P loss from agricultural fields through edge-of-field monitoring in a long-term runoff monitoring project and an on-farm demonstration site, thereby demonstrating the effectiveness of conservation practices for reducing P loss and protecting water quality within diverse fertilizer management systems (e.g., no P fertilizer, fall broadcast P fertilizer, and spring injected P fertilizer).
2. Quantify cover crop implementation impacts on dynamic soil health properties from agricultural fields that have edge-of-field monitoring data in order to explain cover crop impacts on runoff, sediment, and nutrient losses; illustrate the linkage between soil health and water quality protection; and provide a solid foundation for future long-term water quality monitoring projects.
3. Document cover crop impacts on temporal trends in near-surface soil moisture to assist with the explanation of cover crop impacts on runoff, sediment loss, nutrient loss, and soil health.
4. Encourage cover crop implementation and water quality protection by disseminating project results to EQIP eligible producers through field days and extension programing.

Methods

Objective 1

Water quality impacts of cover crops were evaluated at the Kansas Agricultural Watershed (KAW) Field Laboratory (http://www.ksu.edu/kaw) and at an on-farm demonstration site in Geary County Kansas.

Kansas Agricultural Watershed (KAW) Field Laboratory

Water quality impacts of cover crops and P fertilizer management were quantified over a five-year period (fall 2014 through fall 2019) at the KAW Field Laboratory. The KAW Field Laboratory is located in the Bluestem Hills major land resource area (MLRA 76) and soils are mapped as an eroded Smolan silty clay loam with 3 to 7 percent slopes (Fine, smectitic, mesic Pachic Argiustolls). The experimental design was a 2X3 factorial replicated three times in a randomized complete block arrangement with two levels of cover crop (no cover crop, with cover crop) and three levels of P fertilizer management (no P fertilizer addition, 56 lb P_2O_5/ac surface-broadcast in the fall, 56 lb P_2O_5/ac sub-surface applied in spring in a 2x2 placement) (Figure 1). Runoff volume, total suspended solids concentration, total P concentration, and dissolved reactive P concentration for surface runoff were measured at the outlet of each experimental unit for every runoff event during the study using 1.5-ft H-flumes and ISCO automated water samplers equipped with bubbler units and integrated data loggers. Flow-weighted composite water samples were collected for each runoff event for the duration of the study and analyzed for total suspended solids (determined by filtration), total P (determined by persulfate digestion), and dissolved reactive P (determined by molybdate-blue colorimetric analysis following filtration through a 0.45 μm filter). Full details on experimental design and data collection and analysis are provided by Abel (2017), Carver (2018), and Carver et al. (2022).

On-farm demonstration study

Water quality impacts of cover crops in a no-till corn-soybean cropping system were quantified over a 4-year period (2018, 2019, 2020, 2021) with an edge-of-field water monitoring project on a producer field located in Geary County, Kansas. The producer field is located in the Bluestem Hills major land resource area (MLRA 76) and soils are mapped as Tully silty clay loam with 3 to 7 percent slopes (Fine, mixed, superactive, mesic Pachic Argiustolls). The field had been in no-till management for 12 years prior to the study. Edge-of-field surface water quality monitoring sites were established at four terrace outlets, creating 4 drainage areas ranging from 1.9 to 3.4 acres in size (Figure 2). Two of the areas received winter annual cover crops following the cash crop and two did not. Runoff at each watershed outlet was measured with 2.5-ft H-flumes. Water level was recorded every minute with a bubbler-type pressure transducer. A 200-mL (6.8 oz) water sample was collected for every 1 mm (0.04 inch) of runoff and added to a flow-weighted composite water sample for each runoff event. Water samples were and analyzed for total suspended solids (determined by filtration), total P (determined by persulfate digestion), and dissolved reactive P (determined by molybdate-blue colorimetric analysis following filtration through a 0.45 μm filter). Data were analyzed as a completely randomized design with two replications.

<u>Objective 2</u>

Composite soil samples were collected from each experimental unit at the KAW Field Lab in the spring and fall of 2018 and 2019, wet sieved, and stored moist at 4^oC until analysis. Soil samples were analyzed for organic P by the ignition method, water extractable P, and citrate extractable P. Enzyme activities were determined by p-nitrophenol release during incubation with the appropriate buffers and substrates. Treatment effects on soil C cycling were evaluated by determination of total C by combustion, microbial biomass C by fumigation and extraction, and active carbon by the potassium permanganate method. Phospholipid fatty acid (PLFA) analysis was conducted on freeze-dried soil samples by the Soil Health Assessment Center at the University of Missouri by extracting 1-2 g of the samples with Bligh-Dyer extractant and analyzed by gas chromatography.

Treatment effects on physical soil properties were assessed by measuring aggregate stability. Three composite soil samples were collected from the surface 10 cm from each watershed in spring of 2017 and spring of 2018 to assess wet aggregate stability according to the Kemper and Rosenau (1986) method with modifications as described by Presley et al. (2012)

Objective 3

Soil moisture was measured in the top 4 inches of the soil with a FieldScout TDR 300 hand-held probe (Spectrum Technologies, Inc., Aurora, IL) throughout the 2018, 2019, and 2020 growing seasons at the KAW field lab. We did not collect moisture data after May 10, 2020 because of reduced work force and reduced operations in response to the onset of the COVID-19 pandemic. For each measurement date, approximately 20 measurements were taken across each plot. The measurements were averaged to obtain a single value for each plot.

Objective 4

Project results were disseminated to producers and agronomic service providers through state and regional extension and crop consultant training meetings. We held a field day at the KAW Field Lab and a separate field day at the Geary County producer demonstration site. We hosted numerous field visits by staff from state and federal agencies and students and faculty from universities around the world.

Results

Objective 1: Quantify the effects of cover crop implementation on runoff, sediment, and phosphorus (P) loss from agricultural fields through edge-of-field monitoring in a long-term runoff monitoring project and an on-farm demonstration site, thereby demonstrating the effectiveness of conservation practices for reducing P loss and protecting water quality within diverse fertilizer management systems (e.g., no P fertilizer, fall broadcast P fertilizer, and spring injected P fertilizer).

Water quality at the Kansas Agricultural Watershed long-term monitoring project

The KAW Field Lab was in transition from conventional till to no-till during the first year of the study (2014/15), therefore, this year was not included in the data summary. The study period included two crop years with annual precipitation that was slightly greater than and less than average (2015/2016 and 2016/2017) as well as a very wet year (2018/2019) and a very dry year (2017/2018) (Figure 3).

We found that cover crop implementation had minimal impacts on total annual runoff volume except for the very wet 2019 crop year, in which the cover crop decreased runoff by 20% (Figure 4). More importantly than runoff volume, was the cover crop impact on peak runoff and runoff duration, where the cover crop decreased peak runoff rates and increased the runoff duration, which decreased overall runoff intensity (Nelson et al., 2017).

The decrease in runoff intensity resulted in 60 to 70% less sediment loss from the cover crop treatment than from the no cover crop treatment (Figure 5). Furthermore, the effect of cover crop on sediment loss was modified by the P fertilizer treatment, where the cover crop reduced sediment loss more when P fertilizer was added (Figure 6), particularly in 2017, 2018, and 2019.

The cover crop had variable effects on total P (TP) loss, where cover crop increased TP loss in 2018, decreased TP loss in 2019, and had no effect on TP loss the other years (Figure 7a). The cover crop effect on dissolved reactive P (DRP) loss was more consistent, increasing DRP loss in three out of four years of the study (Figure 7b).

The control, or no P application, treatment had the lowest TP and DRP losses (Figures 8 and 9), but also had lower crop yields in 2 of 4 years (Figure 10). The spring injected fertilizer treatment decreased TP losses in 2 of 4 years and DRP losses in 3 of 4 years (Figures 8 and 9) compared to fall broadcast P management. Over the 4-year period, the spring injected treatment had 33% less DRP loss than the fall broadcast management. More detailed analysis of the data is found in the journal publication by Carver et al. (2022).

Water quality at an on-farm demonstration site

The study period included two years with about average rainfall (2020, 2021), one year with rainfall far greater than average (2019) and one year with rainfall far less than average (2018) (Figure 11).

Cover crop effects on water quality at the producer demonstration site followed the same general trends as were observed at the KAW field lab. The cover crop reduced runoff volume in 2019 (the wettest year) but had no impact on runoff volume the other years (Figure 12a). The cover crop tended to reduce sediment loss in three of four years, but the reduction was only statistically significant in 2019 (Figure 12b). The cover crop reduced total P loss in two of the 4 years, but tended to increase dissolved reactive P loss, although the increase was not significant (Figure 13).

Large variation in runoff volume combined with only two replications made it hard to detect treatment effects on sediment, TP, and DRP loss. However, there was less variation in chemical concentrations in the runoff, and therefore easier to detect treatment effects on total suspended sediment, TP and DRP concentrations. The cover crop significantly decreased the total suspended solids concentration in runoff water for 14 of the 27 runoff events (Figure 14a). The cover crop effect on TP concentration in runoff water was variable, where cover crop significantly decreased TP concentration in runoff for 7 events and significantly increased TP concentration in runoff for 5 events (Figure 14b). The cover crop effect on DRP concentration was more consistent, where cover crop significantly increased dissolved reactive P concentration in runoff for 15 of the 27 events (Figure 14c). A more detailed analysis of the data is found in the poster presentation by Nelson et al. (2021).

General conclusions regarding cover crop effects on water quality (Objective 1)

Across both studies we observed that cover crops are a good conservation practice for reducing erosion in no-till agriculture. Cover crops can reduce TP loss in situations with greater risk for erosion, such as the high rainfall in 2019. However, cover crops tend to have no effect or even increase TP loss when the risk for erosion is low. Cover crops can increase DRP concentrations in runoff and DRP loss. Best management practices for P fertilizer, such as sub-surface placement, are more effective than cover crops for reducing P losses in surface runoff.

<u>Objective 2.</u> Quantify cover crop implementation impacts on dynamic soil health properties from agricultural fields that have edge-of-field monitoring data in order to explain cover crop impacts on runoff, sediment, and nutrient losses; illustrate the linkage between soil health and water quality protection; and provide a solid foundation for future long-term water quality monitoring projects.

The data for objective 2 were all collected from the KAW field lab because the KAW field lab had enough treatments and replication to produce adequate statistical power for hypotheses tests.

Cover crop and P fertilizer management effects on soil P and enzyme activities

We found a tendency for greater organic P in the surface soil of the no P control treatment regardless of cover crop treatment (Figure 15). Organic P comprised 60% of the total P in surface soils of the no P control compared to only 40% of total P for the fertilized treatments (data not shown). Application of fertilizer increased the concentration of citrate extractable P and water extractable P in the surface soil compared to the control. The spring injected fertilizer placement tended to decrease the citrate extractable P and water extractable P concentration in the surface soil compared to the fall broadcast treatment except when a cover crop was present (Figure 16). This effect was significant in two out of three years for citrate extractable P and one out of three years for water extractable P.

These results suggest that cover crops could be translocating P that was applied sub-surface in spring injected treatment to the near surface soil. At the same time, cover crops may be increasing the potential for organic P mineralization in all fertilizer management treatments due to increased enzyme activities (Table 1). This body of research demonstrates that cover cropping and P fertilizer management in no-till corn-soybean cropping systems interact, changing where and how P is stored and cycled.

Additional data and analyses related to linkages between cover crops, phosphorus fertilizer management, soil health, and phosphorus bioavailability are presented in the dissertation by Starr (2021).

Cover crop and P fertilizer management effects on soil C, microbial activity, and microbial composition

We found that soil health metrics can have varying levels of response to cover crop implementation. The hypothesis that cover crop implementation would increase total organic carbon and active C was found to be true. Cover crop implementation increased total organic carbon in the spring samples and one fall sampling (F2018) by an average of 15% (Table 2). The active C pool was increased by the cover crop in the spring samplings by 20%, but there was no effect of cover crop in the fall samples (Table 2).

The N-based soil health indicators (total N, dissolved organic N, ammonium, and nitrate) plus dissolved organic C were not affected to any great extent by the cover crop or P fertilizer treatments in this study.

The hypothesis that assays examining microbial biomass and activity indicators (respiration and enzyme activity assays) would increase within cover crops was not entirely in-line with the results of this study. Soil respiration was only greater in the CC treatment in spring 2018 (data not shown). β-glucosidase and β-glucosaminidase enzyme activities increased by 33% and 35% respectively across seasons sampled. These enzyme activities were all significant except for fall 2019 which was not significantly different between cover crop treatments for β-glucosidase (Table 2). This could indicate that β-glucosaminidase is more reliable in detecting enzyme activity in response to cover crop treatments; however, with only one data point of not observing this trend in β-glucosidase this is not definitive.

Microbial biomass C followed a similar trend to active C findings, while microbial biomass N was not found to be impacted by any treatments. We generally failed to reject the null hypothesis that P fertilizer management strategies would not impact C and N soil health metrics in the presence or absence of cover crops, with the exceptions of β-glucosaminidase in spring 2018, and NH4-N in spring 2018, spring 2019, and fall 2019 (data not shown). In general, cover crop implementation had a greater effect on total C, labile C pools, and microbial biomass C and enzyme activity as compared to assays that targeted N pools including total N, labile N, and microbial biomass N.

Cover crops consistently increased gram-positive bacteria, actinomycetes, and AM fungi in soils (Figure 17). Although cover crops significantly increased microbial biomass, the percent community structure was generally not found to vary more than 1% between the cover crop and no cover treatments (Table 3), indicating that cover crop implementation had generally the same effects on all classes of microorganisms.

Additional data and analyses related to soil microbial response to cover crop implementation and P fertilizer management are found in the dissertation by Stewart (2021).

Cover crop effects on aggregate stability

In spring of 2017, after 3 years of cover crop implementation, we found that cover crops had increased the quantity of large (> 4.75 mm) water-stable aggregates at both soil depths by 130 to 150% (Figure 18), however, there was not any significant effect on the other size fractions. In spring of 2018, the cover crops had increased the amount of large (> 4.75 mm) water-stable aggregates at both soil depths by 250 to 270% while simultaneously decreasing the amount of water stable aggregates in the small size fractions (Figure 19). Cover crops also increased the geometric mean diameter and mean weight diameter of the water-stable aggregates for both years (Figure 20).

Objective 3. Document cover crop impacts on temporal trends in near-surface soil moisture to assist with the explanation of cover crop impacts on runoff, sediment loss, nutrient loss, and soil health.

Cover crops significantly decreased soil moisture during a period of low rainfall in the spring of 2018 (Figure 21). This decreased soil moisture corresponded to a significant decrease in runoff for events on May 4 and May 29, 2018 (Figure 22). Cover crops had minimal impact on soil moisture for the remainder of the monitoring period (2019 and spring 2020). Although the cover crop did not have any significant impact on soil moisture for the 2019 growing season (Figure 21), we did observe a decrease in total runoff volume for that growing season. This indicates that the cover crop impact on runoff volume was more likely related to changing physical properties that would increase infiltration (such as increased water stable aggregates, Figure 19 and 20) rather than increased transpiration that would modify soil moisture condition at the time of runoff.

Objective 4. Encourage cover crop implementation and water quality protection by disseminating project results to EQIP eligible producers through field days and extension programing.

Research results were presented at regional training conferences, field days, and scientific meetings throughout the duration of the study, with audiences including farmers, staff from state agencies (e.g., departments of agriculture, natural resources, and environment), NRCS field staff, NRCS and ARS scientists, undergraduate students, graduate students, and University Faculty. In addition, NRCS personnel and EQUIP-eligible stakeholders visited the site on multiple occasions throughout the study. In summary, we made 68 presentations to an estimated cumulative audience of 4843 persons (Appendix A). These presentations included 27 events where EQUIP eligible producers were most likely in attendance. Although, the exact number of EQUIP eligible producers in attendance at these events is unknown, the total approximate audience at events with likely EQUIP eligible producers was 2527 persons (Appendix A).

Challenges

Data collection for the project was delayed due to drought conditions in 2017 and 2018. Large variability in the data and limited number of treatments and replications at the producer demonstration site complicated statistical analysis and reduced statistical power of the tests for treatment impacts. The COVID-19 pandemic decreased workforce availability and complicated data collection in the final years of the project.

SUMMARY OF OUTPUTS

We published two peer-reviewed journal articles, two master's theses, two dissertations, seven non-peer reviewed publications, 19 abstracts, and 4 recorded presentations based on the work from this grant (Appendix B). Many of the publications and presentations are accessible at our project website, https://www.k-state.edu/kaw/.

POTENTIAL PROJECT IMPACTS ON CONSERVATION

Results from this project clearly illustrate that cover crop implementation can consistently decrease soil erosion in no-till agriculture by 60 to 70%. Cover crop use can also improve soil health by increasing total C, enzyme activities, microbial activity, and wet aggregate stability. We expect these results will encourage producers to adopt cover crops to conserve soil and improve soil health. Cover crop implementation increased dissolved reactive P loss and had variable effects on total P loss, with some decreases and some increases depending on the year. We expect state and federal programs will need to pair cover crop implementation with implementation of nutrient management conservation programs if the goal is to reduce both sediment and P losses from soil to water. Following these guidelines will improve soil health and protect water quality.

NEXT STEPS

Because of the undesirable increase of dissolved reactive P loss with cover crop implementation, additional research is needed to more fully understand the cause of this effect and methods to manage cover crops to avoid this effect. Additional research is needed on the effects of cover crop species on dissolved reactive P loss and the interactions between P application rate and cover crop use on P availability in soils, crop growth and yield, and water quality. Long-term studies are needed to determine if cover crop effects on soil physical properties and runoff will mitigate, counteract, or exacerbate cover crop effects on dissolved reactive P loss.

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Table 1. Acid and alkaline phosphatase enzyme activity from spring 2018 – fall 2019 in the 0-5 cm depth of soil at the KAW field lab. Letters indicate significant differences within season ($p<0.05$). Table abbreviations: fall broadcast diammonium phosphate (FB), spring injected ammonium polyphosphate (SI), and no P fertilizer applied (NP) and cover crop treatments - cover crops (CC) and no cover crop (NC).

	Acid Phosphatase				**Alkaline Phosphatase**			
	SP18	**FL18**	**SP19**	**FL19**	**SP18**	**FL18**	**SP19**	**FL19**
NP*NC	103.22	27.39	187.55	188.15	20.83	33.11 C	46.87	62.80
NP*CC	120.4	34.97	217.71	195.01	33.60	57.26 A	58.86	74.79
FB*NC	97.51	26.25	198.91	184.01	15.44	32.22 C	34.34	54.00
FB*CC	141.04	33.34	240.59	215.86	29.48	43.19 B	52.58	62.52
SI*NC	101.07	32.31	194.38	196.02	17.95	42 BC	44.57	70.19
SI*CC	127.61	34.65	239.13	221.93	29.32	45.06 B	56.34	60.47
*SE fert*cover*	*8.75*	*1.74*	*24.5*	*10.41*	*4.71*	*2.37*	*6.51*	*6.92*
p-value	*0.12*	*0.25*	*0.79*	*0.48*	*0.96*	*0.004*	*0.79*	*0.29*
NP	111.81	31.18	202.63	191.58	27.22	45.19 A	52.86	68.80
FB	119.27	29.80	219.75	199.94	22.46	37.71 B	43.46	58.26
SI	114.34	33.48	216.75	208.97	23.63	43.53 A	50.46	65.33
SE fertilizer	*7.75*	*1.31*	*23.19*	*7.36*	*3.34*	*1.68*	*5.32*	*4.89*
p-value	*0.45*	*0.12*	*0.31*	*0.29*	*0.59*	*0.03*	*0.23*	*0.34*
NC	100.6 B	28.65 B	193.61 B	189.39 B	18.07 B	35.78 B	41.92 B	62.33
CC	129.69 A	34.32 A	232.48 A	210.93 A	30.80 A	48.50 A	55.93 A	65.93
SE cover	*7.39*	*1.13*	*22.74*	*6.01*	*2.72*	*1.37*	*4.86*	*4*
p-value	*0.0001*	*0.002*	*0.002*	*0.03*	*0.01*	*<0.0001*	*0.01*	*0.54*

Table 2. Total C, microbial biomass C, active C, β-glucosidase (βG), β-glucosaminidase (βGA) treatment (trt) means, standard error (SE) and p-values in cover crop treatments in spring 2018, fall 2018, spring 2019, and fall 2019. An asterisk (*) is used to indicate significance of $p < 0.05$.

Crop growing prior to sampling	**Spring 2018** *Triticale & Rapeseed*		**Fall 2018** *Soybean*		**Spring 2019** *Winter Wheat & Rapeseed*		**Fall 2019** *Corn*	
	CC	**NC**	**CC**	**NC**	**CC**	**NC**	**CC**	**NC**
Total C								
Trt Means	1.45	1.29	1.72	1.45	1.60	1.38	1.57	1.52
SE	0.04		0.04		0.07		0.06	
p-value	*0.008**		*<0.0001**		*<0.0001**		*0.424*	
MBC								
Trt Means	339.13	314.49	281.09	273.87	96.72	81.47	363.32	370.68
SE	55.27		72.11		12.0		14.11	
p-value	*0.029**		*0.712*		*0.030**		*0.629*	
Active C								
Trt Means	328.34	268.88	326.86	277.77	321.30	275.70	421.69	386.93
SE	19.10		48.13		13.05		16.83	
p-value	*0.001**		*0.755*		*0.033**		*0.175*	
βG								
Trt Means	36.87	24.88	29.03	22.18	21.63	15.77	57.52	49.89
SE	3.00		0.93		3.36		3.38	
p-value	*<0.0001**		*0.0002**		*<0.0001**		*0.087*	
βGA								
Trt Means	11.59	7.84	11.09	8.07	18.07	13.41	21.52	18.09
SE	0.73		0.79		3.01		1.39	
p-value	*<0.0001**		*0.0008**		*0.005**		*0.038**	

Table 3. Mean percent community composition out of total biomass within cover crop (CC) and no cover crop (NC) treatments in fall and spring of 2018 and 2019 at the 0-5 cm depth.

	2018				**2019**			
	Spring		**Fall**		**Spring**		**Fall**	
Crop growing prior to sampling	*Triticale & Rapeseed*		*Soybean*		*Winter Wheat & Rapeseed*		*Corn*	
	CC	**NC**	**CC**	**NC**	**CC**	**NC**	**CC**	**NC**
	(% of total biomass)							
Gram-Neg	31.4	30.6	32.0	32.8	32.9	33.4	32.0	33.0
Gram-Pos	24.9	25.6	25.2	24.5	21.8	19.3	25.0	24.2
Actinomycetes	12.9	13.6	12.6	12.7	11.4	10.3	12.8	12.4
AM Fungi	3.6	3.4	4.2	4.1	4.2	3.7	4.2	4.4
Fungi	3.0	2.6	3.0	2.8	4.3	4.6	2.0	2.2
Other Eukaryotes	1.5	1.3	1.9	1.8	1.9	1.7	1.6	1.6

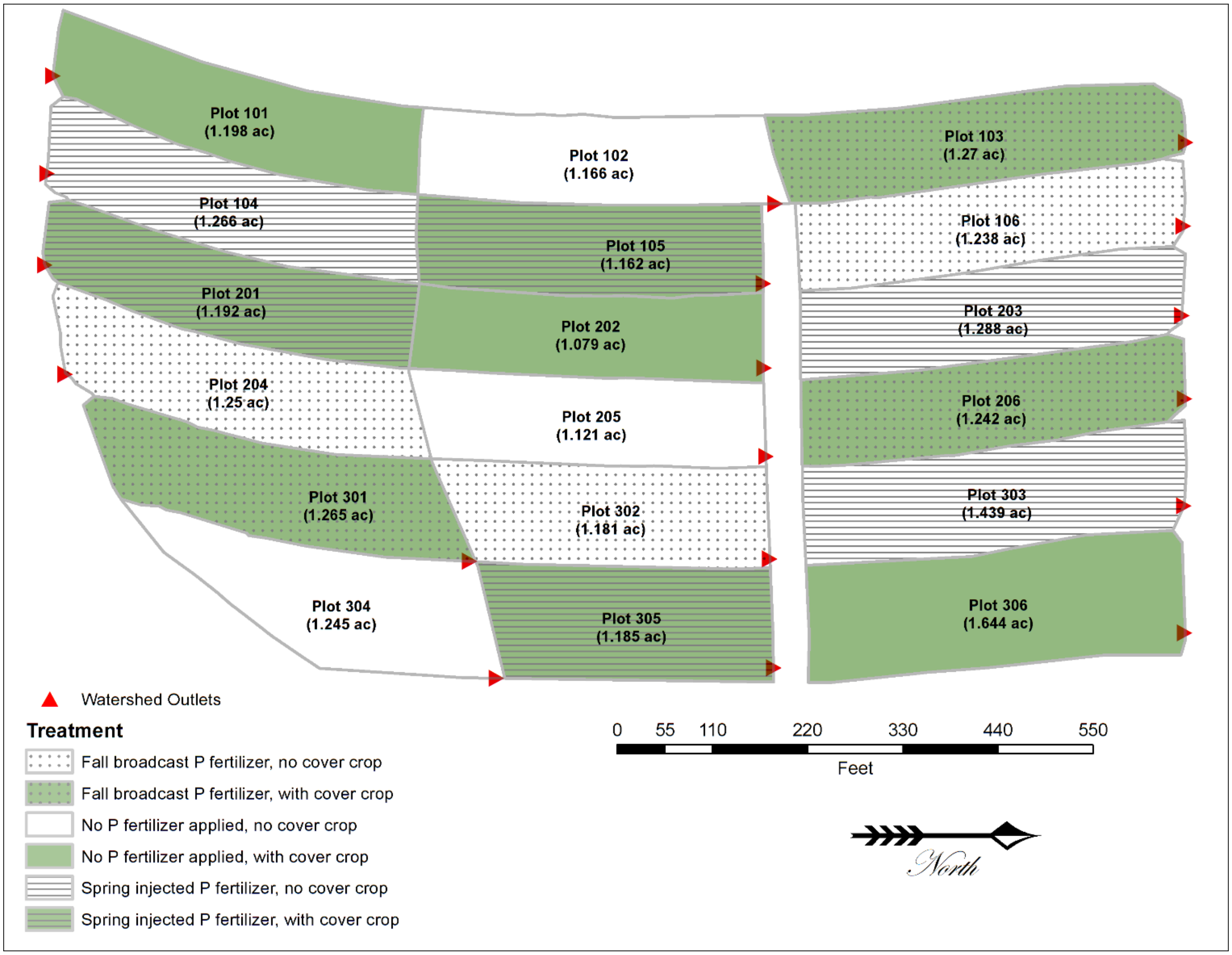

Figure 1. Layout of the Kansas Agricultural Watershed (KAW) project with watershed sizes and management systems. All watershed outlets drain to a grassed waterway or pipe outlet.

Figure 2. Treatment map for the on-farm edge-of-field monitoring project at Geary County, Kansas.

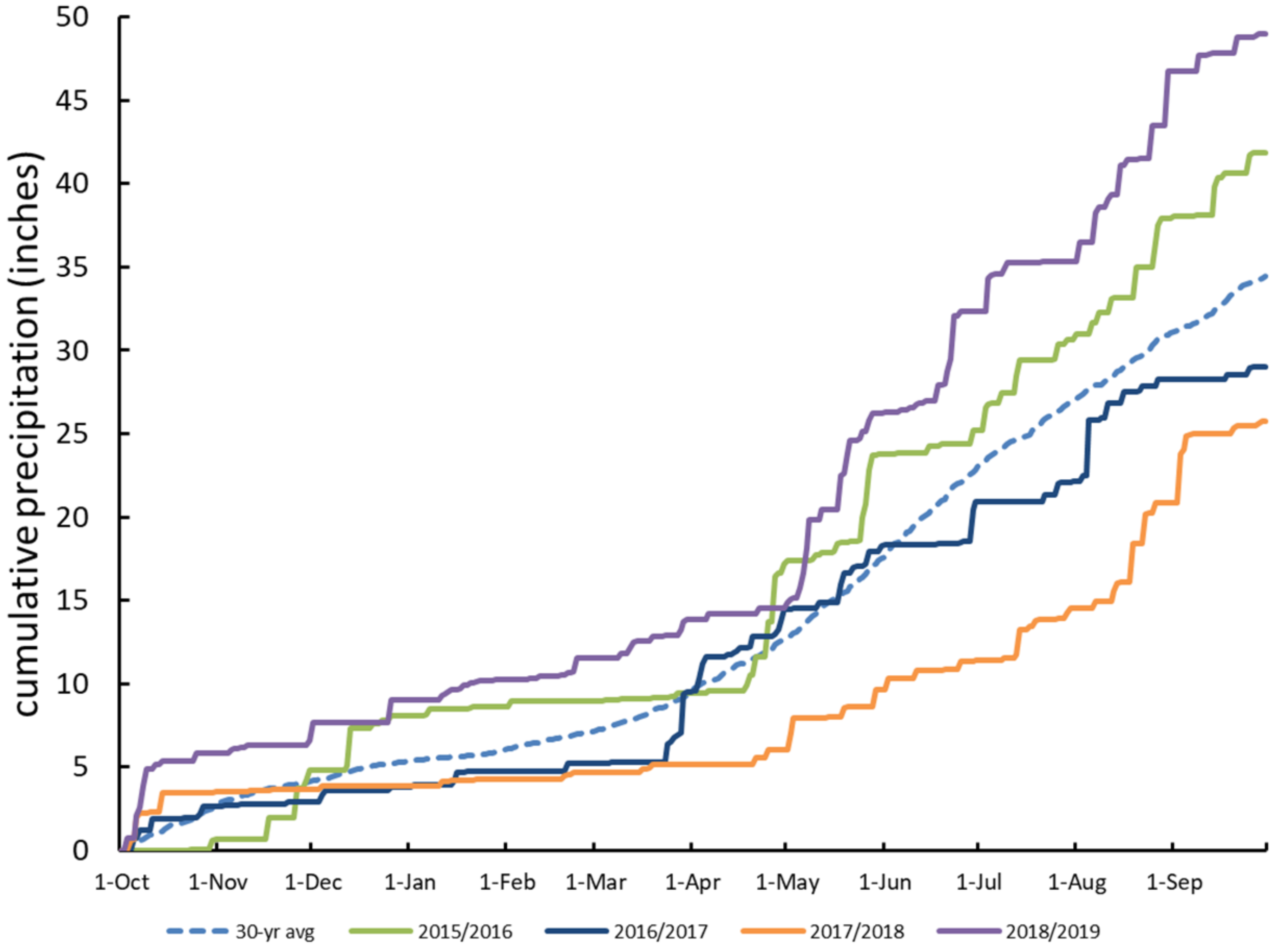

Figure 3. Cumulative daily precipitation at the Kansas Agricultural Watershed field laboratory from fall 2015 through fall 2019 compared to the 30-yr average precipitation.

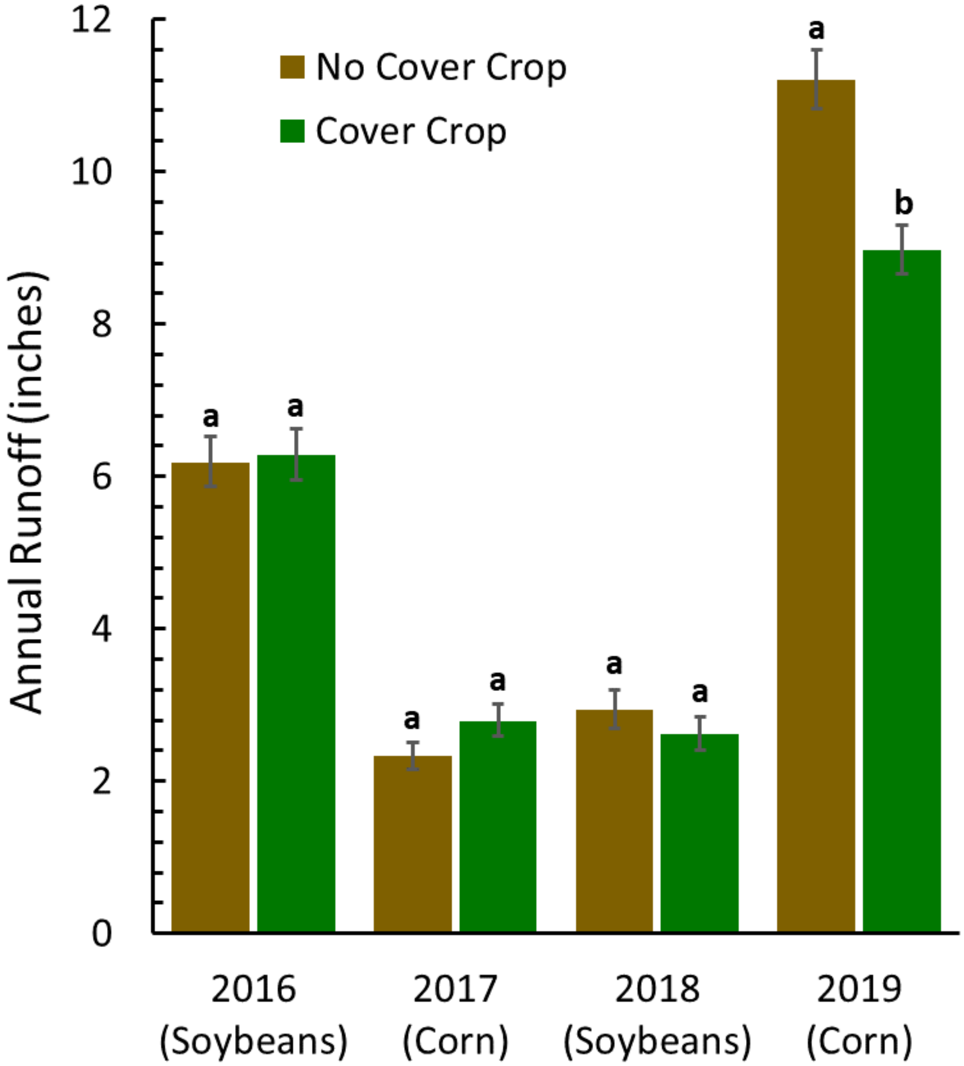

Figure 4. Cover crop effect on annual runoff at the KAW field lab (bars with the same letter within a crop year are not statistically different at α=0.05).

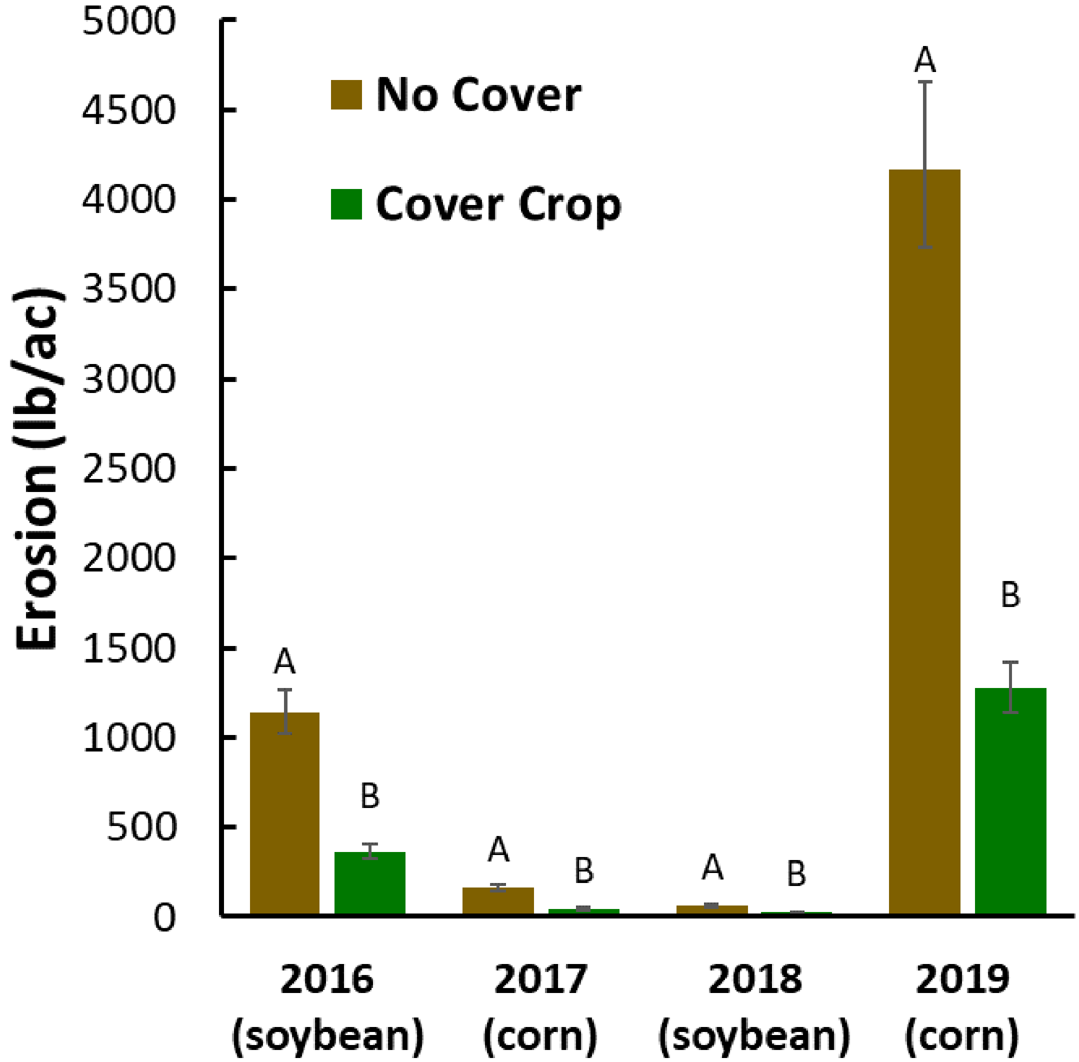

Figure 5. Cover crop effect on annual sediment loss at the KAW field lab (bars with the same letter within a crop year are not statistically different at α=0.05).

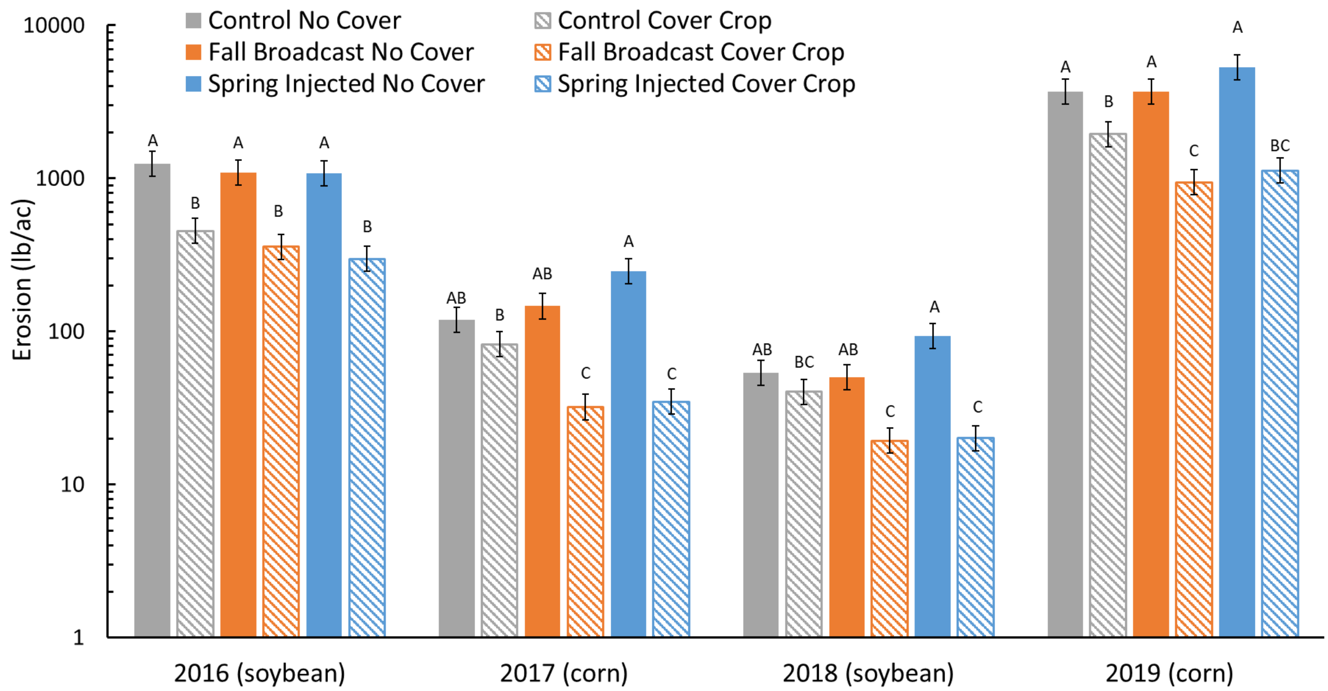

Figure 6. Cover crop and P fertilizer management effect on annual sediment loss at the KAW field lab (bars with the same letter within a crop year are not statistically different at α=0.05).

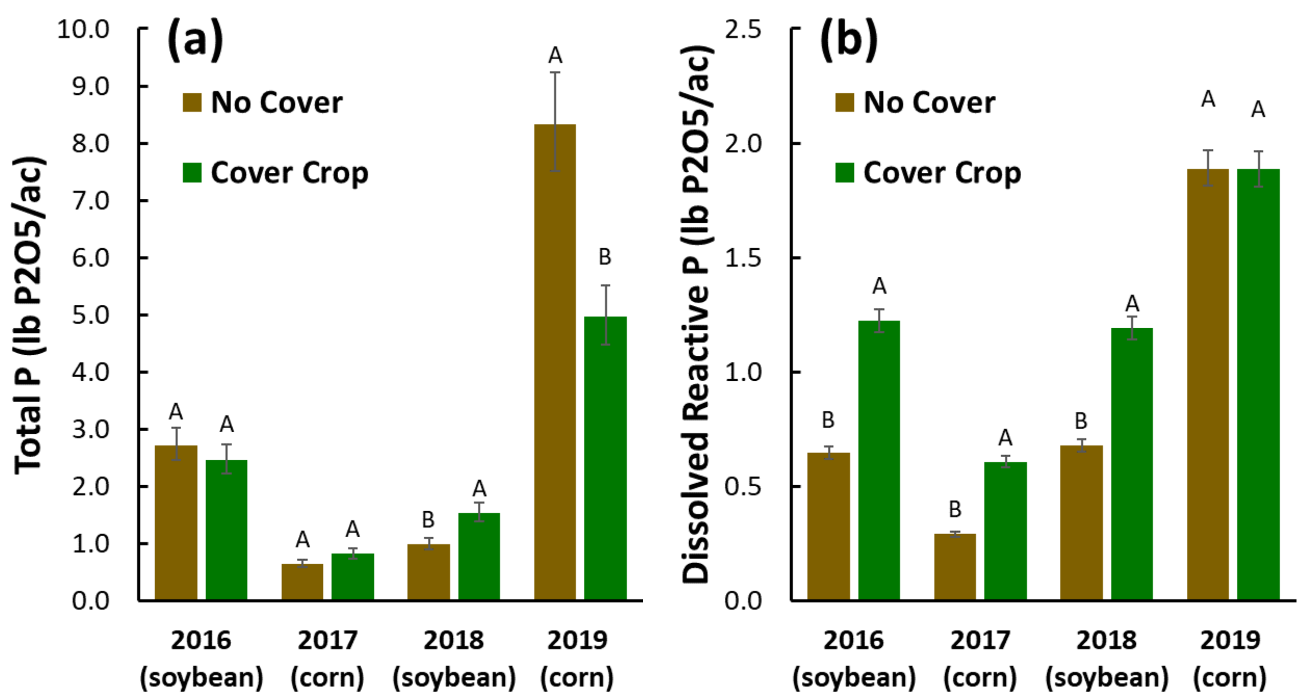

Figure 7. Cover crop effect on annual total P loss (a) and annual dissolved reactive P loss (b) at the KAW field lab (bars with the same letter within a crop year are not statistically different at α=0.05).

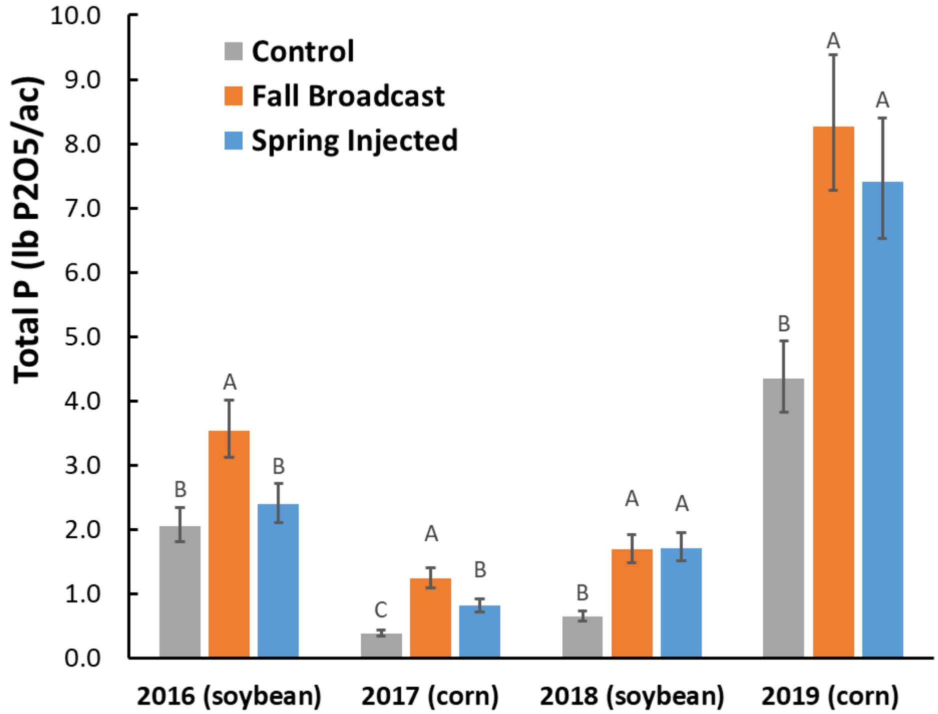

Figure 8. Phosphorus fertilizer management effect on annual total P loss at the KAW field lab (bars with the same letter within a crop year are not statistically different at α=0.05).

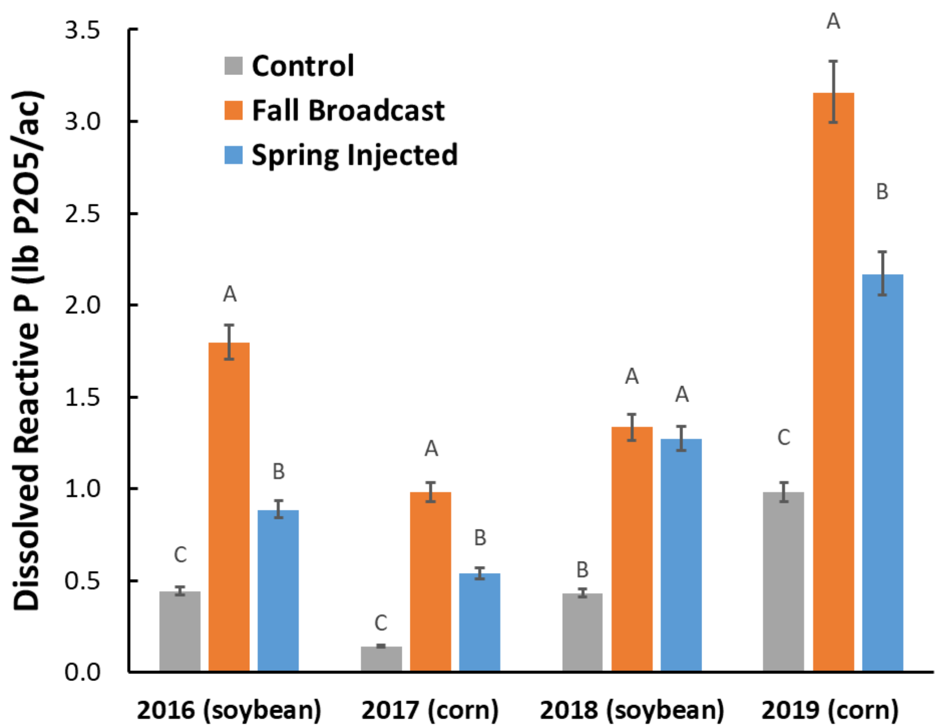

Figure 9. Phosphorus fertilizer management effect on annual dissolved reactive P loss at the KAW field lab (bars with the same letter within a crop year are not statistically different at α=0.05).

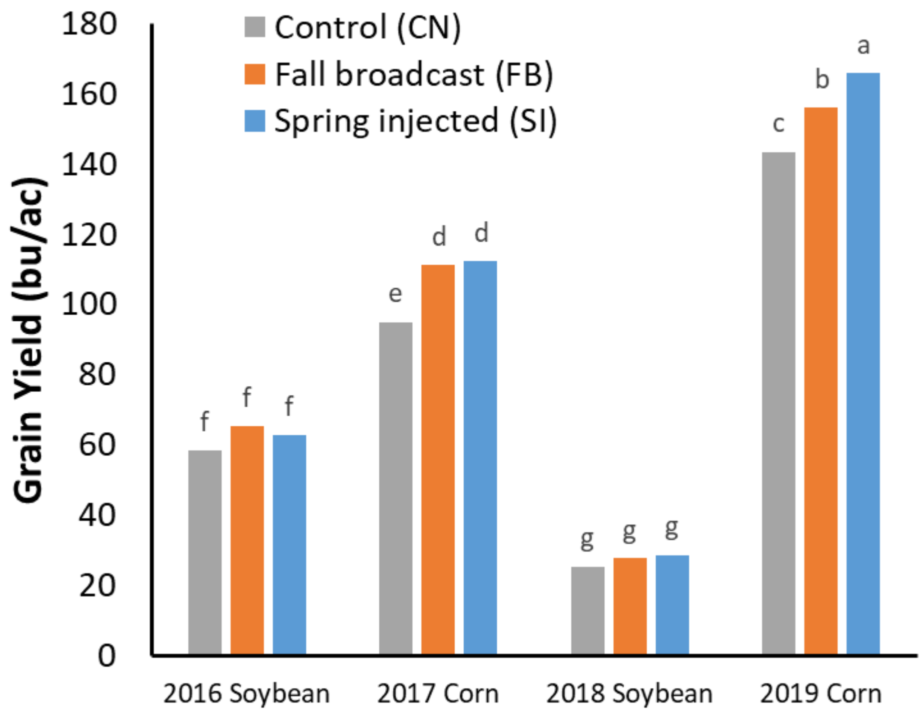

Figure 10. Phosphorus fertilizer management effect on grain yield at the KAW field lab (bars with the same letter are not statistically different at α=0.05).

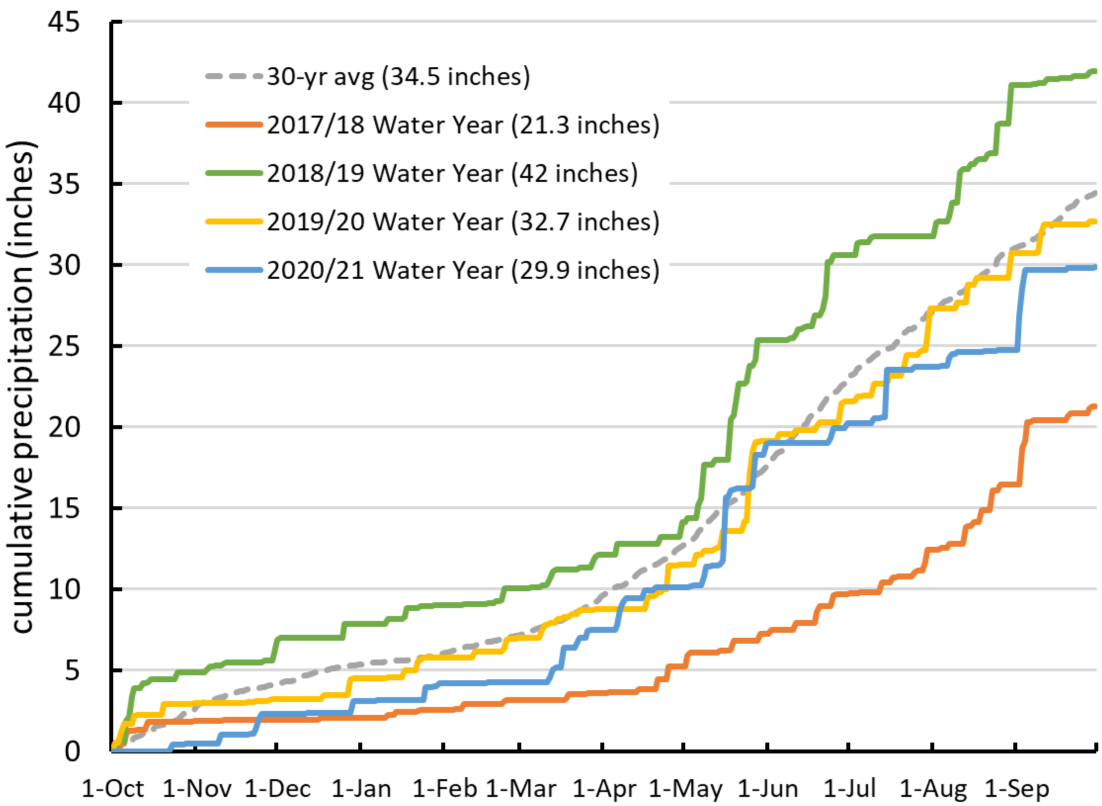

Figure 11. Cumulative daily precipitation at the producer demonstration site from fall 2017 through fall 2021 compared to the 30-yr average precipitation.

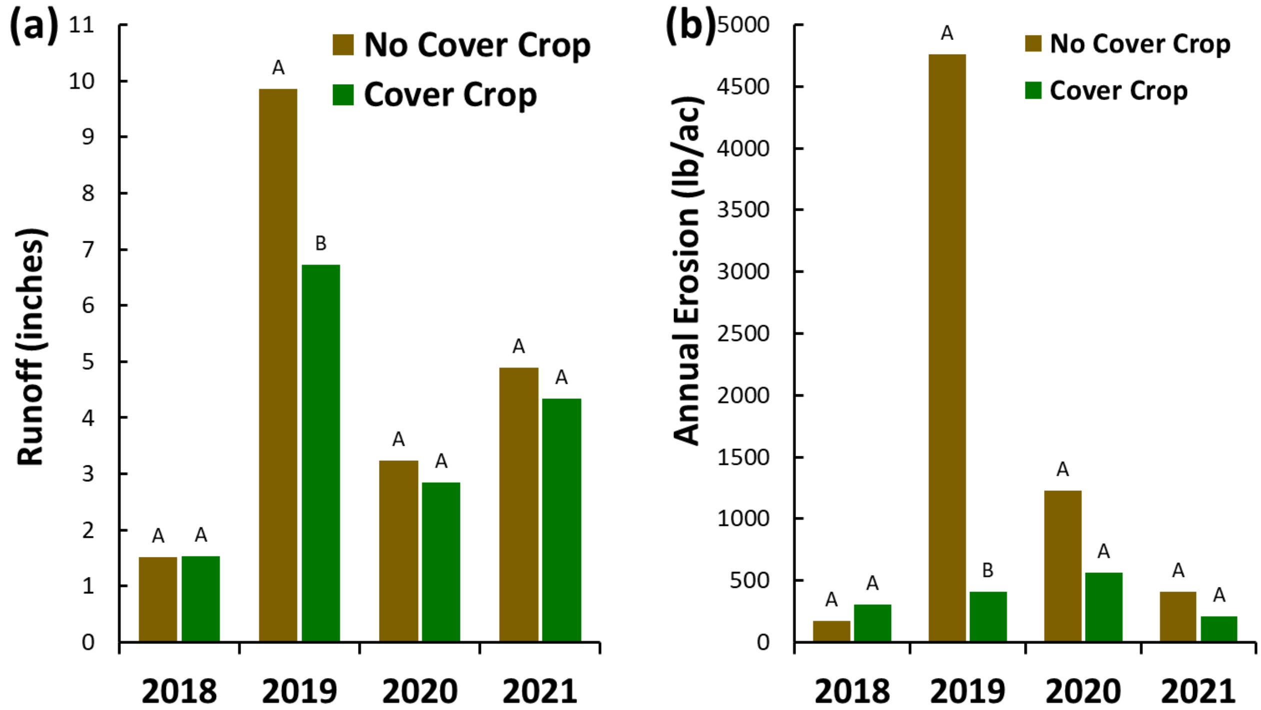

Figure 12. Cover crop effect on runoff (a) and sediment loss (b) at the producer demonstration site (bars with the same letter within a crop year are not statistically different at α=0.05).

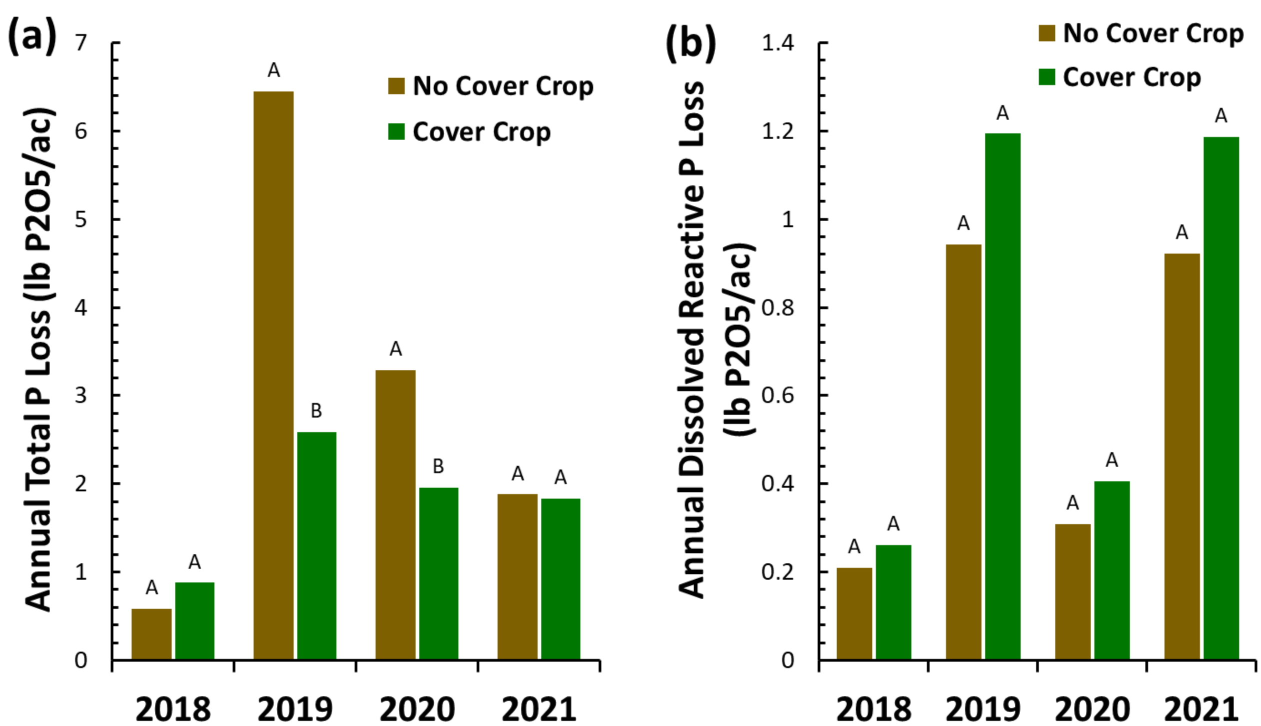

Figure 13. Cover crop effect on total P loss (a) and dissolved reactive P loss (b) at the producer demonstration site (bars with the same letter within a crop year are not statistically different at α=0.05).

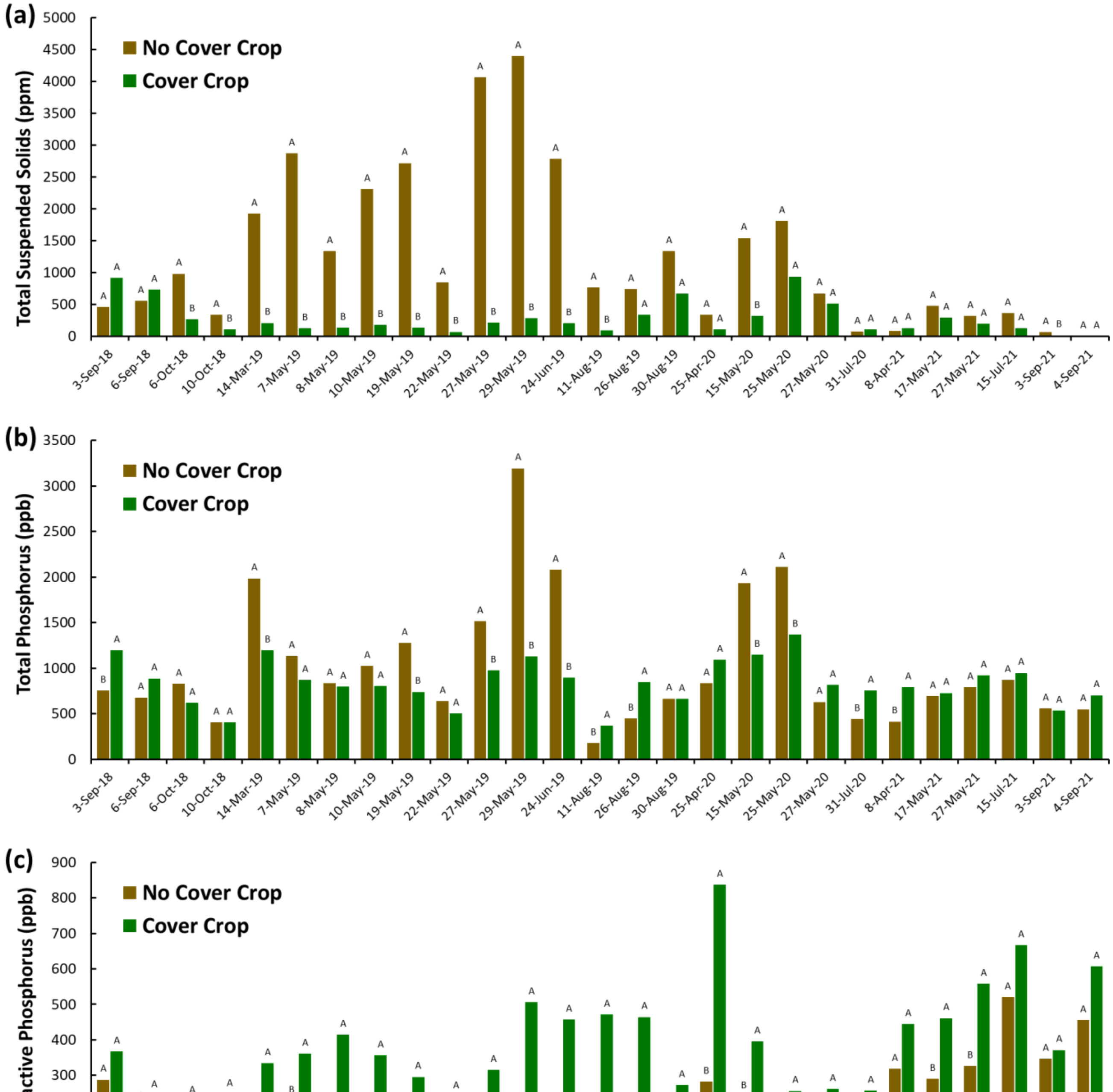

Figure 14. Cover crop effect on (a) total suspended solids concentration, (b) total P concentration, and (c) dissolved reactive P concentration in runoff water at the producer demonstration site (bars with the same letter within a runoff event are not statistically different at α=0.05).

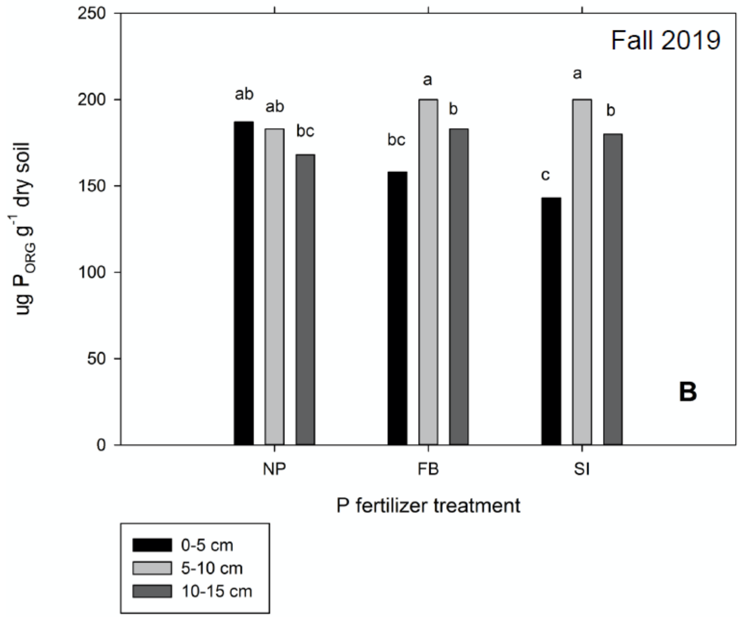

Figure 15. Total organic P concentration (ug PO g^{-1} dry soil) treatment means of depth*P fertilizer interaction at 0-5, 5-10, and 10-15 cm for Fall 2019. Letters signify significant differences ($p<0.05$). Figure abbreviations: fall broadcast diammonium phosphate (FB), subsurface spring injected ammonium polyphosphate (SI), and no P fertilizer (NP).

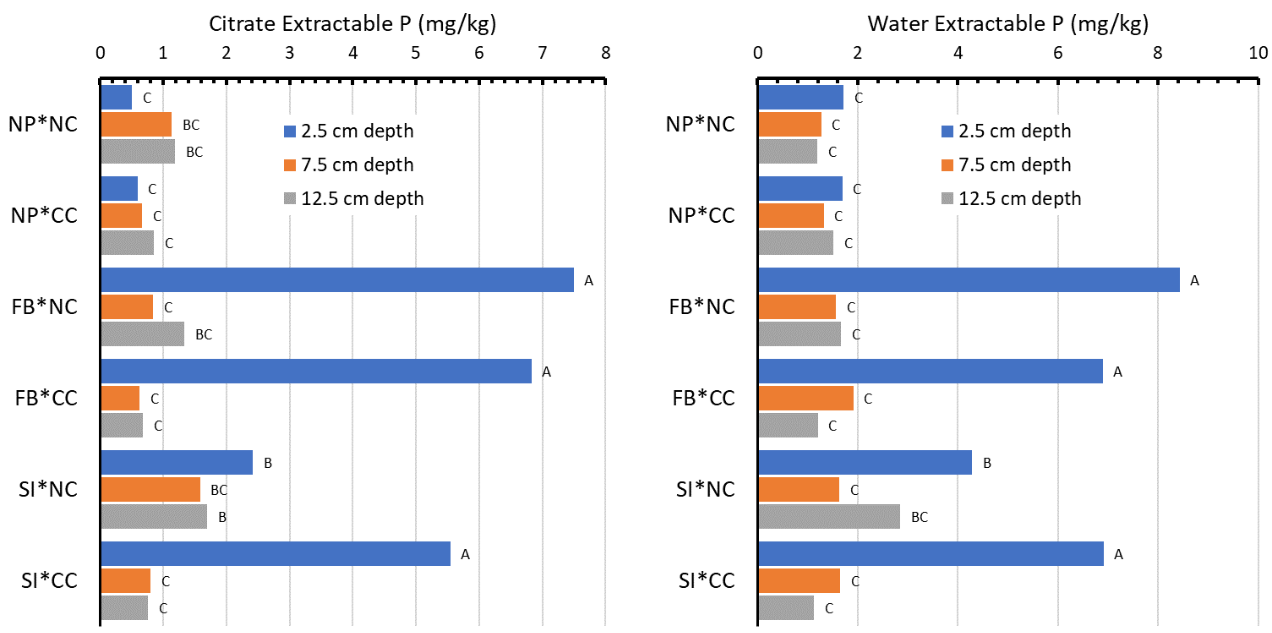

Figure 16. Citrate extractable P and water extractable P in soil as affected by fertilizer and cover crop treatments in spring of 2019 at the KAW field lab (NP= no P fertilizer; FB = fall broadcast P fertilizer; SI = spring injected P fertilizer; NC = no cover crop; CC = with cover crop).

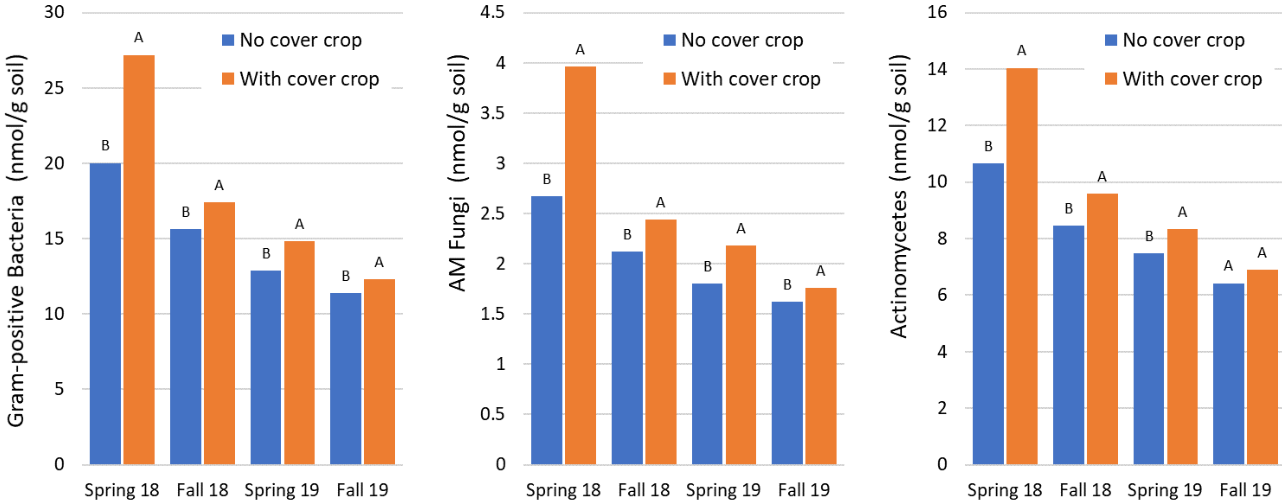

Figure 17. Cover crop effects on microbial biomass in gram-positive bacteria, AM fungi, and actinomycetes in soils at the KAW field lab (letters indicate significant differences within sampling time at $p<0.05$).

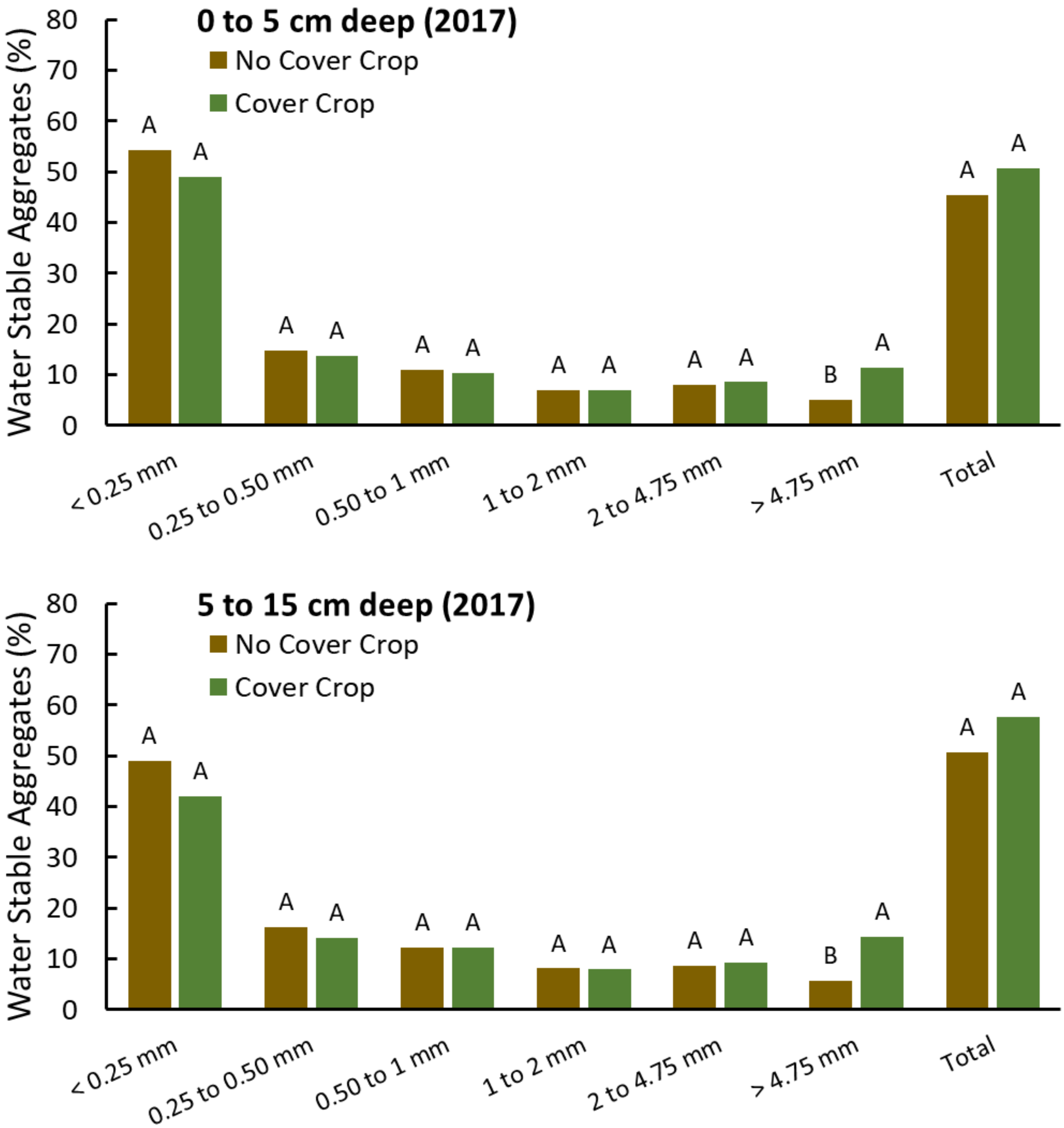

Figure 18. Cover crop effect on water stable aggregates in the 0-5 cm and 5-15 cm soil depths at the KAW field lab in spring 2017 (bars with the same letter within a size grouping are not statistically different at α=0.05).

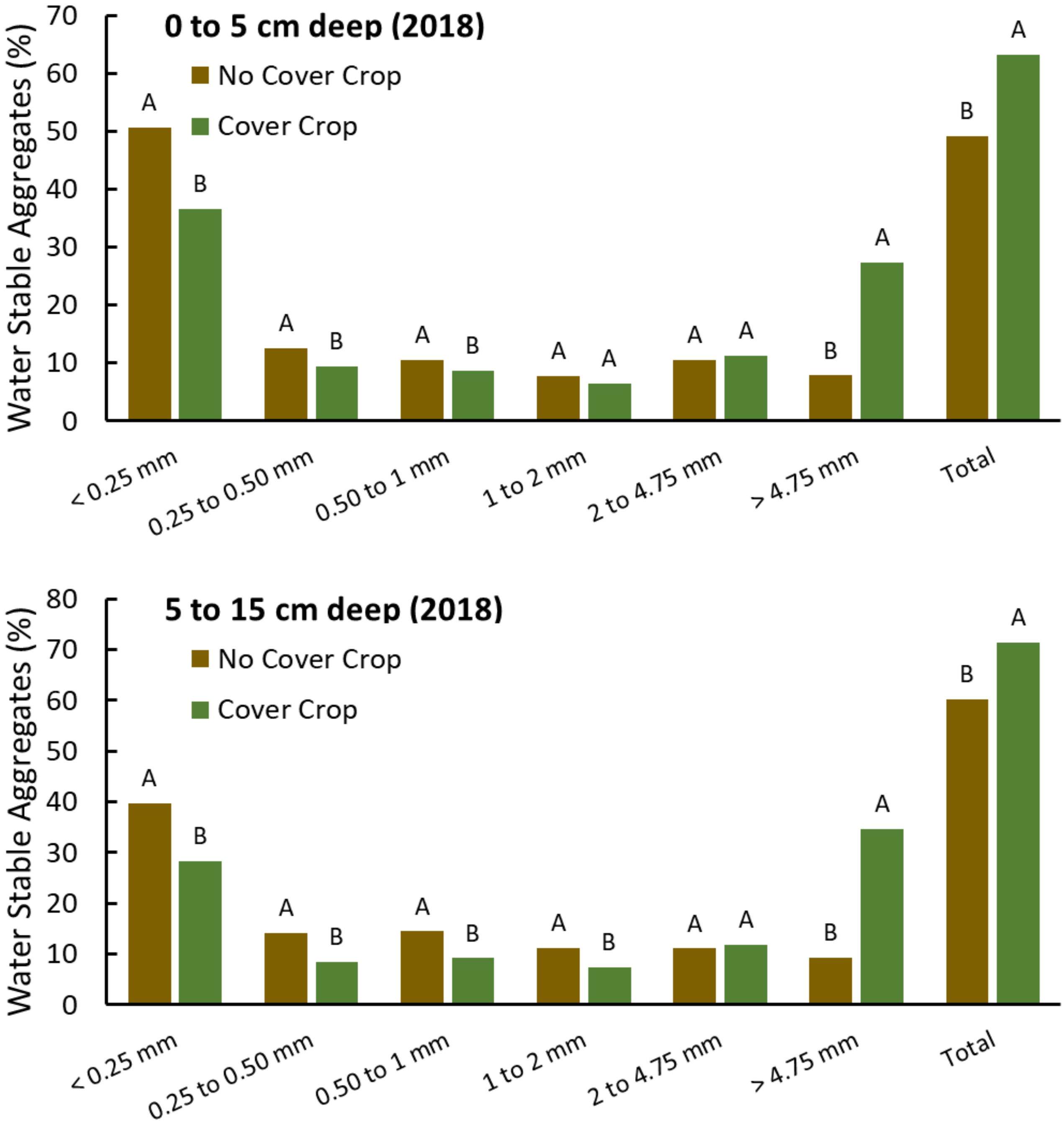

Figure 19. Cover crop effect on water stable aggregates in the 0-5 cm and 5-15 cm soil depths at the KAW field lab in spring 2018 (bars with the same letter within a size grouping are not statistically different at α=0.05).

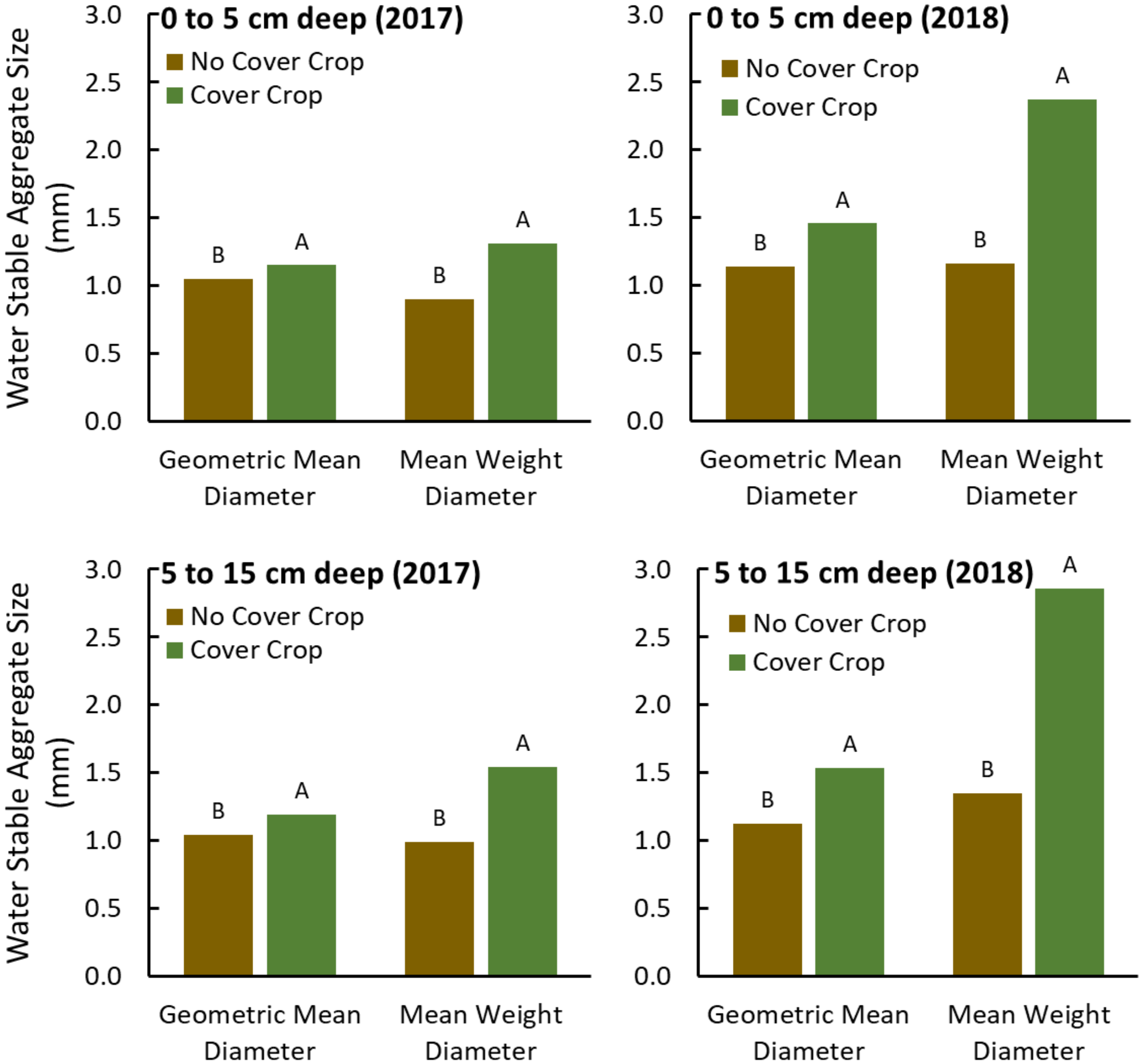

Figure 20. Cover crop effect on geometric mean diameter and mean weight diameter of water stable aggregates in the 0-5 cm and 5-15 cm soil depths at the KAW field lab in spring 2017 and 2018 (bars with the same letter pairing are not statistically different at α=0.05).

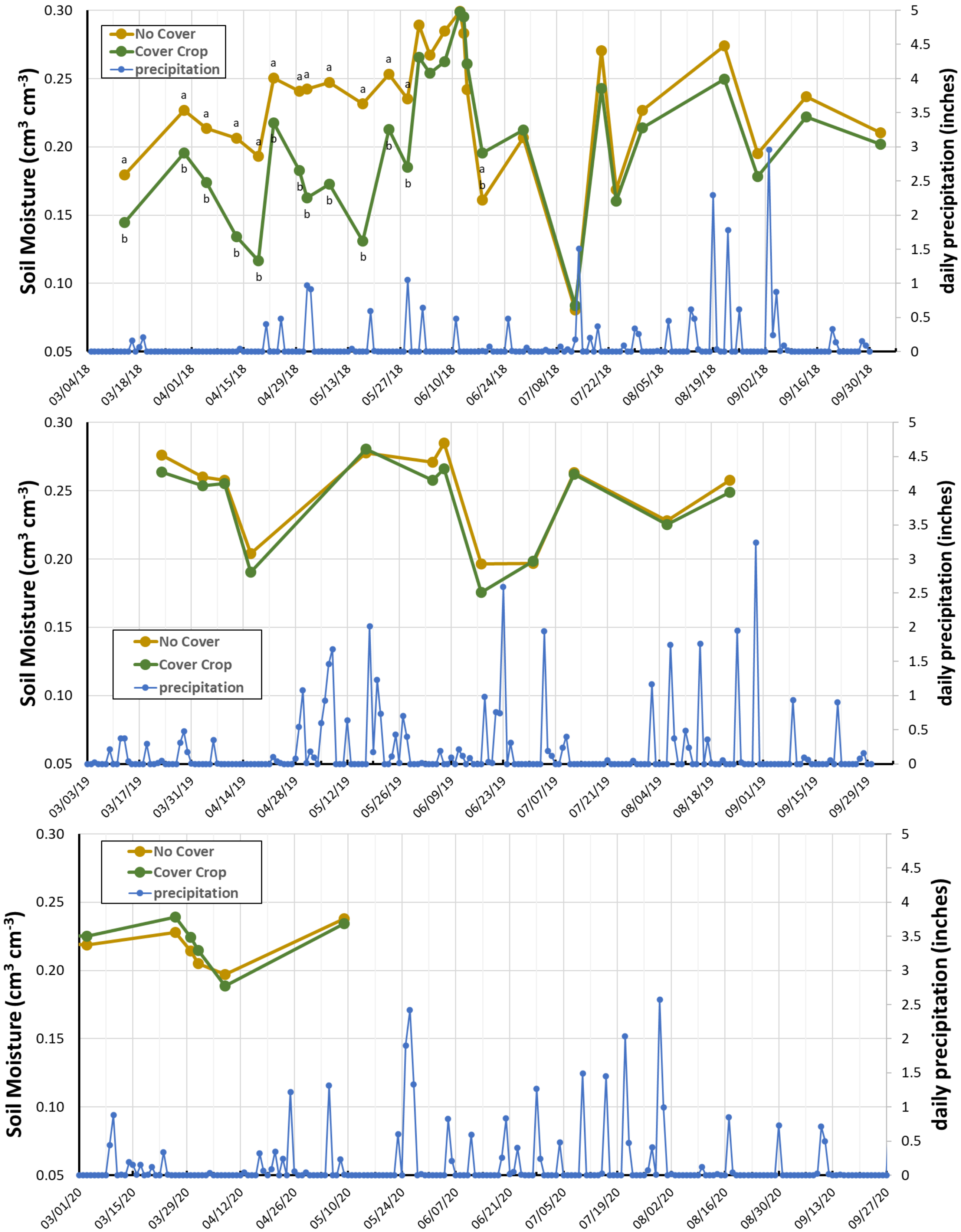

Figure 21. Cover crop effect on near surface soil moisture at KAW field lab (data points within a date that have different letters are statistically different at α=0.05; lack of letters indicate lack of significant difference).

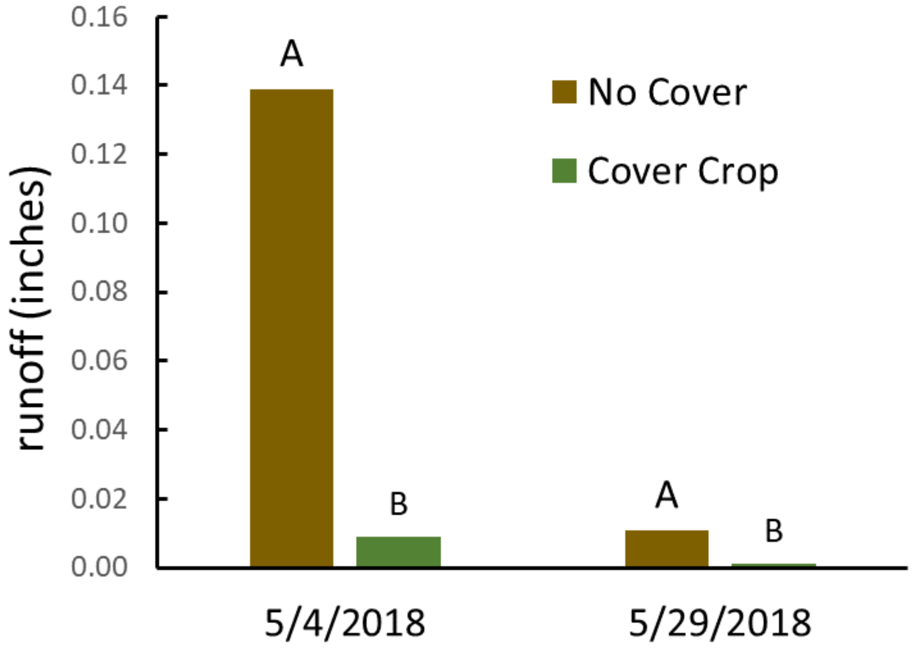

Figure 22. Cover crop effects on runoff for two events in May 2018 when the cover crop soils had significantly less soil moisture compared to no cover crop soils (data points within an event that have different letters are statistically different at α=0.05).

APPENDIX A

Listing of the outreach activities occurring during the reporting period

Based off work associated with this project, there were 68 presentations to an estimated cumulative audience of 4843 persons. This includes 27 presentations to audiences that contained, or likely contained, EQUIP eligible producers with a cumulative audience of 2527 persons.

Date	Event	Presenter	Audience†	Attend-ance
11/7/2016	ASA-SSSA-CSSA annual meeting, Phoenix, AZ	David Abel	University faculty and students, ARS and NRCS scientists	40
11/7/2016	ASA-SSSA-CSSA annual meeting, Phoenix, AZ	Andres Patrignani	University faculty and students, ARS and NRCS scientists	40
2/7/2017	The Fertilizer Institute Annual Meeting	Nathan Nelson	Professionals in fertilizer industry	20
2/13/2017	Agricultural Equipment Technology Conference, Louisville, KY	Nathan Nelson	University faculty and students, ARS and NRCS scientists	50
3/9/2017	Kansas State Conservation Commission Area III Spring Workshop, McPherson, KS	Nathan Nelson	Area producers, crop consultants, agricultural retailers, and university faculty, staff, and students*	60
3/16/2017	Kansas State Conservation Commission Area IV Spring Workshop, Manhattan, KS	Nathan Nelson	Area producers, crop consultants, agricultural retailers, and university faculty, staff, and students*	50
6/13/2017	4R Nutrient Stewardship Summit, Minneapolis, MN	Nathan Nelson	Professionals in agricultural retail and agricultural industry; staff from state, local, and federal government agencies; faculty and students from universities and research organizations.	100
08/08/2017	Australian Grain Farmers visit	DeAnn Presley	Australian farmers interested in cover crops and water quality.	40
10/23/2017	ASA-SSSA-CSSA annual meeting, Tampa, FL	Elliott Carver	University faculty and students, ARS and NRCS scientists	40
10/25/2017	ASA-SSSA-CSSA annual meeting, Tampa, FL	Nathan Nelson	University faculty and students, ARS and NRCS scientists	40
11/3/2017	Agronomy Department Field day, Manhattan, KS	Nathan Nelson	Area producers, crop consultants, agricultural retailers, and university faculty, staff, and students*	163
11/5/2017	ASA-SSSA-CSSA annual meeting, Baltimore, MD	Laura Starr	University faculty and students, ARS and NRCS scientists	40
11/5/2017	ASA-SSSA-CSSA annual meeting, Baltimore, MD	Elliott Carver	University faculty and students, ARS and NRCS scientists	40
11/5/2017	ASA-SSSA-CSSA annual meeting, Baltimore, MD	Elliott Carver	University faculty and students, ARS and NRCS scientists	40

Date	Event	Presenter	Audience†	Attend-ance
11/9/2017	the Governor's Conference on the Future of Water in Kansas, Manhattan, KS	Nathan Nelson	Staff from state, local, and federal government agencies; university faculty and students.	70
11/16/2017	the North Central Extension and Industry Soil Fertility Conference, Des Moines, IA	Elliott Carver	Staff from state, local, and federal government agencies; university faculty and students.	40
12/12/2017	Oklahoma Winter Crop School, Stillwater, OK	Peter Tomlinson	Crop consultants, agronomists, agricultural retailers, university faculty and students.*	50
1/10/2018	Kansas Agricultural Retailer's Association crop production update, Junction City, KS	Nathan Nelson	Crop consultants, agronomists, agricultural retailers, university faculty and students.*	50
1/16/2018	Missouri Regional Advisory Committee, St. Joseph, MO	Peter Tomlinson	Staff from state, local, and federal government agencies; university faculty and students.	30
3/6/2018	the Great Plains Soil Fertility Conference, Denver, CO	Elliott Carver	University faculty and students, ARS and NRCS scientists	30
3/6/2018	the Great Plains Soil Fertility Conference, Denver, CO	Nathan Nelson	University faculty and students, ARS and NRCS scientists	30
3/8/2018	Riley County Cover Crop Workshop, Leonardville, KS	Peter Tomlinson	Area producers, crop consultants, agricultural retailers, and university faculty, staff, and students*	50
5/22/2018	South Central Experiment Station Field Day, Hutchinson, KS	Nathan Nelson	area producers, crop consultants, agricultural retailers, and university faculty, staff, and students*	50
6/12/2018	4R-Summit, Des Moines, IA	Nathan Nelson	Professionals in agricultural retail and agricultural industry; staff from state, local, and federal government agencies; faculty and students from universities and research organizations.	100
6/27/2018	Field visit to Producer demonstration site	Nathan Nelson	Staff from the Kansas Water Office and members of the Neosho Basin Regional Advisory Council*	8
7/19/2018	Soil Health Coalition; Manhattan, KS	Nathan Nelson	Staff from state, local, and federal government agencies; university faculty.	30
7/31/2018	Field visit to the KAW field lab	Nathan Nelson	Attendees of the Nitrogen Use Efficiency conference, including University faculty and students, USDA-ARS scientists;	80
8/14/2018	Kansas River Valley Experiment Station Field Day, Rossville, KS	Nathan Nelson	Area producers, crop consultants, agricultural retailers, and university faculty, staff, and students*	80
8/15/2018	East-Central Experiment Station Field Day, Ottawa, KS	Nathan Nelson	Area producers, crop consultants, agricultural retailers, and university faculty, staff, and students*	100
9/14/2018	Field visit to KAW field lab	Nathan Nelson	Members of the Kansas Water Research Institute Advisory board, including staff from state and federal agencies	8

Date	Event	Presenter	Audience†	Attend-ance
9/27/2018	Public presentation to the Natural Resource and Environmental Science Capstone course	Nathan Nelson	Students and faculty at Kansas State University. Local citizens	12
10/17/2018	Field visit to KAW field lab and producer demonstration site.	Nathan Nelson	Visiting scientists from Brazil	2
12/11/2018	Oklahoma winter crop school, Stillwater, OK.	Nathan Nelson	Crop consultants, agronomists, agricultural retailers, university faculty and students.*	200
1/8/2019	SSSA annual meeting, San Diego, CA	Nathan Nelson	University faculty and students, ARS and NRCS scientists;	40
1/23/2019	Kansas Corn Symposium, Manhattan, KS	Laura Starr and Elliott Carver	Producers from across the state of Kansas,*	50
1/26/2019	Young Farmers and Ranchers of Kansas Conference, Manhattan, KS	Nathan Nelson	Agricultural producers and advisers from across the state of Kansas,*	20
3/13/2019	Soil Health and Water Quality Webinar. The North Central Region Water Network (on-line)	Nathan Nelson	Crop consultants, university faculty, state agency personnel, and NRCS personnel from across the nation*	132 +534 views on-line
4/23/2019	Presentation at NRCS edge-of-field monitoring workshop and field tour	Nathan Nelson	Staff from NRCS, Kansas Department of Agriculture, Kansas Water Office, and Kansas Dept. of Health and Environment.	20
4/25/2019	Cover crop field day at producer demonstration site.	Nathan Nelson, Elliott Carver, Laura Starr	Local area producers, KSU extension staff*	15
6/11/2019	Presentation at 4R Summit, Cleveland, OH.	Elliott Carver	Agricultural and scientific professionals from private industry and government agencies.	50
7/5/2019	Field tour of the KAW	Nathan Nelson	Undergraduate Students visiting from Acharya N.G. Ranga Agricultural University (ANGRAU) in India	30
7/29/2019	Presentation at the SWCS annual conference	Peter Tomlinson	Agricultural and scientific professionals from universities, NRCS, ARS, and state government agencies.	50
8/1/2019	Field tour of the KAW	Nathan Nelson	Members of the Kansas Water Congress; farmers, agricultural professionals, and staff from government agencies*	15
10/31/2019	Research and the State, Manhattan, KS	Laura Starr	Faculty, staff, and students at Kansas State University	200
10/31/2019	Research and the State, Manhattan, KS	Catherine Stewart	Faculty, staff, and students at Kansas State University	200
11/11/2019	ASA-SSSA-CSSA annual meeting, San Antonio, TX	Nathan Nelson	Faculty, staff, and scientists from universities, federal agencies, state agencies, and private sector companies	30
11/12/2019	ASA-SSSA-CSSA annual meeting, San Antonio, TX	Laura Starr	Faculty, staff, and scientists from universities, federal agencies, state agencies, and private sector companies	60

Date	Event	Presenter	Audience†	Attend-ance
11/12/2019	ASA-SSSA-CSSA annual meeting, San Antonio, TX	Catherine Stewart	Faculty, staff, and scientists from universities, federal agencies, state agencies, and private sector companies	60
12/5/2019	KARA Crop Production Update, Salina, KS	Nathan Nelson	Agricultural professionals from around the state of KS*	50
1/8/2020	Servi-Tech Professional Development Conference	Nathan Nelson	Crop Consultants*	90
1/21/2020	Northwest Certified Crop Advisors Conference, St. Joseph, MO	Peter Tomlinson	Agricultural retailers and agronomists*	120
1/22/2020	2020 Kansas HAB Stakeholders' meeting, Topeka, KS	Peter Tomlinson	State & Federal Agency staff, University researchers and city, county and other lake stakeholders	200
1/23/2020	Meadowlark District Nutrient Management and Soil Health Workshop, Holton, KS	Nathan Nelson	Area producers, staff from KS Department of Health and Environment, and staff from K-State Research and Extension.*	40
2/12/2020	Midwest Cover Crops Conference, Kansas City MO	Peter Tomlinson	Midwest cover crop researchers, Agricultural retailers, agronomists and producers	60
2/19/2020	Douglas Co. Conservation District Meeting, Lawrence, KS	Peter Tomlinson	Agricultural Producers*	20
3/10/2020	Great Plains Soil Fertility Conference	Elliott Carver	Professionals from the soil fertility industry, faculty and students from universities in the Great Plains, staff from federal agencies.	100
8/28/2020	Tour of KAW field lab	Nathan Nelson	Staff from NRCS and conservation commissions*	6
8/28/2020	Riley County Soil Health Workshop, presentation on Soil Health	Laura Starr	Area producers, staff from state and local agencies, agricultural consultants.*	30
9/3/2020	Phosphorus Management Workshop (webinar)	Nathan Nelson	State and federal agency staff, conservation professionals, agricultural professionals*	78
9/30/2020	Kansas Soil Health Partnership	Nathan Nelson	Staff from state and federal agencies, University faculty and staff*	30
11/9/2020	ASA-SSSA-CSSA annual meeting, virtual	Nathan Nelson	Faculty, staff, and scientists from universities, federal agencies, state agencies, and private sector companies	100
11/9/2020	ASA-SSSA-CSSA annual meeting, virtual	Elliott Carver	Faculty, staff, and scientists from universities, federal agencies, state agencies, and private sector companies	40
12/4/2020	Field visit with NRCS and area producers	Nathan Nelson	NRCS staff and area producers interested in EQUIP programs related to water quality visited the site for a field tour*	6
2/16/2021	Minnesota Agricultural Water Resource Center virtual Nutrient Management Conference	Nathan Nelson	Certified crop advisors, agronomists, and staff from state and federal agencies*	430

Date	Event	Presenter	Audience†	Attend-ance
3/5/2021	Field visit and training for NRCS staff	Nathan Nelson	Chad Remley, John Warner, and Tom Roth visited the producer runoff demonstration site for information about how to design and install an edge-of-field monitoring site	4
11/8/2021	ASA-SSSA-CSSA annual meeting, Salt Lake City, UT	Nathan Nelson	Faculty, staff, and scientists from universities, federal agencies, state agencies, and private sector companies	20
11/8/2021	ASA-SSSA-CSSA annual meeting, Salt Lake City, UT	Abigail Kortokrax	Faculty, staff, and scientists from universities, federal agencies, state agencies, and private sector companies	30
11/10/2021	ASA-SSSA-CSSA annual meeting, Salt Lake City, UT	Elliott Carver	Faculty, staff, and scientists from universities, federal agencies, state agencies, and private sector companies	20
11/18/2021	Governor's Conference on the Future of Water in Kansas, virtual event	Nathan Nelson	Staff from state, local, and federal government agencies; university faculty and students.	120

† An asterisk (*) following the audience description indicates that the audience would have likely included EQUIP eligible producers.

APPENDIX B

Listing of published works based on project data

Peer-reviewed publications (2)

Carver, R.E., N.O. Nelson, K.L. Roozeboom, G.J. Kluitenberg, P.J. Tomlinson, Q. Kang, and D.S. Abel. 2022. Cover crop and phosphorus fertilizer management impacts on surface water quality from a no-till corn-soybean rotation. J. Environ. Mgmt. 301:113818 https://doi-org/10.1016/j.jenvman.2021.113818 (KAES publication 21-334-J).

Carver, E., N.O. Nelson, K.L. Roozeboom, and M.B. Kirkham. 2020. Species and Termination Method Effects on Phosphorus Loss from Plant Tissue. J. Environ. Qual. 49:97-105. https://doi.org/10.1002/jeq2.20019 (KAES publication 19-287-J)

Theses and Dissertations (4)

Starr, L.M. 2021. Linkages between cover crops, phosphorus fertilizer management, soil health, and phosphorus bioavailability in replicated research watersheds. Ph.D. dissertation. Kansas State Univ. Manhattan, KS. https://hdl.handle.net/2097/40982.

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