COVER CROP EFFECTS ON SOIL MOISTURE AND WATER QUALITY

by

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Abstract

Eutrophication of freshwater lakes and streams is linked to phosphorus (P) fertilizer loss from agriculture. Cover crops could help mitigate P loss but producers are concerned that they may use too much water. This study was conducted to better understand the effects cover crops have on soil moisture and P loss. Volumetric water content (θ) was measured at the Kansas Cover Crop Water Use research area at 10 depths throughout a 2.74 m soil profile in 5 cover crop treatments and compared to θ measured from a chemical fallow control. Total profile soil moisture in sorghum sudangrass (1.02 m) and forage soybean (1.03 m) did not significantly differ from chemical fallow (1.05 m) at the time of spring planting. However, water deficits were observed in double-crop soybean (1.01 m), crimson clover (0.99 m), and tillage radish (0.99 m). At the Kansas Agricultural Watersheds, runoff was collected and analyzed for total suspended solids, total P, and DRP from 6 cover crop/fertilizer management treatments over two years. In the first water year the cover crop reduced runoff, sediment, and total P loss by 16, 56, and 52% respectively. There was a significant cover by fertilizer interaction for DRP loss. When P fertilizer was broadcasted in the fall with a cover crop, DRP loss was reduced by 60% but was unaffected in the other two P fertilizer treatments. Results were different in the second water year. The cover crop reduced sediment loss (71% reduction), as was seen in year one, but neither the cover crop nor the fertilizer management had a significant effect on runoff volume or total P loss overall. Contrary to the 2014-2015 results, cover crop increased DRP load by 48% in 2015-2016. DRP load was 2 times greater in the fall broadcast treatment than it was in the spring injected treatment but there was not a significant fertilizer by cover crop interaction. In order to determine the long term effects of cover crops and P fertilizer management P loss parameters should be tracked for several more years.

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Dedication

"The Lord God took the man and put him in the Garden of Eden to work it and take care of it." (Genesis 2:15). I dedicate this thesis first to the Lord in that this research would contribute to the better stewardship of His beautiful creation. Second, I dedicate this thesis to the Lord's most beautiful creation, my wife Kendra.

Chapter 1 - Implications of Phosphorus Loss

Phosphorus (P) fertilizer is utilized in agriculture systems throughout the world to maximize crop yield. However, P can be carried by surface runoff into nearby lakes and streams causing an over enrichment of mineral nutrients known as eutrophication (Correll, 1998). Eutrophication often leads to massive algae blooms which diminish the aesthetic value and usefulness of lakes and streams. These algal blooms cause hypoxic zones (oxygen deprived zones) that kill fish and other aquatic life, upsetting freshwater ecosystems (Welch, 1978). Hypoxic zones occur when aquatic microorganisms use the majority of the available oxygen to breakdown the excessive algae growth, causing higher aquatic life to suffocate (Figure 1.1). Unfortunately, the negative effects of a eutrophic system reach beyond the shoreline. In 2011 the Kansas Department of Health and Environment reported 34 cases of human and animal illness associated with harmful algae blooms, including five dog deaths and hospitalization of two humans (Trevino-Garrison et al., 2015). Algae also increases water treatment costs dramatically. Hudnell (2010) reported that algae costs the United States economy 2.2 to 4.6 billion dollars every year in treatment costs.

Critical values for P entering freshwater systems vary because of the unique properties of various aquatic ecosystems (Welch, 1978). Nonetheless, the suggested standard is that stream P levels should not exceed 0.05 mg L^{-1} if the stream directly enters a lake or reservoir (Table 1.1) (Havlin et al., 2005). What is undeniably clear is that excessive P concentration is the most common cause of eutrophication of freshwater systems (Correll, 1998). An increasingly greater area of Lake Erie has been affected by eutrophication in recent years. Scavia et al. (2014) project that Lake Erie would need a 78% reduction in dissolved reactive phosphorus (DRP) to bring levels back to where they were in the early 1990s. Estimates suggest that 50 to 70% of P that reaches surface water is from a nonpoint agriculture source (Havlin et al., 2005). If P loss from agriculture production is reduced, eutrophication of receiving water bodies and the problems associated with them could be mitigated.

Suppliers and consumers want assurance that their products are produced in an environmentally sustainable way. High profile companies like Walmart, Cargill, John Deere, Monsanto, Coca-Cola, and 91 others have joined the Food to Market initiative (an alliance focused on defining, measuring and advancing the sustainability of food, fiber and fuel production) (Field to Market, 2016). Not surprisingly, one of Field to Market's six primary goals is to solve water quality problems by reducing sediment, phosphorus, nitrogen, and pesticide loads from U.S. cropland. Because the public cares about sustainable, environmentally safe production methods, farmers will likely need to give account for the environmental impacts of their production practices. This will increase the need for clear water quality standards and guidelines on how excessive nutrient loads from agriculture can be prevented.

Phosphorus Transport Processes

Inorganic P fertilizers rapidly convert into orthophosphate ($H_2PO_4^-$ or HPO_4^{-2}) when they are applied to soils. Some orthophosphate will remain dissolved in the soil solution where it is readily available for plant uptake, but a large amount will become bound to soil particles and organic matter (Havlin et al., 2005). Both particulate P and soluble P can be transported from cropland into lakes and streams through surface runoff (Figure 1.2). However, P losses in surface runoff are generally dominated by the particulate form, closely linking P loss and erosion. (Gburek et al., 2005). Surface runoff and soil erosion will occur when the rate of rainfall exceeds the rate at which the soil can absorb that precipitation. Many factors, such as soil texture, restricting layers, surface residue, and soil moisture content prior to rainfall, will affect the soil's ability to absorb moisture. Massive P losses can occur if fertilizer is applied to already saturated or frozen soils because the conditions limit the fertilizer's interaction with the soil (Gburek et al., 2005). Furthermore, when rain falls on already saturated or frozen soils, increased runoff volumes occur due to the soil's inability to store the added moisture. Both factors, limited fertilizer/soil interaction and reduced water infiltration, will result in greater nutrient losses. Other transport processes that impact water quality include macropore flow (nutrients carried rapidly in water through large openings in the surface) and leaching (nutrients carried slowly through the soil in percolating water) (Havlin et al., 2005). Conservation tillage practices increase macropore flow, allowing more rainfall to infiltrate into the soil subsurface and consequently producing less surface runoff and P loss (Shipitalo et al., 2000). Leaching, however, is generally considered to be an insignificant transport method for P because of strong P adsorption to soil particles. The components of the hydrological cycle (Figure 1.3) introduced here are dynamic and will be influenced greatly by weather, management practice, and cropping system.

Rainfall Timeliness and Residue

North-eastern Kansas typically receives the greatest precipitation in both quantity and intensity during the spring and summer months (Figure 1.4) (U.S. Climate Data, 2016). Phosphorus concentrations in surface runoff generally exhibit curvilinear decay based on time since fertilizer application (Harmel et al., 2009). Vadas et al. (2011) adds that P loss is a factor of both the amount of time elapsed since P fertilizer application and the precipitation intensity. Large amounts of P are lost during heavy rainfall events that occur shortly after P application (Liu et al., 2016). Surface-applied P can move into the subsoil if conditions are conducive, but unfortunately weather rarely cooperates. Macropores facilitate P transport into the soil subsurface during rainstorms, but the effectiveness of this process depends on light rainstorms preceding the first major runoff producing storm (Shipitalo et al., 2000). Because yield from crops receiving P fertilizer in the fall has not proven to be significantly different than crops receiving it in the spring (Mallarino et al., 2009), applying P fertilizer in the fall could maximize the time prior to a runoff-producing rain event thereby minimizing the risk of P loss without reducing crop yield.

In a study that looked at sediment and nutrient loss as a function of three different rainfall intensities (65, 85 and 105 mm h^{-1}) and four different percent cover amounts (0%, 25%, 50% and 75%), increasing rainfall intensity increased sediment (Figure 1.5) and nutrient loss without exception (Jin et al., 2009). Increasing percent cover (residue) reduced erosion, particularly under high rainfall intensities. This illustrates that maintaining residue cover is an important best management practice for reducing P loss via surface runoff.

Management Practices to Reduce P Transport

Agricultural management practices such as fertilizer source, placement, and rate, tillage, and physically constructed features can all significantly affect P loss.

Tillage

Percent residue cover and soil surface roughness both influence runoff and are directly affected by tillage practice (Havlin et al., 2005). Conventionally tilled systems have a decreased amount of crop residue on the soil surface because the soil is regularly turned. Common conventional tillage implements like the disk plow leave less than 10% of the crop residue on the soil surface. Increased understanding about the agronomic benefits of no-till, the effectiveness of herbicides for controlling weeds, along with the availability and affordability of no-till equipment has allowed for widespread adoption of no-till cropping systems across the Midwest.

An estimated 96 million acres in the United States is under no-till cultivation based on a 2012 census, nearly 35% of all U.S. cropland. Kansas ranks among the top 10 no-till states in the U.S. based on area of cropland under no-till (Figure 1.6) (Dobberstein, 2014).

Unfortunately, one of the drawbacks of no-till production is that broadcasted P fertilizers are left exposed on the soil surface. What is gained by reducing erosion and associated sediment-bound P loss by increased residue and reduced soil disturbance may be lost because the P source is left in a position more vulnerable to runoff. In a study comparing three different tillage practices (none, conservation, conventional) in corn (*Zea mays*), conservation tillage reduced sediment loss 49% compared to conventional tillage but increased the DRP concentrations in surface runoff (Gaynor and Findlay, 1995). Ulen et al. (2010) reported a fourfold increase of DRP lost from no-till production compared to conventional tillage. Dissolved reactive P can have an immediate impact on receiving waters and 70% of total P lost from no-till/broadcast fertilized fields is in the dissolved reactive form (Seo et al., 2005). No-till and conservation tillage practices effectively reduce soil erosion but increase P loss from broadcast applied fields when compared to conventional tillage (Gaynor and Findlay, 1995). The greater P loss in runoff from the conservation tillage treatments could be connected to P leaching from crop residue, surface-placed P fertilizers, or P stratification causing P enrichment in surface soil.

Placement, Source, and Rate

To reduce P loss in systems where incorporation through tillage is not an option, farmers may choose to inject or knife P fertilizer in a band below the soil surface. Soluble, bioavailable, and total P losses can all be reduced by placing P fertilizer below the zone of interaction between the soil and surface runoff according to Kimmell et al. (2001) and Bundy et al. (2005). No-till practices that leave increased amount of residue on the soil surface can decreased runoff volume

(Jin et al., 2009) but Zeimen et al. (2006) found no-till management to increases runoff volume and nutrient loss when compared to chisel/disk management. In this case tillage may have aerated and dried the soil allowing for more water infiltration and consequently less runoff and nutrient loss when compared to the no-till treatment (Zeimen et al., 2006).

Some research suggests the banding P fertilizer may increase crop yield compared to broadcast application (Figure 1.7) (Havlin et al., 2005). An experiment analyzing growth and yield effects of P placement on corn found that a deep band of 15 cm was resulted in the highest yield among the four P placement treatments (no P, shallow P band at 5 cm, deep P band at 15 cm, split P bands at 5 and 15 cm) (Zhao YaLi et al., 2014). The study found that deep P placement increased corn yield by 9.9% over the shallow P placement, indicating that deep P placement is optimum for corn growth (Table 1.2). But again researchers do not all agree about the relationship between placement and yield. Bordoli and Mallarino (1998) found no yield response in corn to P placement at any of their research sites. Similarly, Borges and Mallarino (2000) didn't find a yield response in soybean to P placement. Differences in initial soil test P between these studies may have influenced outcomes. Zhao Yali's (2014) research was conducted under conditions were average soil test P was 17.24 mg kg^{-1} in the top 20 cm but Bordoli and Mallarino's (1998) and Borges and Mallarion's (2000) research was conducted across may different sites having a wide range of initial soil test P. The inconsistency among the research suggests that the effect P fertilizer placement has on crop yield is dynamic and may depend on many other environmental and biological factors.

There are some differences among inorganic P sources but the common ammonium phosphates, superphosphates, and nitric phosphate are often considered equal in terms of their ability to maximize crop yield. Research suggests that ammonium-N may increase P availability but generally P uptake by plants is most closely correlated with the plant root mass (Bundy et al., 2005).

Organic P sources can be a very economical source of P if crops are grown near livestock facilities, but the economic advantage rapidly decreases as the distance the animal waste must be transported increases. If animal litter is available, it can be just as effective in producing yield as inorganic P sources but should be managed carefully. Poultry litter at a rate of 13.5 Mg ha^{-1} produced similar yields in corn compared to inorganic fertilizer and didn't cause residual soil test P to reach levels considered harmful to surface water (Sistani et al., 2010). Figure 1.8 compares inorganic fertilizer with a 13.4 Mg ha^{-1} manure application over ten years in continuous wheat production, and again little difference is observed in crop yield. In practice, however, repeated use of manure often results in water quality problems because of the rate at which it is applied. When manure is applied based on crop nitrogen requirement, P is applied at 3 to 5 times the needed rate (Havlin et al., 2005). This over application of P is subject to loss and over time can result in extremely high soil test P levels.

Constructed Conservation Adaptations

Constructed conservation features such as terraces, vegetative barriers, grassed waterways, and tile drainage can all impact P transport with differing effectiveness. Terracing is often the first control measure for reducing erosion from any sloping field. Terraces have been constructed on hillslopes all over the world to reduce the harmful effects of erosion for centuries. In southern China, level terraces planted to grass are highly effective in conserving water and soil compared to a bare sloping ground (Zhang et al., 2015). Beetle bank vegetative barriers like the one diagramed in Figure 1.9 may reduce erosion but are most often seen as marginally effective at best. When testing beetle bank vegetative barriers effectiveness for reducing erosion, Stevens et al. (2009) observed trends in sediment reduction but the results were statistically insignificant. The effectiveness of grassed waterways are highly variable depending on specific waterway attributes such as the length of the waterway and the hillslope gradient where it is located (Dermisis et al., 2010). Figure 1.10 and Figure 1.11 show sediment reduction as a function of waterway length and hillslope gradient respectively. They show that as the slope degree decreases and the length increases sediment loads are reduced. Although not all terrace constructions and vegetative covers are equal in their preservation capacity, the research is in agreement that these constructed features decrease sediment and nutrient loss from surface runoff. Nutrient and sediment loss is not however always the focus of constructed adaptations. Tile drainage is a production necessity for some poorly drained fields that can unfortunately result in increased P transport to lakes and streams. Although P is transported primarily through surface runoff because of its affinity to bind to the soil (Zimmer et al., 2016), Gentry et al. (2007) measured increased DRP and particulate P concentrations in tiles as discharge increased, identifying the tiles also as a P transport pathway.

Utilization of cover crops

Cover crops have received attention recently across agriculture communities as a fallow alternative. They have been shown to increase water infiltration, reduce runoff, reduce soil erosion, reduce weed pressure, improve soil physical, biological, and chemical properties, and, in the case of legume cover crops, contribute nitrogen to subsequent crops (Dabney, 1998; Dabney et al., 2001). As previously discussed, increased crop residues and vegetative covers decrease runoff and erosion and, by association, P loss. It is therefore logical to expect that cover crops also could reduce P loss. However, the literature is somewhat unclear. Wilson et al. (2014) conducted modeling research focused on P loss in the southern branch of the Root River

Watershed. In their model, management intensive rotational grazing was compared to traditional conservation methods (conservation tillage, cover crops, and filter strips) using the Soil and Water Assessment Tool (SWAT). Large reductions in P loss were simulated from sloping areas planted to cover crop or filter strips, leading to the conclusion that cover crops with filter strips have the greatest reductions per-unit treated area of all management practices tested (Table 1.3; Figure 1.12). Aronson et al. (2016) came to a different conclusion. Their study, located in Scandinavia and Finland, was conducted in an effort to better understand the role cover crops play in reducing nitrogen and P loss by runoff and leaching. In this case, ryegrass (*Lolium*) was the cover crop of interest. The research suggested that cover crops do not substantially reduce total P losses by runoff and leaching but the author admits that freeze-thaw climate conditions over the winter could have been a factor. The ability of cover crops to reduce P loss may be climate dependent. Freezing-thawing cycles have been shown to increase P loss from the roots and shoots of the cover crop (Liu et al., 2013), detracting from their appeal as a P loss reducing practice. Erosion protection and P retention benefit of cover crops may also be highly dependent on the distribution of rain and the erosion potential during the year (Havlin et al., 2005). These environmental variables make studying cover crop's impact on P loss challenging, pushing many researchers to scale down their studies so that they have greater control. The small amount of research about cover crop effects on nutrient loss generally focuses on conventionally tilled management systems and is conducted on relatively small plots that do not always correlate well to the field scale (Dabney, 1998). More research over multiple years at the field scale is needed to better understand the role cover crops play in preventing P loss.

Cover crops can provide benefits beyond the potential for reduced P loss. A cover crop can be defined as any living ground cover that is planted before, during, or after a main crop which is commonly killed prior to planting the next crop (Hartwig and Ammon, 2002). The best cover crop species will depend on the specific management goals of the individual producer. Winter legume cover crops like crimson clover (*Trifolium incarnatum*), hairy vetch (*Vicia villosa*), or Austrian winter pea (*Pisum sativum subsp. arvense*) can decrease nitrogen fertilizer need for corn by 10 to 75 kg ha^{-1} because of their ability to fix atmospheric nitrogen (Decker et al., 1994). Brassica cover crops such as forage radish (*Raphanus sativus*) may help break up compaction layers providing the subsequent main crop access to water and nutrients that would be otherwise unavailable (Williams and Weil, 2004). Brassicas also have a remarkable aptitude for nutrient scavenging, particularly P. Their extensive root systems explore a large percent of the soil and may be able to recover and cycle P for use by a main crop (Nanzyo et al., 2002). Although cover crops like ryegrass or sudangrass do not fix atmospheric nitrogen, they can be effective at increasing soil organic nitrogen due to the greater carbon content of their biomass (Kuo et al., 1997). These cover crop species may also prove beneficial for keeping nitrogen from leaching from the soil profile by holding it in their biomass, as shown in (Figure 1.13) (Meisinger et al., 1990). Furthermore, cover crops that don't contribute to soil nitrogen may do a better job at suppressing weeds (Hill et al., 2016). Before choosing a cover crop it is important to know what benefit you desire from it. Benefits, however, may come at a cost.

Cover crops may also have some disadvantages. One of the largest concerns is that cover crops may use water that would otherwise be available for the main crop and thereby reduce main crop yield. A study conducted in Garden City, KS suggests that in years of above-average precipitation (>486mm), low biomass cover crops do not appear to have a negative effect on subsequent wheat yields (Arnet, 2010). In semiarid areas however cover crops may hinder dryland crop yields because of their water use (Dabney et al., 2001). Whether or not a cover crop will reduce a subsequent main crop's yield depends predominantly upon quantity and timing of precipitation. Sub-humid to humid regions receiving an approximate annual rainfall above 750 mm are generally well suited for cover crops. However, the timing of cover crop termination is also very important. Negative effects have been observed when there is insufficient time after cover crop termination for precipitation to recharge soil water (Unger and Vigil, 1998). A study looking at the effect of termination date of a legume cover crop on a subsequent winter wheat main crop found that soil water at wheat planting was reduced by 55 mm when the cover crop was terminated in early June (Nielsen and Vigil, 2005). When termination was delayed until late July, soil water at wheat planting was reduced by 104mm (Table 1.4), with corresponding decreases in wheat yield (Table 1.5). The wheat yield following the cover crop was linearly correlated with soil water at planting. However, Akron Colorado, where Nielsen and Vigil's research was conducted, receives only approximately 421 mm of rainfall annually. The correlation between wheat yield and soil water at planting may not hold true for other geographic locations that receive greater annual precipitation. Further cover crop water use research needs to be conducted, particularly in climates with moderate annual precipitation (800 to 1000 mm).

Hypothesis

In years of near average precipitation (889 mm) for Manhattan, KS I hypothesize that cover crops will not significantly decrease soil moisture at planting of the subsequent main crop compared to fallow and therefore will not reduce yield. However, I do anticipate cover crops to reduce soil moisture throughout its growing cycle thereby increasing infiltration and reducing total runoff. The addition of a winter cover crop (wheat) will significantly decrease P loss in a corn-soybean rotation regardless of tillage practice. The decreased P loss provided by the cover crop will result in P loss from broadcast applied P fertilizer applications comparable to the current best management practice of subsurface injecting.

Objectives

The objectives of this research are twofold. First, to quantify the change in soil water content for five different fallow alternatives (double-crop soybean, crimson clover, tillage radish, forage soybean, sorghum sudangrass) in a no-till sorghum-soybean-winter wheat rotation Second, to quantify the effectiveness of a winter cover crop (wheat; *Triticum*) as a best management practice for reducing P loss in surface runoff in a no-till corn-soybean rotation.

Table 1.1 Suggested critical freshwater thresholds for N and P loading. Critical values are regularly debated. Table values should be viewed as a general guideline for categorization purposes. (Source: Havlin et al., 2005).

Risk Level	Total N	Total P
	---------------------------------*mg L^{-1}*---------------------------------	
Low	<0.5	<0.05
Intermediate	0.5-1.0	0.05-0.1
High	>1.0	>0.1

Total P in streams should not exceed 0.05 mg L^{-1} directly entering lakes or reservoirs; total P should not exceed 0.1 mg L^{-1} in streams not discharged directly into lakes or reservoirs.

Table 1.2 Corn yield at four P placement depths (CK = no P, T5 = 5cm, T15 = 15cm, T5/T15 = split 5cm/15cm) (Source: Zhao YaLi et al., 2014).

Placement depth	2006 (Pot experiment)	2007 (Pot experiment)	2008 (Pot experiment)	2008 (Field experiment)	Mean
			Mg ha^{-1}		
CK	9.7±0.5 c [1]	10.1±0.4 c	10.2±0.6 c	10.8±0.4 c	10.2
T5	10.4±0.6 b	11.2±0.3 b	11.3±0.7 b	11.4±0.7 b	11.1
T15	12.0±0.8 a	12.2±0.8 a	12.4±1.1 a	12.4±0.7 a	12.2
T5/T15	11.5±1.0 ab	11.4±0.6 b	11.7±0.8 ab	11.6±0.6 b	11.6

[1]Mean ± S.D. Means within a column sharing the same letters are no significant at the 0.05 level.

Table 1.3 Description of each alternative scenario simulated in the Soil and Water Assessment Tool. Alternative conservation management scenarios include management practices applied to existing cropland with the goal of reducing sediment and phosphorus losses from fields. The Land use change scenarios simulated cropland areas converted into pasture for management intensive rotational grazing of beef cattle (Source: Wilson et al., 2014).

Alternative Scenario	Description	Watershed area in treatment (%)
Conservation management scenarios		
ConsTill 25	Conservation tillage applied to 25% of cropland in a nontargeted approach	17
ConsTill 4	Conservation tillage applied to all cropland with slope greater than 4%	8.4
Filter 4	10 m filter strip on all cropland with a slope greater than 4%	8.4
CovCrop 4	Cover crops on all cropland with a slope greater than 4%; no manure on croplands with slope greater than 4%	8.4
CovCrop4-ConsTill100	Cover crops on all cropland with a slope greater than 4% and conservation tillage on all remaining cropland; no manure on croplands with slope greater than 4%	67
CovCropFilter4-ConsTill 100	Cover crops and filter strips on all cropland with a slope greater than 4%; conservation tillage on all remaining cropland; no manure on croplands with slope greater than 4%	67
Land use change scenarios		
GLU-steep	Cropland on slopes greater than 4% converted into pasture for grazing in select sub-basins	2.6
GLU-CPI	Cropland with low crop productivity indices converted into pasture for grazing in select sub-basins	2.6
GLU-random	Cropland, chosen at random, converted into pasture for grazing in select sub-basins	2.6

Table 1.4 Available soil water (mm) at wheat planting in conventional till fallow plot and following legumes grown as green fallow at Akron, CO, terminated at four dates. Data is averaged over legume species (Source: Nielsen and Vigil, 2005).

Year	Fallow	T1¥	T2	T3	T4	P_T*	P_{T1}§	P_{T2}§	P_{T3}§	P_{T4}§
	mm									
1994	245	228	182	156	144	<0.01	0.05	<0.01	<0.01	<0.01
1995	293	246	216	181	166	<0.01	<0.01	<0.01	<0.01	<0.01
1996	349	307	259	210	225	<0.01	0.04	<0.01	<0.01	<0.01
1997¶	288	213	203	213	213	0.74	<0.01	<0.01	<0.01	<0.01
1998	283	199	186	159	174	0.03	<0.01	<0.01	<0.01	<0.01
1999	455	387	405	364	357	0.03	<0.01	0.05	<0.01	<0.01
Avg.	320	265#	245#	214#	216#	<0.01#	<0.01	<0.01	<0.01	<0.01

¥ T1, T2, T3, and T4 are four legume termination dates.
* P_T = probability that the null hypothesis of o difference in soil water and wheat planting due to legume termination date is true (as tested by analysis of variance with legume termination date as treatments in a randomized complete block design).
§ P_{T1-T4} = probability that the null hypothesis of no difference in soil water at wheat planting between fallow and each legume termination date is true (as tested by single degree of freedom contrasts).
¶ All legumes terminated on 23 June due to heavy weed pressure.
# Averaged for AWP and FP treatments only.

Table 1.5 Winter wheat yield in conventional till fallow plot and following legumes grown as green fallow at Akron, CO terminated at four dates. Data is averaged over legume species (Source: Nielsen and Vigil, 2005).

Year	Fallow	T1¥	T2	T3	T4	P_T*	P_{T1}§	P_{T2}§	P_{T3}§	P_{T4}§
	---kg ha^{-1}---									
1994-1995	3979	3277	2691	2482	2169	<0.01	<0.01	<0.01	<0.01	<0.01
1995-1996	6032	4960	4535	3119	2320	<0.01	<0.01	<0.01	<0.01	<0.01
1996-1997	4149	3855	3555	2152	2252	<0.01	0.31	0.04	<0.01	<0.01
1997-1998¶	2453	1787	1911	2044	1989	0.65	0.01	0.04	0.11	0.07
1998-1999	4470	2069	2591	2012	2514	0.09	<0.01	<0.01	<0.01	<0.01
1999-2000	2455	1924	2115	1781	1736	0.38	0.08	0.25	0.03	0.02
Avg.	3923	3016#	2950#	2319#	2271#	<0.01	<0.01#	<0.01#	<0.01#	<0.01#

¥ T1, T2, T3, and T4 are four legume termination dates.
* P_T = probability that the null hypothesis of o difference in soil water and wheat planting due to legume termination date is true (as tested by analysis of variance with legume termination date as treatments in a randomized complete block design).
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¶ All legumes terminated on 23 June due to heavy weed pressure.
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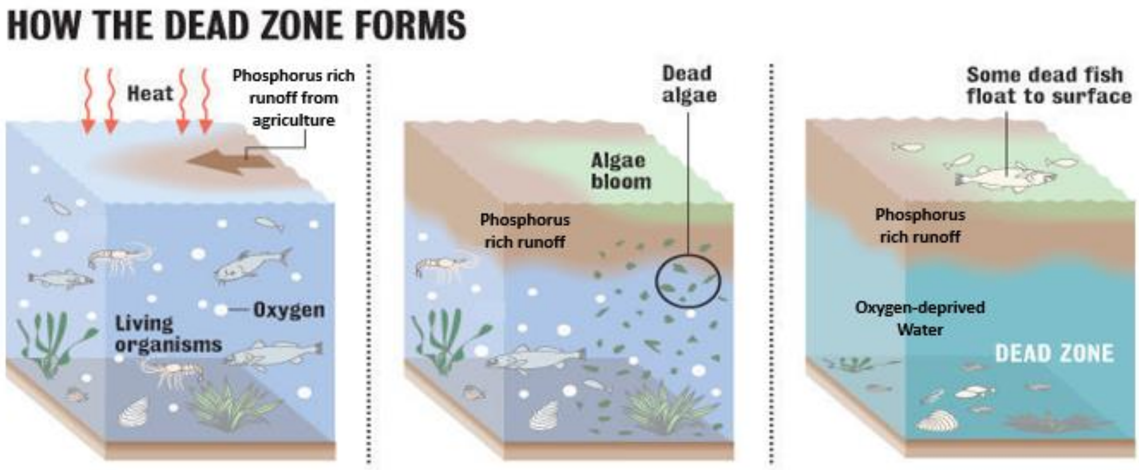

Figure 1.1 How the Dead Zone Forms. Runoff rich in P flows into freshwater lakes and streams and causes algae growth. Microorganisms that decompose the algae consume the oxygen, resulting in the suffocation of higher aquatic life (Adapted: Swenson, 2015).

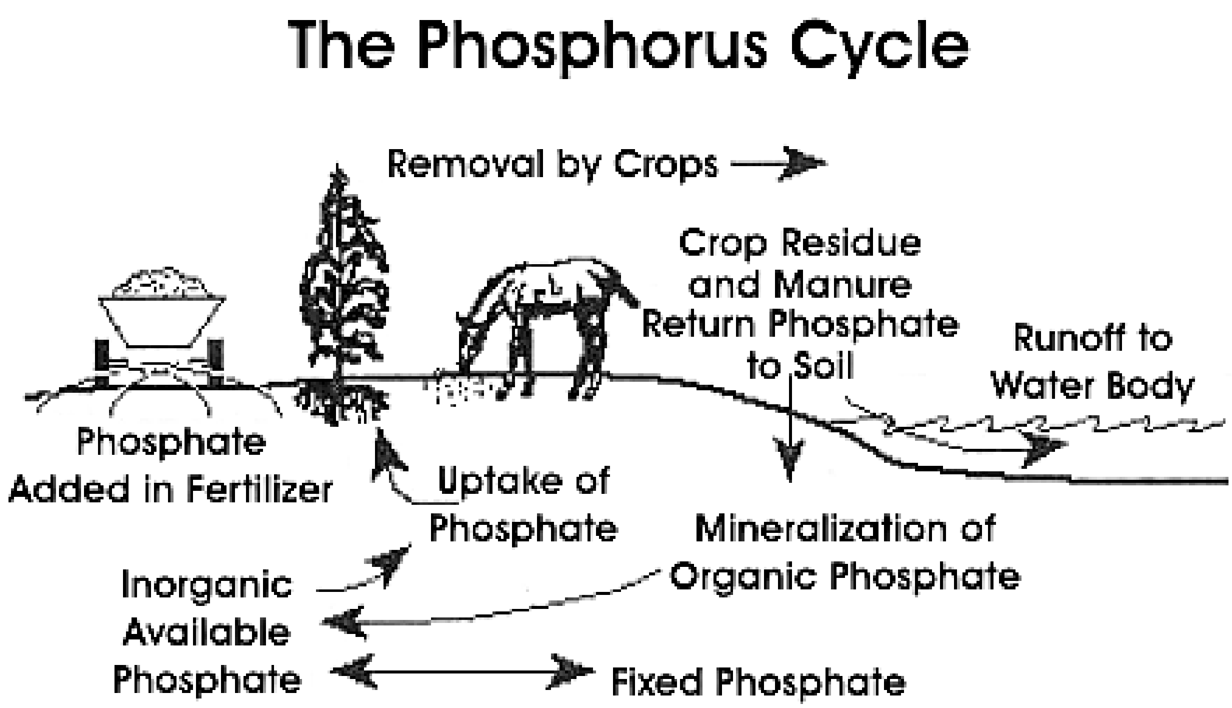

Figure 1.2 A general illustration of the P cycle. Soil, vegetation, fertilizer, and animal waste can all be P sources. These P sources may be transported through surface runoff, erosion, subsurface flow, and channel processes (Source: Gburek et al., 2005).

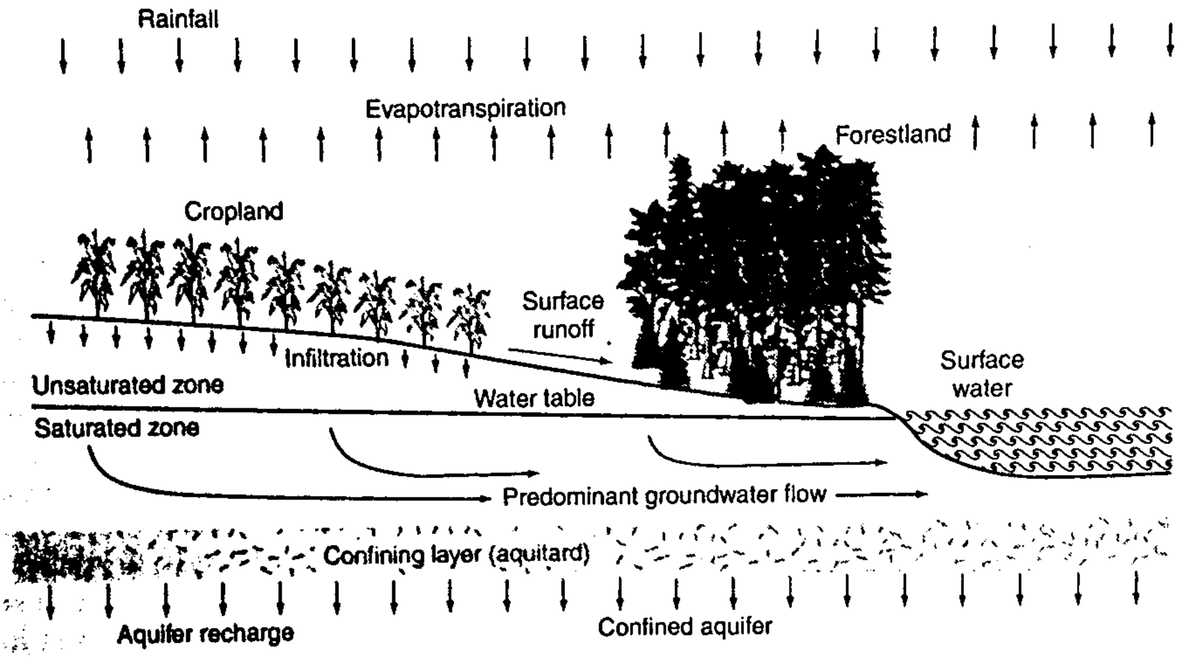

Figure 1.3 A general illustration of the hydrologic cycle (Source: Havlin et al., 2005).

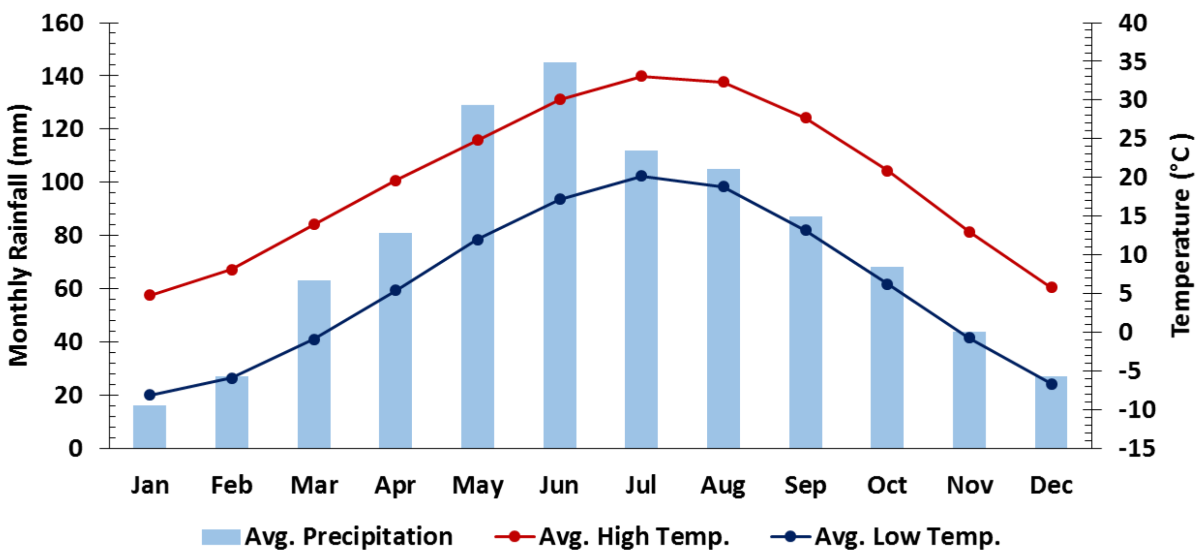

Figure 1.4 Average monthly rainfall for Manhattan Kansas (left axis; mm) plotted with monthly average high and low temperatures (right axis; ˚C) (Source: U.S. Climate Data, 2016).

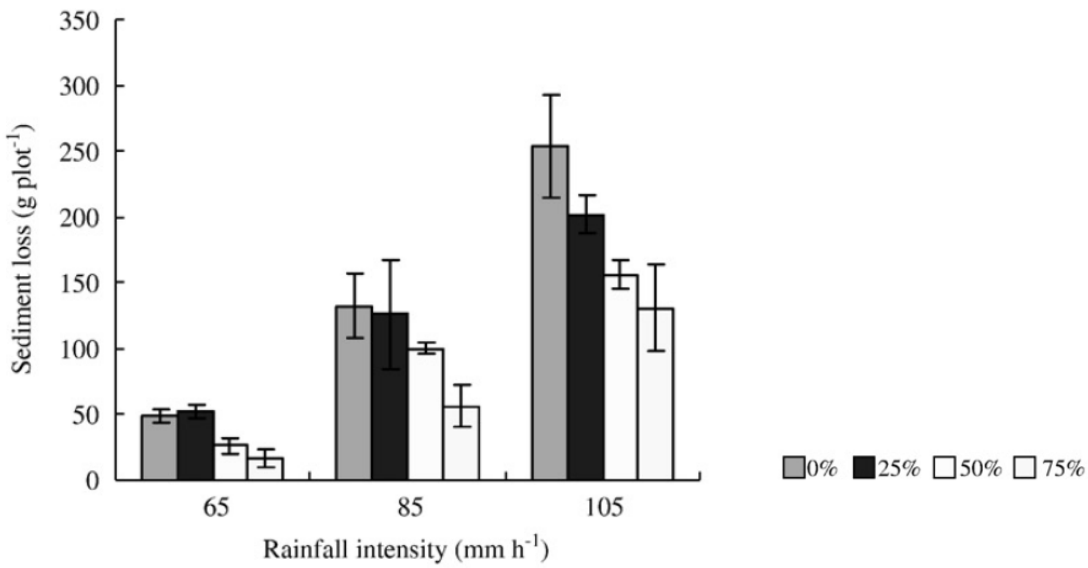

Figure 1.5 Sediment loss for 4 different percent residue amounts (0%, 25%, 50%, 75%) under 3 different rainfall intensities (65, 85, 105 mm h^{-1}) (Source: Jin et al., 2009).

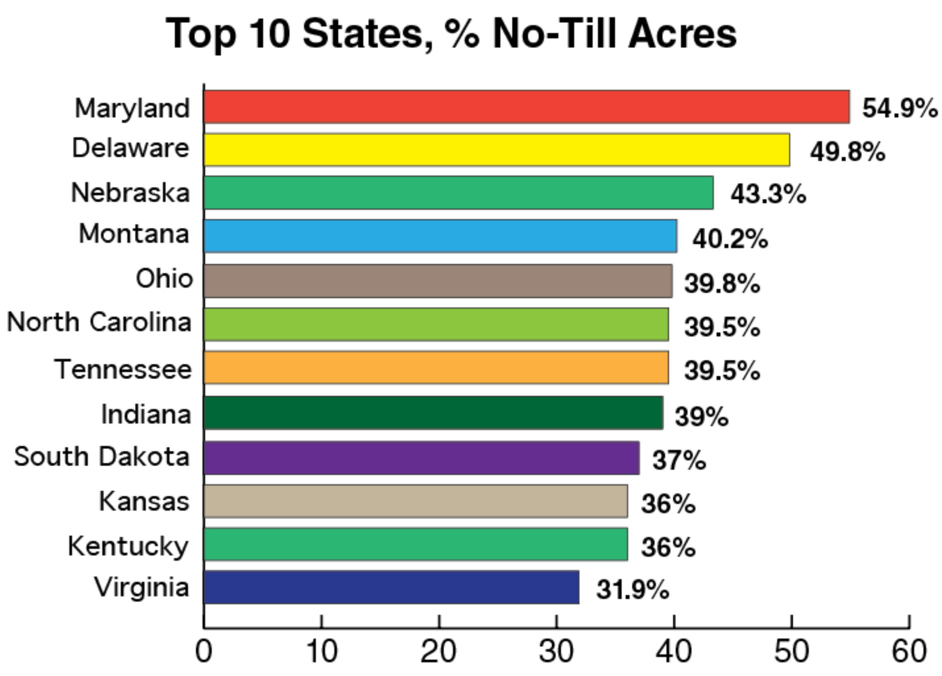

Figure 1.6 The top 10 U.S. state as a percent of cropland in no-till (Source: Dobberstein, 2014)

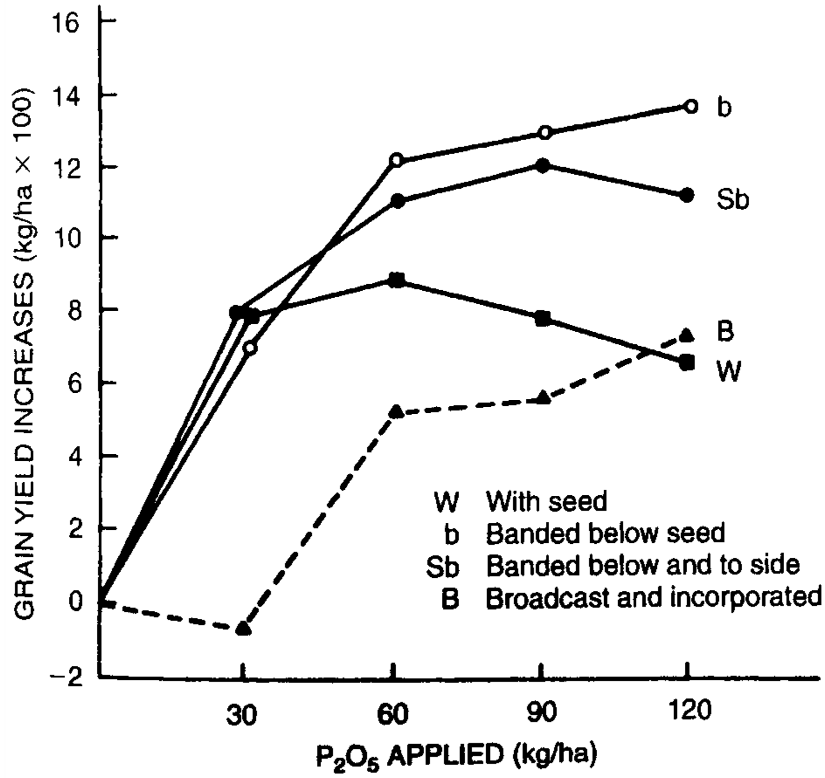

Figure 1.7 The effect of P placement on barley yield in a low soil test P field (Source: Havlin et al., 2005)

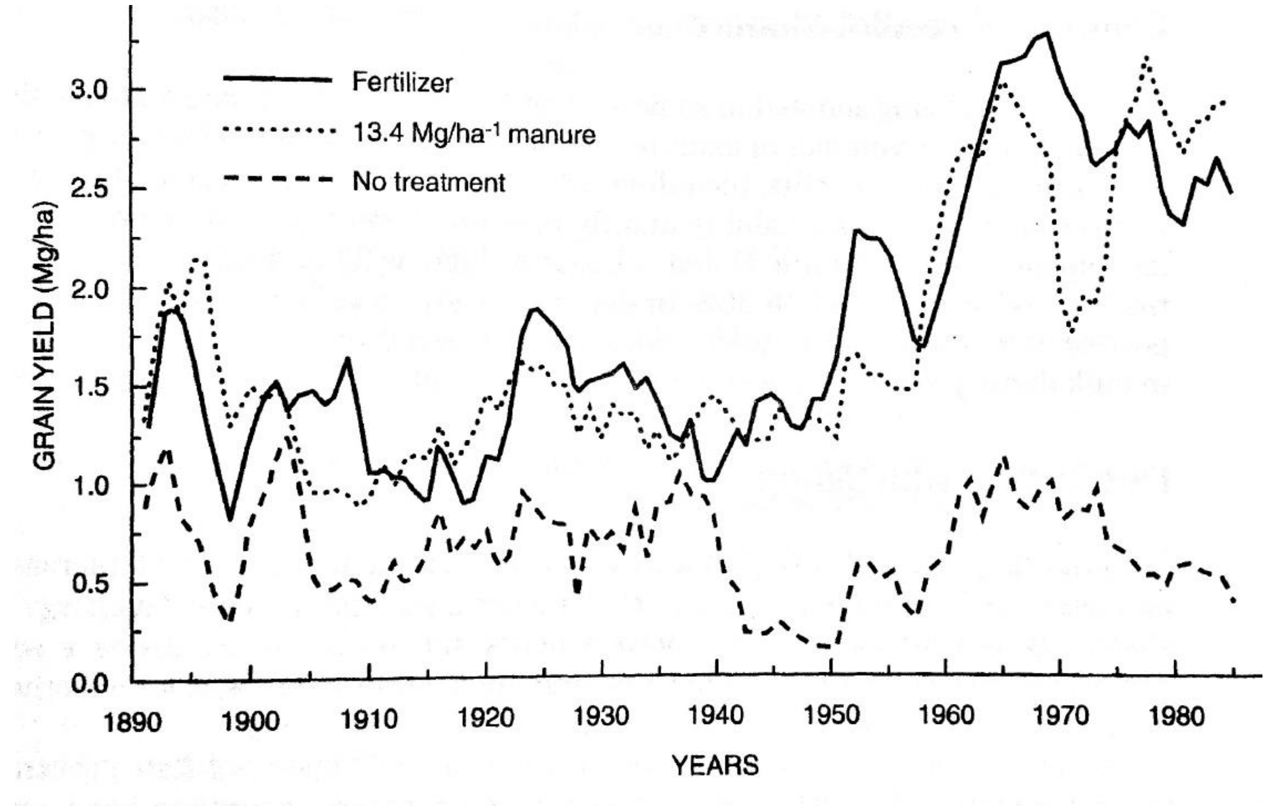

Figure 1.8 Yield comparison of manure and fertilizer in a continuous wheat production (Source: Havlin et al., 2005).

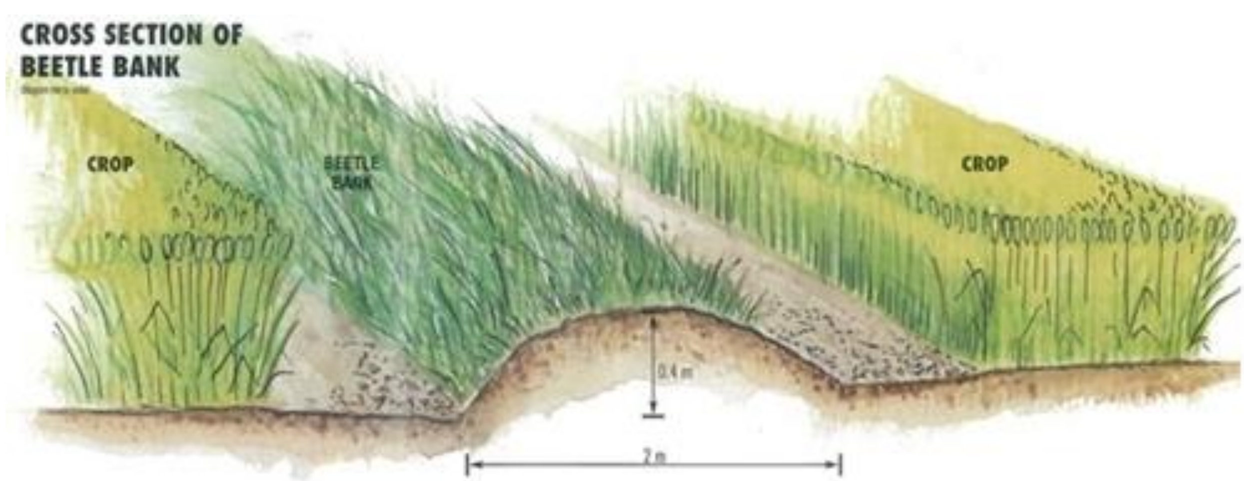

Figure 1.9 Cross section illustration of a Beetle Bank vegetative barrier (Source: Game and Wildlife Conservation Trust, 2016).

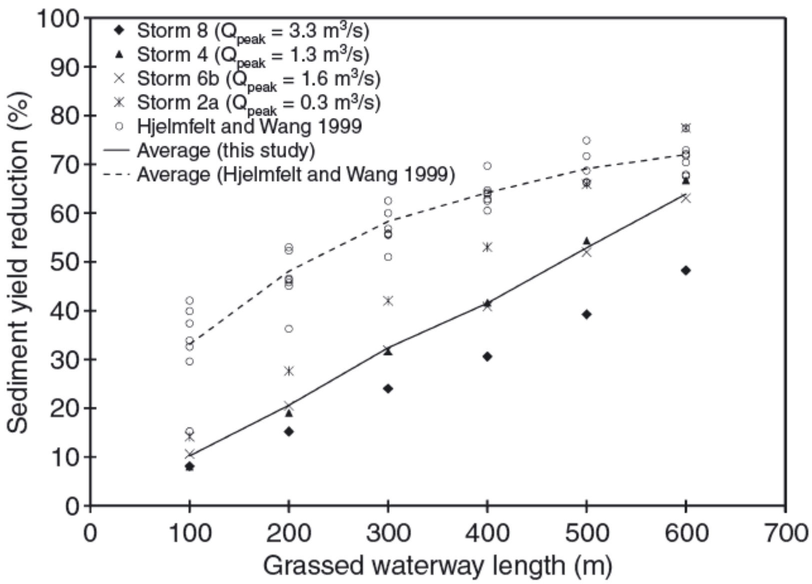

Figure 1.10 Percent sediment loss reduction as a function of grassed waterway length (Source: Dermisis et al., 2010).

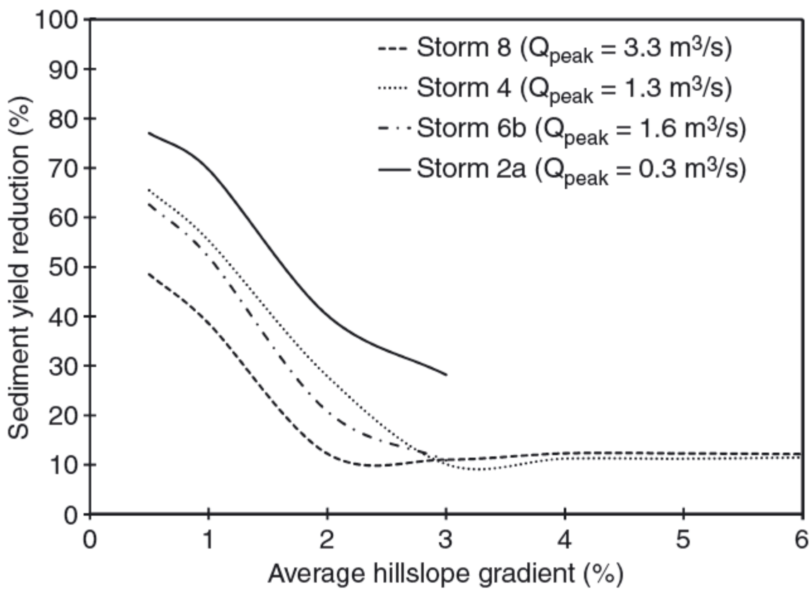

Figure 1.11 Percent sediment loss reduction as a function of average hillslope gradient for 4 different peak flow levels (3.3 m^3/s, 1.3 m^3/s, 1.6 m^3/s, 0.3 m^3/s). As the steepness of the hillslope increases the effectiveness of the grassed waterway at reducing sediment loss decreases (Dermisis et al., 2010).

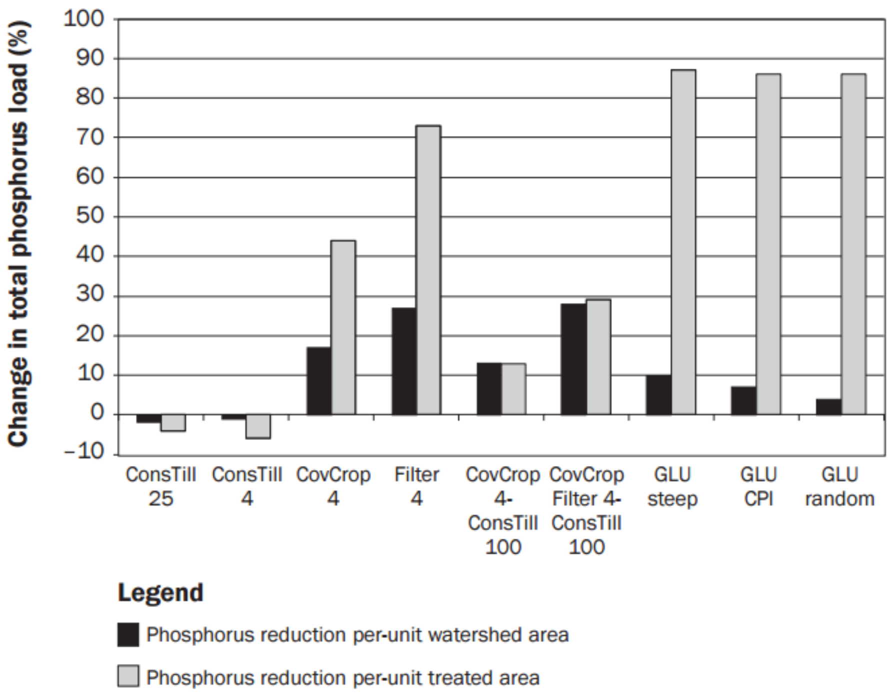

Figure 1.12 Percent change in simulated annual total phosphorus load (averaged over the five-year simulation period) from the hydrologic response units during alternative scenarios relative to baseline scenario. (X-axis terms are described in Table 1.3) This simulation was conducted using the Soil and Water Assessment Tool over the southern branch of the Root River Watershed in Southern Minnesota (Wilson et al., 2014).

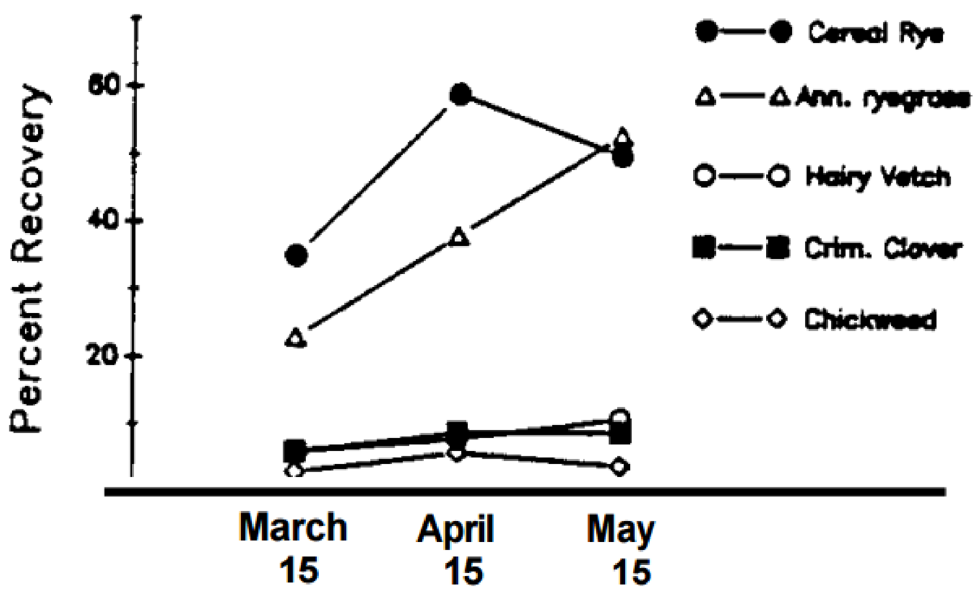

Figure 1.13 Average percent recovery of residual corn fertilizer N by various winter cover crops in Maryland (Source: Meisinger et al., 1990).

Chapter 2 - Cover Crop Effects on Soil Moisture

A cover crop is commonly defined as any living ground cover that is planted before, during, or after a main crop which is commonly killed prior to planting the next crop (Hartwig and Ammon, 2002). They have been shown to increase water infiltration, reduce runoff, reduce soil erosion, reduce weed pressure, improve soil physical, biological, and chemical properties, and, in the case of legume cover crops, contribute nitrogen to subsequent crops (Dabney, 1998; Dabney et al., 2001). Unfortunately, growing cover crops may come at a water cost and therefore may not be beneficial in every cropping system. Sub-humid to humid regions receiving an approximate annual rainfall above 750 mm are generally well suited for cover crops but in semiarid areas cover crops may hinder non-irrigated crop yields (Dabney et al., 2001). Kansas annual precipitation is variable, ranging from 406 mm in the west to 1168 mm in the southeast (Figure 2.1). Therefore, soil moisture drawdown by cover crops could be more costly in some parts of the state more than others. The seasonal distribution of precipitation is also important. Negative effects have been observed when there is an insufficient amount of time after cover crop termination for precipitation to recharge soil water (Unger and Vigil, 1998). Kansas producers considering fallow alternatives would benefit from cover crop water use information.

Objective

The objective of this study was to determine the effects of five fallow alternatives on soil water content throughout the fallow period between wheat harvest and sorghum planting. The fallow alternatives are: sorghum sudangrass, forage soybean, crimson clover, tillage radish, and double crop soybean. Double-crop soybean is not typically considered a cover crop but was added because of its popularity among Kansas farmers as a fallow alternative. In the scope of this chapter, double-crop soybean is always included when referring to cover crop treatments. A chemical fallow treatment was also included as the control.

Hypothesis

I hypothesize cover crop species will use different quantities of water from different soil profile depths throughout their growing season causing changes in soil moisture.

Materials and Methods

The Kansas Cover Crop Water Use study is located in Ashland Bottoms, Kansas, at coordinates 39˚07’24.54”N 96˚38’10.72”W. The soil is classified as a Wymore silty clay loam with 0-1% slopes that is moderately well drained, having a low runoff class and a high water storage capacity (Web Soil Survey, 2013). Plots have been under no-till management in a three year winter wheat-grain sorghum-soybean (*Triticum aestivum* L., *Sorghum bicolor* (L.) Moench, and *Glycine max* (L.) Merr., respectively) rotation with cover crop treatments planted between the wheat and sorghum phase since 2007. The experiment was arranged in a split block design with a split plot treatment structure, replicated four times. Each cropping system phase (wheat, sorghum, or soybean) was represented in each block each year. The cover crops were the whole plot treatment, and N rate was the sub-plot treatment. Blocks were 108 m by 68 m with each crop phase having a dimensions of 36 m by 68 m. The six cover crop plots were 6 m by 68 m and the five N rate subplots were 6 m by 13.6 m (Figure 2.2). Nitrogen was applied as 28% UAN at rates of 0, 45, 90, 135, and 180 kg N ha^{-1} but because fertilizer rate was not considered in this study, data was collected exclusively from subplots receiving 135 kg N ha^{-1} (Figure 2.3)

On June 24, 2015 the wheat was harvested, cover crop treatments were seeded, and the plots were sprayed with 4.7 L ha^{-1} of glyphosate mixed with the recommended amount of ammonium sulfate (AMS). Nitrogen fertilizer was applied immediately after sorghum planting in the 3 year cycle just below the soil surface using a flat coulter injector. A 1590 John Deere seeder was used to plant the cover crop treatments. Treatments included Grazex BMR sorghum-sudangrass [*Sorghum bicolor* L. Moench ssp. *Drummondii*], a late season forage soybean (*Glycine max* (L.) Merr.), double-crop soybean, *Nitro* tillage radish (*Raphanus sativus* L.), crimson clover (*Trifolium incarnatum* L.), and chemical fallow as a control. Species selection was made based on prevalence among farmers, availability of seed, and a desire to have cover crop representation for both summer and winter legume and non-legume crops. All treatments were drilled on a 19 cm row spacing. Sorghum sudangrass was drilled at 23 kg ha^{-1}, double-crop soybean at 450,000 seeds ha^{-1}, forage soybean at 425,000 seeds ha^{-1}, tillage radish at 11 kg ha^{-1}, and crimson clover at 23 kg ha^{-1}. The cover crop emergence was good in 2015. On July 16, 2015 visual inspection estimated percent cover to be 66, 95, 84, 91, 84, and 0% for forage soybean, sorghum sudangrass, double-crop soybean, tillage radish, crimson clover, and chemical fallow respectively (Figure 2.4).

Summer cover crop treatments, sorghum sudangrass and forage soybean, were terminated via roller/crimper on September 9, 2015. Double-crop soybean was harvested on October 20, 2015. The winter cover crop treatments, crimson clover and tillage radish, were winter killed around January 13, 2016. The first freeze occurred on November 26, 2016 but freezing temperatures were brief and the winter cover crops survived (Figure 2.5). On January 13th there was still some green visible in the lower growth of the crimson clover but this was minimal. No green growth was visible in either tillage radish or crimson clover on February 19, 2016, and the smell of rotting radish was pronounced. All treatments were sprayed with a glyphosate, 2,4-D, dicamba mix on April 8, 2016 at rates 3.6 L ha^{-1}, 1.2 L ha^{-1} (0.47 kg L^{-1} amine), and 0.6 L ha^{-1} respectively with 4.5 kg AMS in each 379 L tank to control weeds prior to sorghum planting.

Soil Moisture Data

Precipitation data were gathered from the Kansas Mesonet weather station located adjacent these plots to the north (Figure 2.6). Soil moisture readings were taken every two weeks during the summer months when all the cover crop treatments were actively growing and once a month throughout the winter. The reading dates were July 16, July 30, August 8, August 27, September 9, October 10, November 11, and December 12, 2015, and January 13, February 19, March 18, and May 2, 2016. Profile moisture data was collected using a CPN International 503 DR Hydroprobe Moisture Gauge (Figure 2.7; Figure 2.8). The hydroprobe works by emitting high energy neutrons from the radioactive source lowered into the soil profile via an access tube. Emitted high energy neutrons collide with hydrogen atoms, lose energy, and are reflected back toward the probe where they are measured by the detector. In soils, hydrogen is predominantly associated with water and therefore the count value given by the hydroprobe can be accurately correlated to soil moisture. For this research, a count duration of sixteen seconds was used. That is to say the hydroprobe was set to count the neutron reflection for precisely sixteen seconds at each depth. Measurements were taken at nine depths throughout the soil profile: 15, 46, 76, 107, 137, 168, 198, 229, and 259 cm.

Access tubing must be installed before water measurements can be made using the hydroprobe. For this research, aluminum access tubes 3.05 m long with an outside diameter of 4.13 cm and inside diameter of 4.03 cm were used. A GSRTS Giddings Probe manufactured by Giddings Machine Company, Inc. was used to create a hole 4.13 cm in diameter to a depth of 2.90 m in each plot to accommodate the aluminum access tubing (Figure 2.9). Generally, the aluminum access tube would slide most of the way down the hole with only moderate force but a drop hammer was needed to drive the access tube the final distance and seat it into the soil below

(Figure 2.10). A hand auger was then used to remove any dirt or debris that may have fallen down the access tube during the installation process. Lastly, a metal dummy probe, equal in size to that of the hydroprobe instrument, was lowered down the access tube to verify correct depth and ensure no bends or abrasions in the tubing. Caps made of PVC covered the exposed end of the access tubes, preventing rain and debris accumulating in them when hydroprobe readings were not being collected.

A four minute standard count was done at the beginning and end of moisture readings on every measurement date. The standard count value is necessary for interpreting the count output from the hydroprobe. The standard count provides the baseline count value of the atmosphere. The six minute standard counts ranged from 6647 to 6840. An average of these standard counts was used in calculating the count ratio (CR). The count ratio is equal to the measured count from the soil profile divided by the mean standard count (CR = measured count / standard count). The count ratio is needed for converting counts into volumetric water content (θ; cm^3 cm^{-3}). A site-specific calibration ($\theta = 0.2975*CR – 0.1586$) for the Wymore silty clay loam soil at this site was used to compute θ from count data (Kuykendall, 2015).

The hydroprobe instrument was not used for taking near-surface moisture readings because the instrument's measurement field does not differentiate between soil and atmospheric moisture, resulting in greater error at shallow depths. Therefore, Spectrum Technologies TDR 300 Field Scout outfitted with 12 cm length rods was used to take surface moisture readings (Figure 2.11). The TDR 300 is specifically designed for moisture measurements at the soil surface. Its period output has been correlated to θ in the literature, but, like the hydroprobe, its accuracy depends on soil type and must therefore be calibrated (Benor et al., 2013). The volumetric water content calibration used for the TDR 300 in this research is θ = TDR period*0.000214 – 0.412. This calibration produces an R^2 of 0.993 and a root square mean error of 0.0129 cm^3 cm^{-3} (Kuykendall, 2015). TDR readings were taken from the same plots and at the same time as were the hydroprobe readings. To reduce the amount of time required to make moisture measurements, only one TDR 300 reading was collected from each plot. Actual area measured by the hydroprobe and TDR 300 at each depth can vary. Nonetheless, a fixed 15 cm radius was assumed for measurement depths 46 – 259 cm. A radius of 9 cm was considered for the 15 cm depth. A 6 cm radius was considered at the surface for the TDR 300 instrument.

Statistical Analysis

Volumetric water content measurements were analyzed statistically in two separate ways. First, soil water content (m) for each date was computed for the entire 2.74 m profile as $\sum \theta_i l_i$, where θ_i is the volumetric water content for layer i (m^3 m^{-3}) and l_i is the thickness of layer i (m). Layer thickness were 0.12 m for layer 1, 0.18 m for layer 2, and 0.30 m for layers 3 to 10. Treatment effects on soil water content were analyzed using repeated measures analysis of variance with PROC GLIMMIX (SAS v. 9.4) where date was repeated (Appendix A). This analysis was used to show the change in total soil water for each treatment throughout time. Second, treatment effects on θ at each specific depth were analyzed for each date using PROC GLIMMIX (SAS v. 9.4), where layer depths were treated as sub-plots within a cover crop treatment. This was done to better understand how cover crop species affect soil moisture throughout a soil profile (Appendix B).

Results and Discussion

Total Profile

The first soil moisture measurements were taken on July 16, 2015. Analysis of summed θ for the 2.74 m soil profile showed no difference in soil water between chemical fallow and any of the five cover crop treatments at this time (Table 2.1). This was expected considering the minimal biomass production/accumulation of all cover crop treatments on this date. It is therefore reasonable to view the deviations in soil moisture that were measured later in the growing season as treatment effects. The cover crop treatments significantly reduced soil water compared to chemical fallow by September 9, 2015 (Table 2.1). September 9th was the date of summer cover crop (forage soybean and sorghum sudangrass) termination. Therefore, is it not surprising that this date marks maximum drawdown for these species. Maximum drawdown also occurs on September 9th for double-crop soybean despite its harvest date of October 20, 2015 (Figure 2.12). Double-crop soybean's maximum drawdown occurring on September 9th rather than on the October 9th measurement is likely a result of the soybean growth stage and the precipitation that occurred between these two dates. As the double-crop soybean approaches physiological maturity its water use can be expected to decrease. Maximum drawdown for the winter cover crop species (crimson clover and tillage radish) occurred on November 13, 2015. Drawdown for the five cover crop treatments on their respective maximum drawdown dates is shown in Figure 2.13. Green tissue was still visible on tillage radish and crimson clover later in the season on December 10, 2015 and January 13, 2016, respectively, but the drawdown effect these winter species had on soil water dramatically decreased after the first freeze that occurred on November 26, 2015. The onset of freezing temperatures may have decreased water uptake by the winter cover crop species, but it is more likely that the change in soil water between November 13th and December 10th is primarily a result of the above-average precipitation occurring at this time (Figure 2.6). On May 2, 2016, the last measurement date before sorghum planting, no significant drawdown difference was measured between chemical fallow and the summer cover crop treatments according to the total 2.74 m profile analysis, but differences remained for the winter cover crop species and the double-crop soybean compared to chemical fallow (Figure 2.12; Table 2.1). Negative effects have been observed when there is insufficient time after cover crop termination for precipitation to recharge soil water (Unger and Vigil, 1998). Perhaps the early termination of the summer cover crop species allowed enough time for precipitation to recharge soil water but the later termination of the double-crop soybean and the winter cover crop species resulted in insufficient recharge time. The treatment mean estimates for total profile soil water content at all sampling dates (Figure 2.12) can be found in Table 2.2.

On the last reading date, May 2, 2016 the effect of cover crop species was still significant, but the species by depth interaction was not (Table 2.3). The winter cover crop treatments and double-crop soybean were different from chemical fallow (Figure 2.14). None of the cover crop treatments (excluding chemical fallow) were different from each other. It is interesting that the average θ on May 2^{nd} for each treatment correlates perfectly with the order in which these cover crops were terminated. Naturally, chemical fallow has the greatest θ. The two summer cover crops terminated on September 9, 2015 had the next greatest θ. Double-crop soybean was next being harvested on October 20, 2015. The tillage radish was winter terminated by the January 13, 2016 measurement date. Crimson clover survived the longest (winter terminated by 2/19/16) and had the smallest θ. This trend appears to support Unger and Vigial's (1998) findings that cover crop termination date is an important factor impacting soil moisture at planting.

Contrasting Species

Various cover crop species have been credited with different agronomic benefits according to their unique biology. Winter legume cover crops like crimson clover can decrease nitrogen fertilizer need because of their ability to fix atmospheric nitrogen (Decker et al., 1994).

Brassica cover crops like tillage radish may help break up compaction layers (Williams and Weil, 2004) and increase nutrient cycling due to their extensive root system (Nanzyo et al., 2002). Therefore, one might also expect cover crop species to use different quantities of water from different depths in the soil profile. Crimson clover and tillage radish were found to be quite contrasting in location of moisture drawdown on November 13, 2016, the date of winter cover crop maximum drawdown (Figure 2.15). In the crimson clover treatment, 82% of the total moisture drawdown occurred above the 107-cm depth whereas only 54% occurred above the 107 cm depth in the tillage radish treatment. Although both of these cover crops produce relatively small amounts of biomass, and low biomass cover crop species may be well suited for drier climates (Arnet, 2010), crimson clover may be a poor choice. The drier soil observed for crimson clover may indicate that it would struggle to survive in water limiting environments. If crimson clover does survive, it could result in moisture deficits at spring planting, if it is able to survive at all. Moisture deficits at shallow depths could particularly hinder a subsequent main crop because only the shallow soil moisture is initially available to a main crop seedling. Deficits in this zone at spring planting could delay or reduce emergence which would likely decrease main crop yield. In contrast, the extensive rooting structure of the tillage radish may give it access to water found deep in the soil profile. This is an advantage to tillage radish in avoiding water stress during dry periods but it also may be an advantage to the subsequent main crop. The comparatively greater shallow soil moisture in the tillage radish treatment at spring planting may increase emergence and seedling vigor of the subsequent main crop (Figure 2.15). However, precipitation will recharge surface moisture before that at lower depths. From this perspective moisture drawdown from shallow depths could be an advantage in that it takes less time and precipitation for recharge.

Comparisons by depth for the summer cover crops and double-crop soybean are less interesting. These species appear to drawdown soil moisture at more moderate depths but in much the same way (Figure 2.16). Perhaps differences between these summer species would become apparent if termination was delayed. The mean estimates for analysis by depth can be found in Table 2.4; Table 2.5; Table 2.6.

Conclusion

Cover crops had different effects on soil moisture and total soil water content depending on growth patterns and management. Cover crops that were terminated earlier, such as the summer cover crop species, had water content similar to the fallow at sorghum planting. These crops would likely have less impact on sorghum growth and yield, particularly for years with average fall and winter precipitation. Cover crops that were terminated later, such as the winter cover crop species, had water content that differed from fallow at sorghum planting, and therefore, could negatively impact sorghum growth and yield. Sorghum sudangrass, forage soybean, and double-crop soybean had similar water drawdown by depth but crimson clover and tillage radish were contrasting. Kansas producers should consider their specific climate pattern and management plan when selecting a cover crop species. More extensive cover crop water use research is needed to understand how other cover crop species drawdown soil water.

Table 2.1 Significance (p-value) for contrasts between chemical fallow (CF) and other cover crop treatments from ANOVA for analysis of total soil profile water where volumetric water content (θ) was summed for the 2.74 m soil profile.

Label	Emergence July 16, 2015	Summer Maximum Drawdown September 9, 2015	Winter Maximum Drawdown November 13, 2015	Spring Planting May 2, 2016
CF vs CC	0.1161	<0.0001	<0.0001	0.0135
CF vs DCS	0.4962	<0.0001	<0.0001	0.0485
CF vs FS	0.8341	<0.0001	<0.0001	0.2401
CF vs SS	0.1693	<0.0001	<0.0001	0.1826
CF vs TR	0.3152	<0.0001	<0.0001	0.0132

Crimson Clover (CC), Chemical Fallow (CF), Double-crop Soybean (DCS), Forage Soybean (FS), Sorghum Sudangrass (SS), Tillage Radish (TR)

Table 2.2 Mean profile water content (m) for cover crop treatments measured from the surface to the 2.74-m soil depth for each measurement date (m/d/yy). The least significant difference (LSD) for comparisons within a measurement date is 0.046 and LSD for comparisons within a treatment is 0.023.

Trt*	7/16/15	7/30/15	8/11/15	8/27/15	9/9/15	10/9/15	11/13/15	12/10/15	1/13/16	2/19/16	3/18/16	5/2/16
							m					
CC	0.944	0.934	0.933	0.873	0.819	0.848	0.745	0.950	0.952	0.953	0.941	0.993
CF	0.981	0.998	1.007	1.010	1.011	1.018	1.000	1.031	1.027	1.017	1.008	1.053
DCS	0.965	0.933	0.930	0.869	0.808	0.840	0.831	0.914	0.939	0.944	0.937	1.006
FS	0.976	0.943	0.944	0.870	0.804	0.853	0.840	0.932	0.956	0.965	0.960	1.026
SS	0.949	0.923	0.928	0.882	0.832	0.908	0.889	0.946	0.959	0.964	0.958	1.022
TR	0.958	0.934	0.929	0.888	0.846	0.853	0.802	0.909	0.916	0.920	0.909	0.993

*Treatment (Trt), Crimson Clover (CC), Chemical Fallow (CF), Double-crop Soybean (DCS), Forage Soybean (FS), Sorghum Sudangrass (SS), Tillage Radish (TR), Least Significant Difference (LSD). Missing data on 10/9/15 and 11/13/15 could cause a false significance based on LSD.

Table 2.3 The p-values for fixed effects of depth, cover crop species, and the depth by cover crop species interaction from the ANOVA on volumetric water content by sampling date.

Date	Depth	Species	Species*Depth
7/16/2015	<0.0001	0.6052	0.4840
7/30/2015	<0.0001	0.0094	<0.0001
8/11/2015	<0.0001	0.0039	0.0009
8/27/2015	<0.0001	<0.0001	<0.0001
9/9/2015	<0.0001	<0.0001	<0.0001
10/9/2015	<0.0001	<0.0001	<0.0001
11/13/2015	<0.0001	<0.0001	<0.0001
12/10/2015	<0.0001	<0.0001	0.0237
1/13/2016	<0.0001	0.0009	0.0004
2/19/2016	<0.0001	0.0055	0.0002
3/18/2016	<0.0001	0.0027	0.0050
5/2/2016	<0.0001	0.0447	0.2378

Table 2.4 Mean volumetric water content (cm^3 cm^{-3}) for cover crop treatments measured from the surface to the 2.74-m soil depth for each measurement date (m/d/yy).

Trt*	7/16/15	7/30/15	8/11/15	8/27/15	9/9/15	10/9/15	11/13/15	12/10/15	1/13/16	2/19/16	3/18/16	5/2/16
	cm^3 cm^{-3}											
CC	0.345	0.336	0.333	0.304	0.280	0.293	0.252	0.342	0.343	0.343	0.336	0.360
CF	0.357	0.362	0.365	0.364	0.365	0.365	0.355	0.369	0.363	0.361	0.357	0.379
DCS	0.352	0.331	0.332	0.306	0.283	0.298	0.296	0.330	0.335	0.338	0.334	0.366
FS	0.353	0.332	0.335	0.303	0.279	0.299	0.293	0.334	0.340	0.344	0.340	0.370
SS	0.345	0.329	0.332	0.311	0.289	0.320	0.315	0.342	0.343	0.346	0.341	0.371
TR	0.345	0.334	0.334	0.317	0.299	0.304	0.282	0.329	0.328	0.332	0.325	0.362
LSD	n.s.	0.017	0.017	0.018	0.020	0.017	0.016	0.012	0.013	0.013	0.013	0.012

*Treatment (Trt), Crimson Clover (CC), Chemical Fallow (CF), Double-crop Soybean (DCS), Forage Soybean (FS), Sorghum Sudangrass (SS), Tillage Radish (TR), Least Significant Difference (LSD). Not significant (n.s.). Missing data on 10/9/15 and 11/13/15 could cause a false significance based on LSD.

Table 2.5 Mean volumetric water content (cm^3 cm^{-3}) for 10 soil profile layers for each measurement date (m/d/yy).

Depth	7/16/15	7/30/15	8/11/15	8/27/15	9/9/15	10/9/15	11/13/15	12/10/15	1/13/16	2/19/16	3/18/16	5/2/16
	cm^3 cm^{-3}											
6 cm	0.323	0.269	0.277	0.224	0.192	0.227	0.184	0.277	0.222	0.249	0.225	0.331
15 cm	0.360	0.286	0.294	0.229	0.187	0.243	0.208	0.350	0.363	0.349	0.330	0.373
46 cm	0.434	0.422	0.409	0.370	0.336	0.386	0.358	0.426	0.430	0.431	0.428	0.435
76 cm	0.412	0.410	0.406	0.382	0.357	0.379	0.362	0.403	0.412	0.412	0.411	0.418
107 cm	0.379	0.381	0.378	0.362	0.341	0.345	0.335	0.361	0.380	0.381	0.380	0.394
137 cm	0.341	0.344	0.347	0.337	0.322	0.313	0.311	0.329	0.340	0.345	0.344	0.376
168 cm	0.316	0.320	0.324	0.321	0.310	0.301	0.302	0.312	0.322	0.323	0.323	0.351
198 cm	0.323	0.269	0.277	0.224	0.192	0.227	0.184	0.277	0.222	0.249	0.225	0.331
229 cm	0.360	0.286	0.294	0.229	0.187	0.243	0.208	0.350	0.363	0.349	0.330	0.373
259 cm	0.434	0.422	0.409	0.370	0.336	0.386	0.358	0.426	0.430	0.431	0.428	0.435
LSD*	0.412	0.410	0.406	0.382	0.357	0.379	0.362	0.403	0.412	0.412	0.411	0.418

*Least Significant Difference (LSD). Missing data on 10/9/15 and 11/13/15 slightly changes the LSD for some comparisons on these dates.

Table 2.6 Mean volumetric water content (cm^3 cm^{-3}) for 10 soil profile layers for each cover crop treatment on each measurement date (m/d/yy).

Trt and Depth*	7/16/15	7/30/15	8/11/15	8/27/15	9/9/15	10/9/15	11/13/15	12/10/15	1/13/16	2/19/16	3/18/16	5/2/16
	cm^3 cm^{-3}											
CC1	0.335	0.301	0.255	0.192	0.109	0.161	0.089	0.278	0.258	0.266	0.235	0.326
CC2	0.370	0.298	0.289	0.160	0.106	0.128	0.053	0.346	0.372	0.362	0.334	0.378
CC3	0.444	0.437	0.437	0.362	0.295	0.331	0.227	0.433	0.439	0.442	0.440	0.445
CC4	0.405	0.406	0.407	0.397	0.351	0.370	0.271	0.397	0.413	0.413	0.410	0.421
CC5	0.375	0.375	0.374	0.372	0.368	0.365	0.316	0.362	0.363	0.365	0.367	0.388
CC6	0.326	0.331	0.333	0.331	0.331	0.328	0.323	0.335	0.331	0.330	0.329	0.357
CC7	0.280	0.289	0.294	0.296	0.301	0.303	0.297	0.303	0.301	0.303	0.300	0.322
CC8	0.290	0.296	0.295	0.296	0.297	0.299	0.299	0.301	0.302	0.299	0.300	0.312
CC9	0.302	0.307	0.316	0.311	0.313	0.315	0.317	0.326	0.315	0.318	0.318	0.324
CC10	0.322	0.323	0.329	0.326	0.324	0.329	0.327	0.339	0.333	0.331	0.330	0.332
CF1	0.340	0.323	0.334	0.304	0.318	0.297	0.253	0.281	0.207	0.232	0.228	0.322
CF2	0.377	0.381	0.365	0.357	0.342	0.334	0.305	0.354	0.354	0.334	0.318	0.360
CF3	0.439	0.444	0.443	0.447	0.441	0.445	0.436	0.443	0.443	0.444	0.442	0.445
CF4	0.415	0.420	0.419	0.418	0.422	0.421	0.421	0.419	0.420	0.419	0.421	0.422
CF5	0.386	0.397	0.399	0.394	0.398	0.395	0.390	0.397	0.399	0.393	0.394	0.403
CF6	0.355	0.366	0.376	0.379	0.375	0.380	0.373	0.375	0.376	0.377	0.371	0.386
CF7	0.332	0.343	0.353	0.363	0.360	0.361	0.362	0.372	0.377	0.365	0.362	0.376
CF8	0.308	0.313	0.323	0.329	0.334	0.341	0.332	0.348	0.352	0.348	0.341	0.358
CF9	0.299	0.306	0.310	0.319	0.322	0.333	0.331	0.343	0.346	0.337	0.336	0.350
CF10	0.322	0.328	0.329	0.329	0.334	0.345	0.349	0.358	0.360	0.358	0.357	0.370
DCS1	0.336	0.236	0.263	0.205	0.190	0.219	0.212	0.269	0.213	0.242	0.225	0.334
DCS2	0.371	0.272	0.281	0.208	0.161	0.234	0.228	0.355	0.367	0.354	0.338	0.385
DCS3	0.428	0.415	0.392	0.349	0.313	0.370	0.366	0.421	0.419	0.424	0.419	0.430

Trt and Depth*	7/16/15	7/30/15	8/11/15	8/27/15	9/9/15	10/9/15	11/13/15	12/10/15	1/13/16	2/19/16	3/18/16	5/2/16
							$cm^3\ cm^{-3}$					
DCS4	0.411	0.412	0.403	0.359	0.327	0.356	0.362	0.405	0.408	0.405	0.404	0.413
DCS5	0.383	0.378	0.379	0.347	0.307	0.312	0.311	0.337	0.376	0.383	0.380	0.392
DCS6	0.348	0.343	0.344	0.333	0.309	0.292	0.288	0.305	0.328	0.341	0.338	0.375
DCS7	0.314	0.312	0.319	0.314	0.296	0.279	0.286	0.290	0.312	0.306	0.315	0.347
DCS8	0.301	0.308	0.306	0.305	0.298	0.288	0.285	0.292	0.298	0.298	0.299	0.324
DCS9	0.304	0.309	0.313	0.315	0.310	0.310	0.306	0.309	0.307	0.307	0.307	0.325
DCS10	0.322	0.325	0.321	0.324	0.320	0.322	0.317	0.319	0.327	0.322	0.321	0.330
FS1	0.324	0.228	0.263	0.179	0.174	0.194	0.182	0.263	0.213	0.241	0.217	0.325
FS2	0.343	0.227	0.248	0.163	0.109	0.181	0.168	0.321	0.336	0.321	0.298	0.356
FS3	0.428	0.425	0.390	0.321	0.280	0.361	0.355	0.411	0.417	0.417	0.417	0.423
FS4	0.412	0.414	0.408	0.362	0.321	0.372	0.368	0.404	0.414	0.411	0.413	0.415
FS5	0.389	0.389	0.390	0.360	0.308	0.333	0.329	0.369	0.391	0.394	0.394	0.394
FS6	0.360	0.362	0.363	0.355	0.329	0.309	0.312	0.338	0.359	0.360	0.362	0.378
FS7	0.335	0.332	0.337	0.334	0.320	0.302	0.302	0.315	0.338	0.349	0.344	0.374
FS8	0.314	0.316	0.320	0.318	0.315	0.306	0.300	0.304	0.311	0.316	0.321	0.355
FS9	0.311	0.310	0.312	0.313	0.310	0.307	0.300	0.300	0.302	0.312	0.311	0.339
FS10	0.318	0.319	0.324	0.324	0.322	0.321	0.315	0.319	0.318	0.318	0.322	0.344
SS1	0.323	0.255	0.267	0.218	0.149	0.267	0.199	0.290	0.222	0.259	0.227	0.335
SS2	0.351	0.265	0.274	0.217	0.178	0.313	0.284	0.367	0.376	0.360	0.345	0.381
SS3	0.433	0.413	0.398	0.359	0.323	0.415	0.402	0.427	0.433	0.431	0.429	0.435
SS4	0.414	0.413	0.408	0.386	0.361	0.384	0.392	0.407	0.414	0.412	0.414	0.419
SS5	0.370	0.372	0.370	0.362	0.346	0.344	0.353	0.368	0.390	0.384	0.381	0.394
SS6	0.325	0.328	0.339	0.321	0.305	0.290	0.304	0.320	0.332	0.346	0.345	0.380
SS7	0.307	0.314	0.319	0.312	0.297	0.280	0.295	0.299	0.313	0.322	0.321	0.358
SS8	0.297	0.300	0.302	0.304	0.299	0.288	0.292	0.301	0.307	0.306	0.311	0.335
SS9	0.308	0.307	0.315	0.308	0.306	0.301	0.306	0.312	0.315	0.312	0.312	0.328
SS10	0.319	0.320	0.325	0.322	0.325	0.318	0.321	0.332	0.326	0.327	0.330	0.342
TR1	0.280	0.271	0.279	0.247	0.214	0.222	0.168	0.281	0.218	0.256	0.220	0.342
TR2	0.345	0.272	0.305	0.270	0.227	0.267	0.209	0.360	0.374	0.362	0.345	0.379
TR3	0.432	0.399	0.393	0.380	0.364	0.392	0.361	0.420	0.426	0.426	0.423	0.433
TR4	0.412	0.399	0.389	0.370	0.359	0.371	0.356	0.387	0.406	0.408	0.406	0.416
TR5	0.370	0.374	0.356	0.339	0.321	0.320	0.313	0.330	0.359	0.364	0.362	0.391
TR6	0.335	0.335	0.329	0.300	0.286	0.280	0.265	0.302	0.316	0.316	0.319	0.376
TR7	0.328	0.328	0.324	0.308	0.289	0.279	0.269	0.294	0.292	0.296	0.297	0.330
TR8	0.301	0.309	0.306	0.301	0.288	0.278	0.265	0.282	0.274	0.272	0.272	0.304
TR9	0.315	0.317	0.323	0.315	0.314	0.306	0.296	0.312	0.302	0.296	0.291	0.320
TR10	0.331	0.332	0.334	0.337	0.331	0.324	0.314	0.326	0.318	0.321	0.315	0.326
LSD1	0.034	0.036	0.033	0.031	0.032	0.030	0.033	0.030	0.030	0.029	0.028	0.031
LSD2	0.037	0.038	0.035	0.034	0.036	0.032	0.034	0.031	0.031	0.030	0.029	0.032

*Treatment (Trt), Crimson Clover (CC), Chemical Fallow (CF), Double-crop Soybean (DCS), Forage Soybean (FS), Sorghum Sudangrass (SS), Tillage Radish (TR), Least Significant Difference for comparison within a cover crop treatment (LSD1), Least Significant Difference for comparison between a cover crop treatments (LSD2), 6 cm (1), 15 cm (2), 46 cm (3), 76 cm (4), 107 cm (5), 137 cm (6), 168 cm (7), 198 cm (8), 229 cm (9), 259 cm (10). Missing data on 10/9/15 and 11/13/15 could cause a false significance based on LSD.

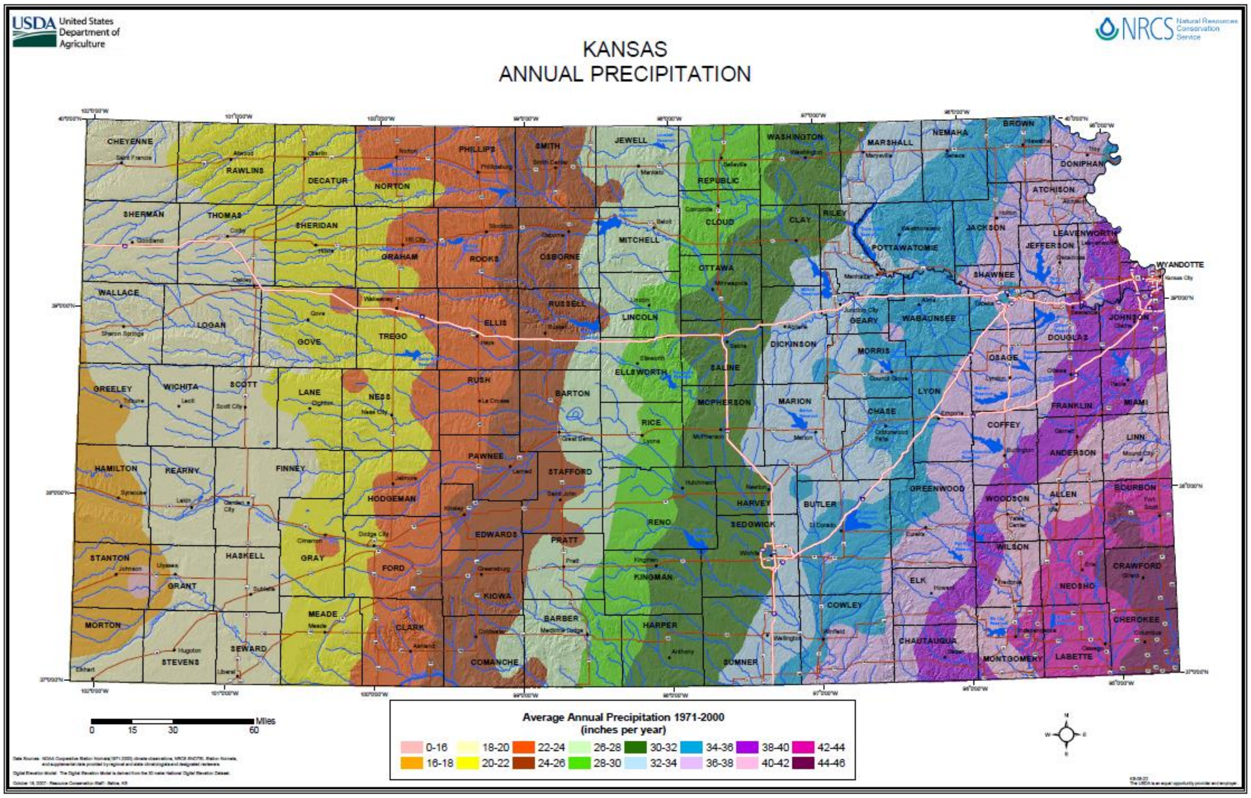

Figure 2.1 Annual precipitation ranges across the state of Kansas.

Figure 2.2 Satellite imagery of the Kansas Cover Crop Water Use research area. This image, taken in 2014, shows each phase of the cropping system: soybean (dark green), sorghum (light green), and cover crops over wheat residue (variably shaded thin strips) replicated in each of the four blocks.

SL	SNL	DSB	CF	WNL	WL
5	6	2	1	4	3
161 120N	166 160N	171 120N	176 160N	181 160N	186 0N
162 0N	167 80N	172 40N	177 80N	182 120N	187 160N
163 80N	168 120N	173 80N	178 0N	183 0N	188 80N
164 160N	169 40N	174 0N	179 120N	184 80N	189 120N
165 40N	170 0N	175 160N	180 40N	185 40N	190 40N

DSB	WNL	WL	SL	SNL	CF
2	4	3	5	6	1
201 40N	206 0N	211 40N	216 0N	221 0N	226 40N
202 160N	207 160N	212 120N	217 40N	222 40N	227 120N
203 0N	208 80N	213 160N	218 120N	223 80N	228 160N
204 80N	209 40N	214 80N	219 80N	224 160N	229 80N
205 120N	210 120N	215 0N	220 160N	225 120N	230 0N

WL	DSB	SL	WNL	SNL	CF
3	2	5	4	6	1
361 120N	366 80N	371 160N	376 0N	381 0N	386 120N
362 40N	367 120N	372 120N	377 40N	382 80N	387 160N
363 0N	368 40N	373 80N	378 80N	383 120N	388 0N
364 160N	369 160N	374 40N	379 160N	384 160N	389 80N
365 80N	370 0N	375 0N	380 120N	385 40N	390 40N

WNL	CF	DSB	SNL	WL	SL
4	1	2	6	3	5
401 80N	406 120N	411 40N	416 0N	421 0N	426 120N
402 40N	407 160N	412 0N	417 40N	422 40N	427 160N
403 160N	408 0N	413 120N	418 120N	423 160N	428 40N
404 120N	409 80N	414 80N	419 160N	424 80N	429 0N
405 0N	410 40N	415 160N	420 80N	425 120N	430 80N

Figure 2.3 Plot maps indicating the 24 individual plots from which soil moisture data was collected (blue). Plots received 135 kg ha^{-1} of nitrogen (120N on map indicates 120 lb N ac^{-1}). Six cover treatments replicated 4 times were studied: forage soybean [summer legume (SL)], sorghum sudangrass [summer non-legume (SNL)], crimson clover [winter legume (WL)], tillage radish [winter non-legume (WNL)], double-crop soybean (DSB), and chemical fallow (CF) as a control.

Forage Soybean
66% cover

Sorghum Sudangrass
95% cover

Double-crop Soybean
84% cover

Tillage Radish
91% cover

Crimson Clover
84% cover

Chemical Fallow
0% cover

Figure 2.4 Cover crop emergence on July 16, 2015. The white circles are the PVC caps that cover the access tubes used to take soil moisture reading with the hydroprobe throughout the soil profile.

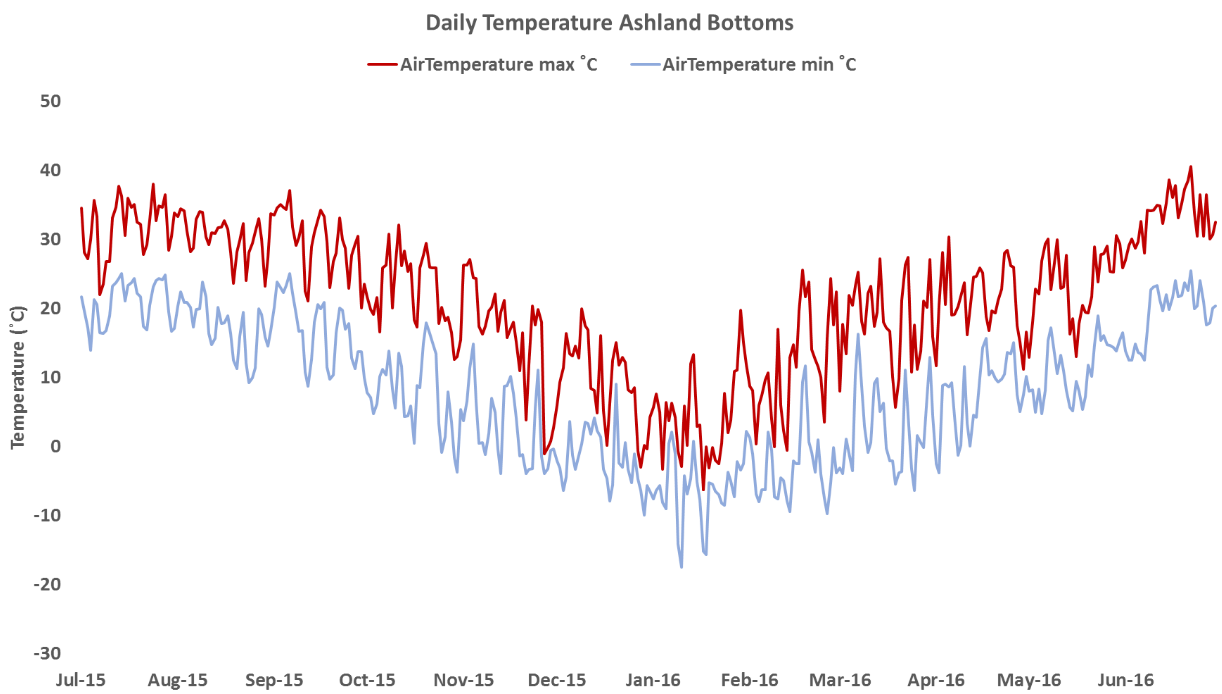

Figure 2.5 Daily maximum and minimum air temperature at the Kansas Cover Crop Water Use Study during the period soil moisture data was collected (July – May). Temperature data was collected from the Kansas mesonet weather station adjacent to the Kansas Cover Crop Water Use study.

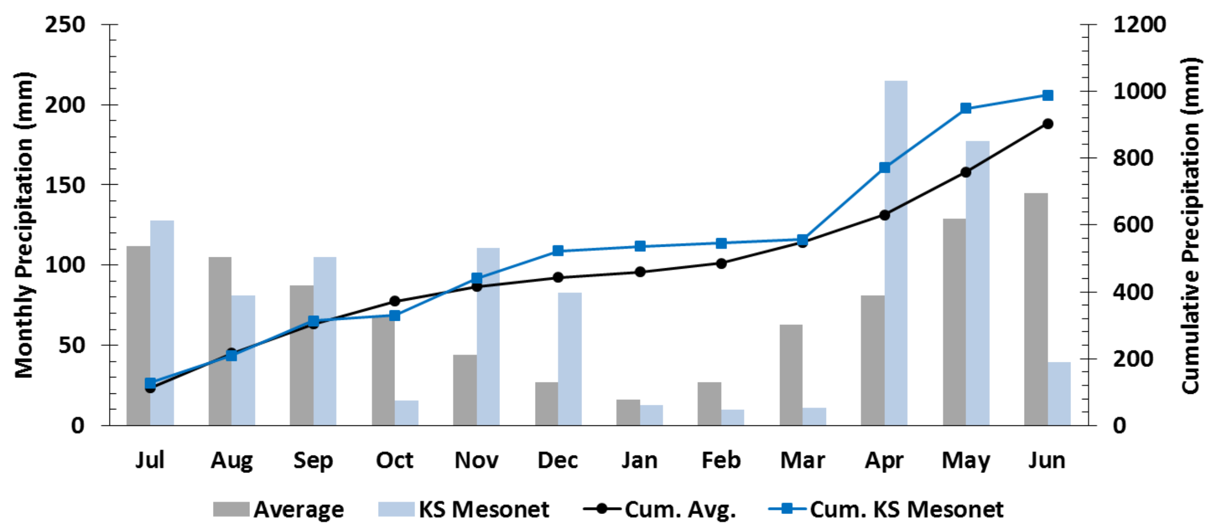

Figure 2.6 Precipitation occurring for the time period of soil moisture readings at the Kansas Cover Crop Water Use study (July 16, 2015 to May 2, 2016).

Figure 2.7 503 DR Hydroprobe Moisture Gauge used to take soil moisture reading throughout the soil profile.

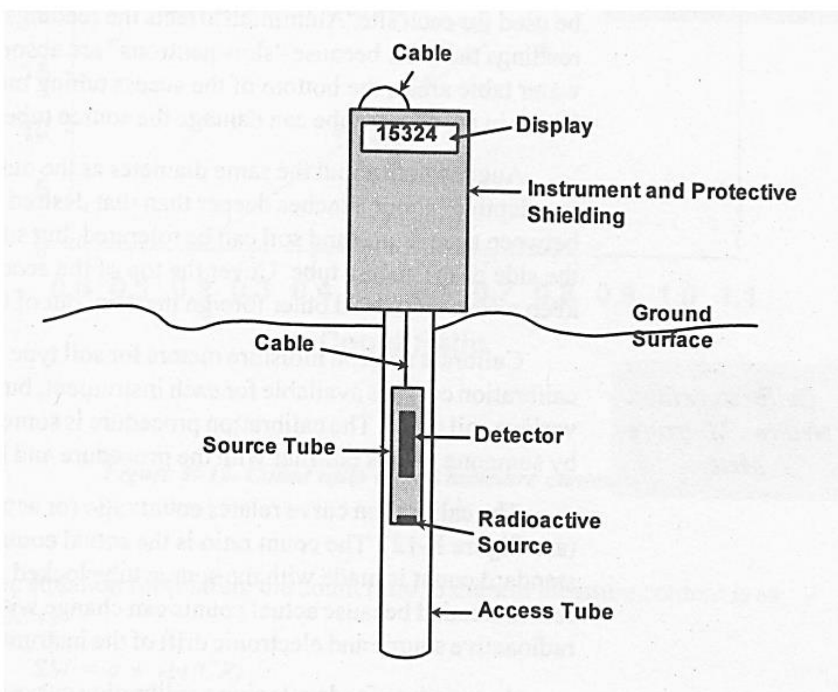

Figure 2.8 Schematic of the 503 DR Hydroprobe Moisture Gauge and how it is used in collecting soil moisture data.

Figure 2.9 Tractor mounted GSRTS Giddings Probe being used to install aluminum access tubes at the Kansas Cover Crop Water Use research site.

Figure 2.10 A drop hammer being used to drive the aluminum access tube to the final depth and seat it into the soil below.

Figure 2.11 The TDR 300 Field Scout instrument used to measure near surface soil moisture (0-12 cm).

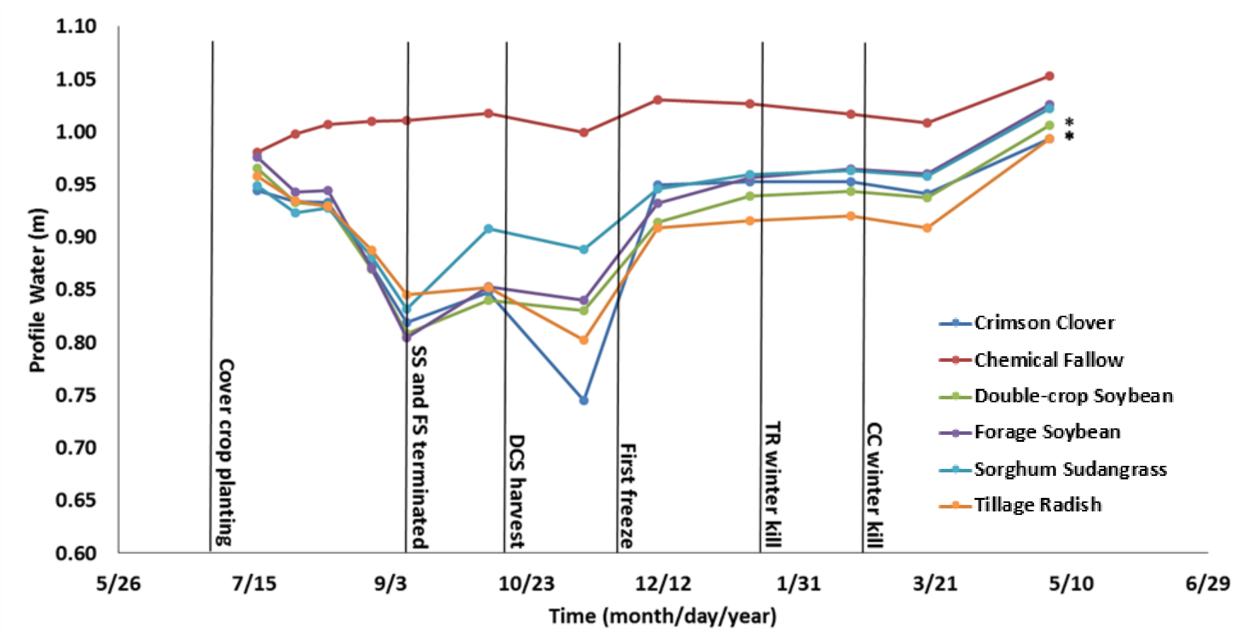

Figure 2.12 Total soil water for the 274 cm deep profile plotted over time. Key cropping system dates are noted by the vertical black lines and corresponding text. Cover Crop (CC), Sorghum Sudangrass (SS), Forage Soybean (FS), Double-crop Soybean (DCS), Tillage Radish (TR). On the last measurement, species marked with an (*) are statistically different than chemical fallow at $p<0.05$, see Table 2.2 for full statistical comparisons.

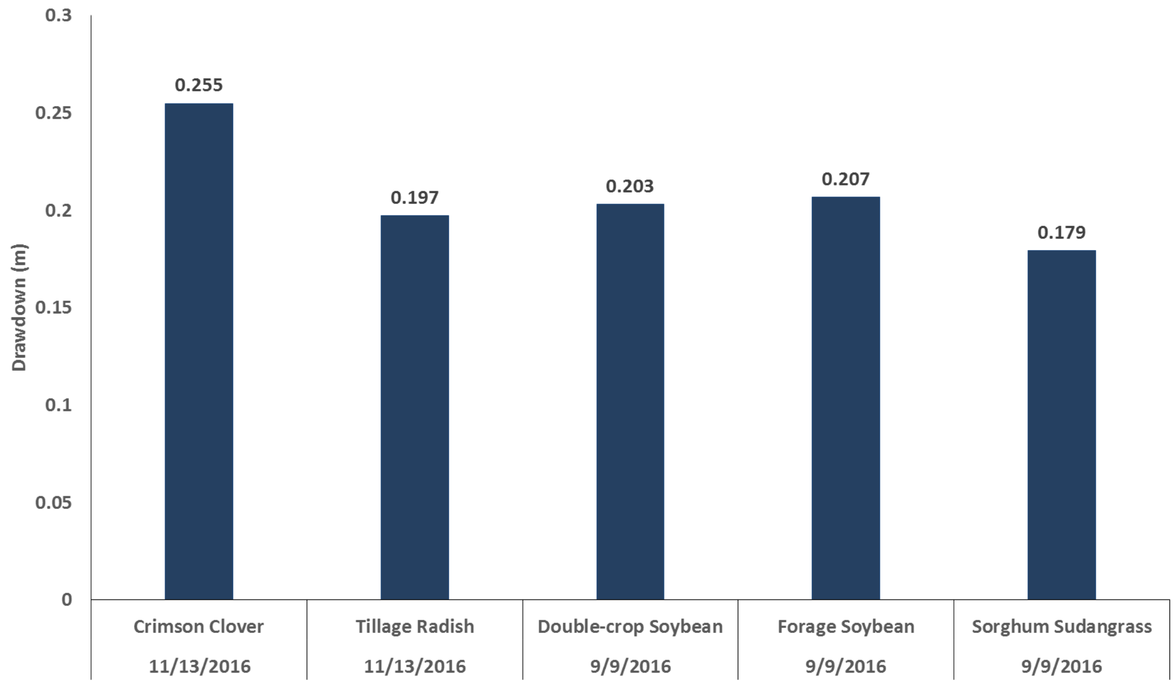

Figure 2.13 Maximum drawdown for each cover crop treatment. Maximum drawdown occurred on September 9th for the summer cover crop species (sorghum sudangrass and forage soybean) and double-crop soybean. Maximum drawdown occurred on November 13th for the winter cover crop species (crimson clover and tillage radish) as seen in Figure 2.12. Drawdown is defined as the moisture deficit from the chemical fallow control.

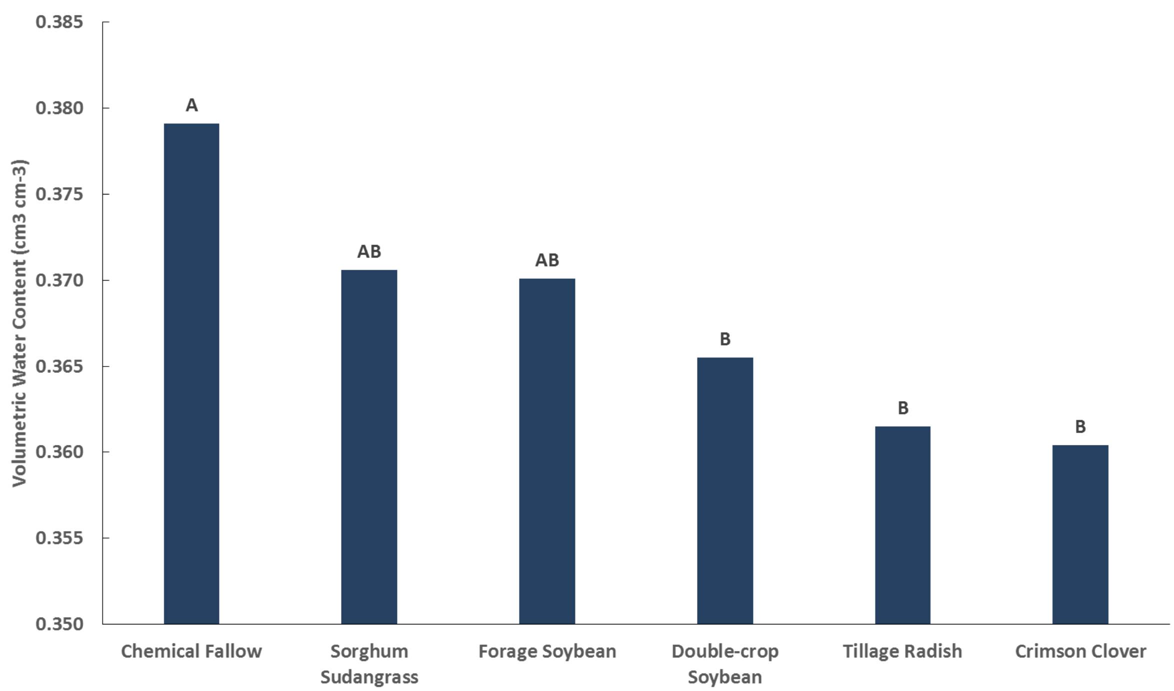

Figure 2.14 Mean volumetric water content for each cover crop treatment for a 2.74 m soil profile on the last measurement before sorghum planting (May 2, 2016).

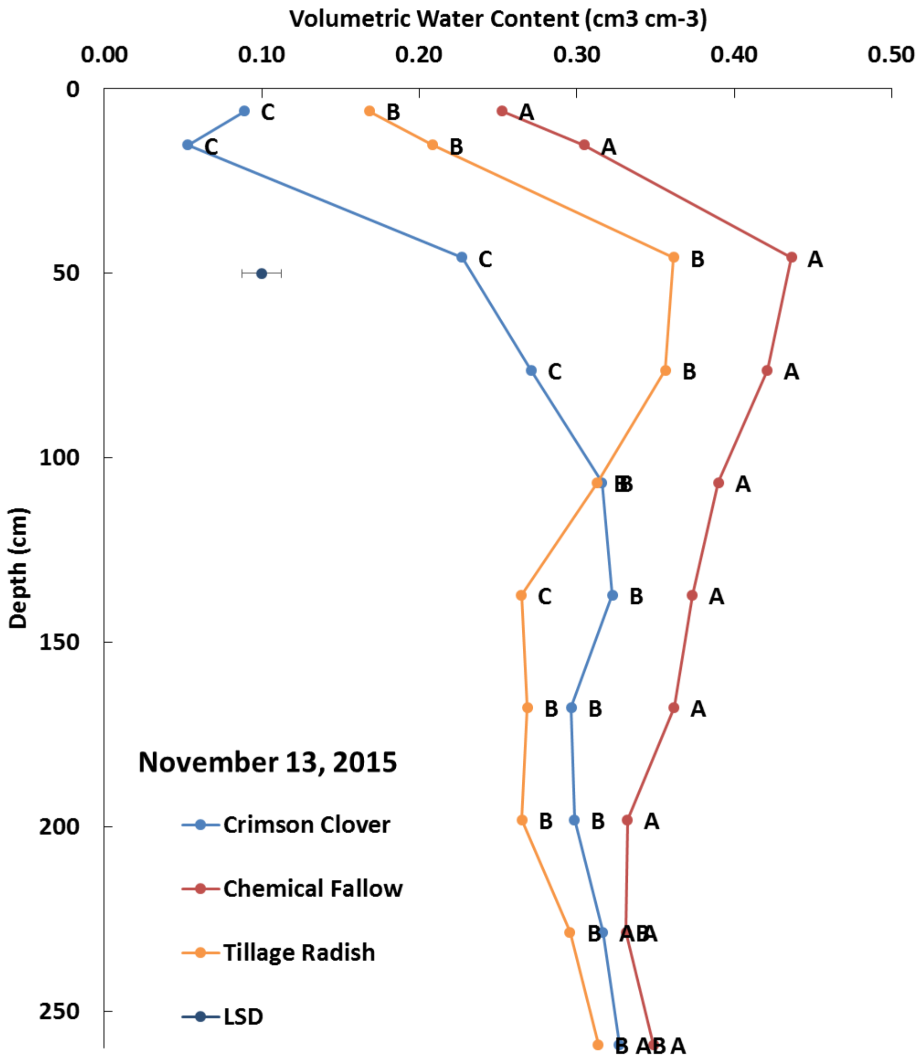

Figure 2.15 Volumetric water content throughout the profile for winter cover crop treatments (crimson clover and tillage radish) on the date of maximum drawdown (November 13, 2015) for winter cover crop species. (Different letters indicate a significant difference at $p<0.05$).

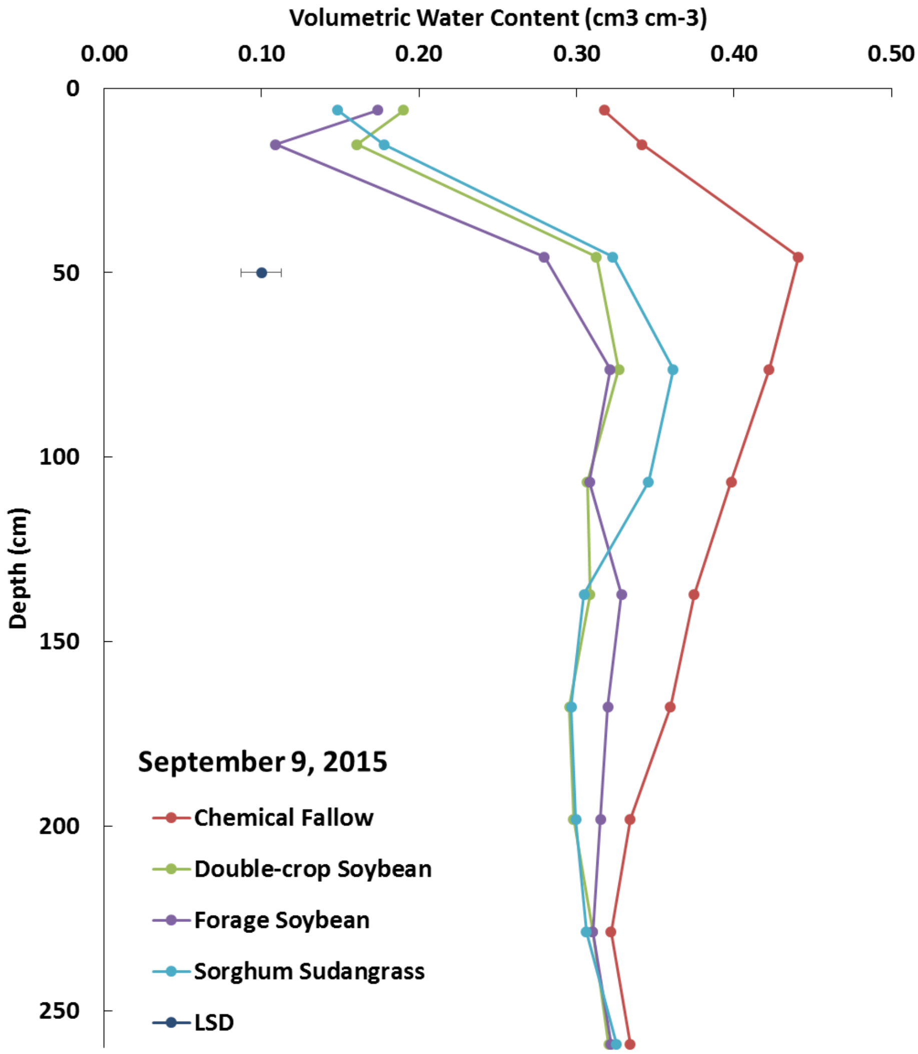

Figure 2.16 Volumetric water content throughout the profile for summer cover crop treatments (sorghum sudangrass and forage soybean) and double-crop soybean on the date of maximum drawdown (September 9, 2015) for these cover crop species. The least significant difference (LSD) indicated by the error bars on the dark blue point is 0.026 cm^3 cm^{-3}.

Chapter 3 - Kansas Agricultural Watersheds under Conventional Till Management

Excessive phosphorus (P) concentration is the most common cause of eutrophication of freshwater systems (Correll, 1998), and 50 to 70% of P that reaches surface water is from a nonpoint agriculture source (Havlin et al., 2005). The public's demand for improved agricultural sustainability and conservation practices is made clear in Field to Market's goal to "solve water quality problems by reducing sediment, P, nitrogen, and pesticide loads from U.S. cropland" (Field to Market, 2016), but P transport processes are dynamic, making solutions less obvious.

Both particulate P and soluble P can be transported from cropland into lakes and streams through surface runoff (Figure 1.2), but generally the particulate form dominates, closely linking P loss and erosion. (Gburek et al., 2005). Typically, management practices like no-till are believed to reduce runoff volume, erosion, and by association P loss, but this is not always true. Zeimen et al. (2006) found no-till management to increase runoff volume and nutrient loss when compared to chisel/disk management. Without tillage, surface broadcasted P fertilizer is left exposed on the soil surface where it is susceptible to being washed away by surface runoff. Soluble, bioavailable, and total P losses can all be reduced by placing P fertilizer below the zone of interaction between the soil and surface runoff (Bundy et al., 2005; Kimmell et al., 2001), but the equipment and fertilizer needed to do this is expensive. Even if producers do everything right for minimizing P loss, there are still some factors beyond their control.

Phosphorus loss in surface runoff is a factor of both the amount of time elapsed since P fertilizer application and precipitation intensity (Vadas et al., 2011). Rain can be unpredictable, but adjusting management practices based upon seasonal trends could help mitigate the risk. Kansas receives the majority of its runoff-producing precipitation in the spring. Therefore, P fertilizer application in the fall could reduce the risk of P loss because P concentrations in surface runoff generally exhibit curvilinear decay based on time since fertilizer application (Harmel et al., 2009). Although helpful, seasonal based management may not do enough to reduce P loss.

Cover crops have attracted interest across agriculture communities for a variety of reasons, one of which is their potential for reducing nutrient loss. Unfortunately, contradictory results are found in the literature. In a modeling study by Wilson et al. (2014), large reductions in P loss were simulated from sloping areas planted to cover crop or filter strips, leading to the conclusion that cover crops with filter strips have the greatest reductions per-unit treated area of all management practices tested (Figure 1.12) but Aronson et al. (2016) concluded that cover crops do not substantially reduce total P losses. Field research spanning multiple water years is needed to shed light on the role cover crops play in reducing P loss.

The objective of this study is to quantify the impacts winter cover crops and fertilizer management practices have on nutrient and sediment loss in surface runoff from a conventionally tilled corn-soybean rotation.

Materials and Methods

The Kansas Agricultural Watersheds (KAW) Field Laboratory was established in 2014 to quantify the impacts of cropping systems on surface water quality. It is located 3 km due east of the Manhattan regional airport in Ashland Bottoms Kansas, an approximate 25 minute drive from the Kansas State University campus. The soil at the KAW is classified as an eroded Smolan silty clay loam with 3-7% slopes. The KAW research area is 14.8 ha including waterways, border areas, and 18 small watersheds approximately 0.5 ha each.

Soil Testing

Prior to implementation of any treatments and prior to the lime application and tillage, base-line soil samples were collected on October 28, 2014 from three marked GPS locations within each plot (Figure 3.1). Points one and three are located on the backslope of the above terrace toward the south and north ends of a watershed respectively. Point two is taken in the terrace channel near the center of a watershed in the north-south direction. Composite soil samples comprised of 21 soil cores were collected within a 5 meter radius of each points (Figure 3.2). Each of the 21 soil cores was split and separated at the 5 cm depth making a total of six composite samples from each plot. Sampling all 18 watersheds (plots) produced 108 soil samples: 54 surface samples (0-5 cm) and 54 subsurface samples (5-15 cm). Soil samples were analyzed for pH, buffer pH, Mehlich P, total P, potassium, nitrate, total nitrogen, and total carbon.

Cropping System Treatments

Treatments for the current study were initiated in the fall of 2014. The treatments are arranged in a factorial structure with two levels of cover crop (with and without cover crop) and three level of P fertilizer management (none, fall broadcast, and spring injected). These six treatments were replicated three times in a randomized complete block experimental design. (Figure 3.3). The experiment was blocked according to position on the hillslope where treatments in block one were at the top of the hillslope, treatments in block two were in the middle, and treatments in block three were at the bottom. This was done because position on the hillslope could impact hydrology and thereby bias results.

Cropping System

Following site establishment (Appendix C), the site management was transitioned to a no-till corn-soybean cropping system. Some deviations from the long term management plan were made during the 2014-2015 growing season due to the unique conditions present in the beginning of the study. Key cropping system operations are summarized in Table 3.1.

Tillage

Despite the proposed plan for research to be conducted under no-till management, a chisel plow followed by a disc was used to cultivate research plots on November 7, 2014 (Table 3.1). Tillage was necessary in this first cycle to reduce the impacts of compaction caused by equipment during the set up phase and to incorporate lime application necessary to optimize soil pH.

Cover Crop

A cover crop mix containing Hard Red Winter Wheat (*Triticum aestivum* L.), Rapeseed (*Brassica napus* L.), and Hairyvetch (*Vicia villosa* L.) was planted to the appropriate plots on November 13, 2014 (Table 3.1). Seeding rates were 135 kg ha^{-1}, 6 kg ha^{-1}, and 9 kg ha^{-1} for wheat, rapeseed, and hairy vetch respectively. Ideally, the cover crop would be planted immediately after harvest, but tillage and a lime application delayed cover crop planting in this cycle.

Fertilizer

Diammonium Phosphate (DAP, 18-46-0) was applied with a Barber spreader to the six watersheds receiving the fall broadcast P fertilizer treatment on January 12 and 13, 2015 (Table 3.1). Despite calibration efforts, the DAP was applied at 181 kg ha^{-1}, 57 kg ha^{-1} greater than our target rate of 124 kg ha^{-1}, supplying the fall broadcast treatment with 33 kg N ha^{-1} and 83 kg P_2O_5 ha^{-1}. It was discovered later that a piece of the spreader was missing. This caused some fertilizer to fall outside of the collection pan during the calibration process which resulting in the over application. Although the actual rate applied was above the intended amount, it was applied consistently across each treatment receiving fall broadcast fertilizer. Human error resulted in one pass (3.05 m) being applied incorrectly to plot 205 along the north and west boundary of the watershed. Plot 205 is a control plot that was to receive no P fertilizer and no cover crop. The mistake was mitigated by incorporating the misapplied fertilizer with disc tillage on January 30, 2015.

Treatments receiving the spring injected P fertilizer had ammonium polyphosphate (APP, 10-34-0) applied in a 2x2 placement with the seed at planting on April 14, 2015 (Table 3.1). APP was applied at a rate of 174 L ha^{-1} to match the 83 kg P_2O_5 ha^{-1} applied to the fall broadcast treatments.

Nitrogen fertilizer was injected into a 10 cm deep coulter slot in the form of 28% UAN. Coulters were on a 38 cm spacing and positioned to apply 19 cm on either side of the corn row. Fertilizer was applied to all of block one on April 14, 2015, to block two and half of block three (plots 304, 305, 306) on April 15, 2015, and to the second half of block three (plots 301, 302, 303) on the morning of April 16, 2015. The control treatment received 146 kg N ha^{-1}, the fall broadcast treatment received 114 kg N ha^{-1}, and the spring injected treatment received 122 kg N ha^{-1} bringing all treatments up to 146 kg N ha^{-1} (Table 3.1). Applicator error resulted in double application of 28% UAN on two to four rows in plot 106.

Corn Planting

Corn hybrid DKC53-56RIB (Table 3.2) from Dekalb (Monsanto, St. Louis) was used primarily. However, we ran out of this specific hybrid and had to use DKC52-61RIB, a hybrid of similar maturity, as a substitute in some areas. DKC52-61RIB was planted in the outer two rows of the four row planter in plot 304 and the eastern half of plots 301 and 302. The western half of plots 301, 302, and all of the border area were planted entirely with the DKC52-61RIB hybrid.

Planting took place on April 14, 2015 (Table 3.1). Corn emergence was observed on April 27, 2015. The monitor for the planter was broken at the time of planting resulting in intermittent blank rows that resulted from seed bridging. These skips were filled in after emergence on May 13, 2015. A detailed listing of all the skips can be found in Table 3.3.

Although the intended seeding rate was 64,000 seeds ha^{-1}, the effective seeding rate was closer to 128,000 seed ha^{-1} because the planter configuration (incorrect seed plate) resulted in dropping double or triple seeds. Stand counts confirmed a plant population of 117,000 plants ha^{-1}. Corn was thinned by hand to a population of 50,210 plants ha^{-1} in two rows 9.1 m long at each of the sub-plot locations used for soil and plant sample collection (Figure 3.1). These known locations were also used later when collecting corn biomass and yield data.

Herbicide

A herbicide mix consisting of Visor, Duel II Magnum, Calisto, Glyphosate, and ammonium sulfate (AMS) was applied at a rate of 145 L ha^{-1} to the entire KAW research area on April 16, 2015 (Table 3.1). Target rates for Visor, Duel II Magnum, Calisto, and Glyphosate were 1.89, 0.35, 0.2, 1.42 L ha^{-1} respectively with 8 oz. of AMS added to each 227 L tank. This herbicide mix served as the burndown for the cover crop treatment and killed any emerging weeds.

Combine Harvest

The corn in block one was harvested with a combine on September 18, 2015 and blocks two and three on September 21, 2015 (Table 3.1; Figure 3.4). Grain weight from each plot was measured with a weigh wagon. Block one was harvested with a combine sieve that was too small resulting in a significant amount of grain loss. The sieve was however changed before harvesting blocks two and three and much less grain was lost.

Sample Collection and Analysis

Cover Crop Biomass

Hand sickles were used to harvest 6 row meters of the cover crop from three points (Figure 3.1) in each plot on April 14, 2015 (Table 3.1). Plant tissue was cut just above the soil surface. Samples were dried to constant weight at approximately 60˚C, then weighed.

Hand Harvesting Corn

Corn ears from two 9.1-m-long rows were hand harvested from blocks one and two on September 10, 2015 and block three on September 15, 2015 at the three sub-plot locations where the plant population was thinned to the correct density (Table 3.1; Figure 3.1). Harvest of block three was delayed due to a large rain event on September 10, 2015. Storms that occurred between September 10 and 15 resulted in lodging and defoliation of some corn plants across the site but the effects were minimal at the sub-plot locations. Hand harvest was done carefully, leaving the corn husks connected to the stalks. The corn ears were weighed, bagged in burlap sacks, and loaded for transport. To determine the above-ground biomass, ten stalks were harvested from each sub-plot location by cutting just above the brace roots with a hand sickle. Stalks were weighed and then chopped with a chipper/shredder. A 200 to 300-g sample of the chopped stalk biomass was placed in a brown paper bag and weighed for moisture determination. Stalk samples were dried at 60˚C, weighed, and prepared for nutrient analysis by grinding to < 2mm with a Wiley Mill (Thomas Scientific, Swedesboro).

The corn ears were shelled using an ALMACO Ear Corn Sheller (ALMACO, Nevada) on October 5, 2015, and grain samples were collected for nutrient analysis. Grain samples from six plots (302-2, 304-1, 305-1, 305-2, 305-3, 306-2) were lost during the shelling process. After shelling, grain samples were ground using a Rancilio Rocky Doserless Coffee Grinder and submitted to the K-State Testing Laboratory for analysis. A similar procedure was done with the cobs collected from the three sub-plots. Wet weight was recorded, dried at 60˚C for several days, dry weight was recorded, mechanically ground, and submitted for tissue analysis.

Water Sample Collection

Automated ISCO water samplers (6700 or 6712 series) equipped with a 730 bubbler flow module collected flow-weighted composite water samples for each runoff event. Samplers were set to be “enabled” when water depth exceeded 0.015 m. Once enabled, a 200-mL sample was collected for each 1 mm of runoff, which is roughly equivalent to 5 cubic meters. Samples were deposited into a 10 L bottle and retrieved for analysis generally within 24 hr of the precipitation event. Back in the lab, the composite samples were well shaken to ensure sediment and organic matter was suspended in the sample solution. After mixing the sample, 200 to 400 mL were abruptly poured into a 500-mL container, which was submitted to the K-State Testing Lab for nitrate, ammonium, DRP, total suspended solids, total nitrogen, and total P analysis. Samples were maintained at 4˚C until analysis was complete to minimize any microbial activity between sample collection in the field and nutrient analysis in the lab.

K-State Testing Lab Procedure for Water Analysis

Total suspended solids (TSS) was determined by filtration (EPA method 160.2; Csuros, 1997). A 0.45 µm filter paper was dried in an oven overnight at 60˚C and weighed. A 50- to 100-mL subsample was drawn while actively stirring the sample and filtered through the dried 0.45 µ filter paper. A 20-mL aliquot of the filtered solution was kept for further chemical analysis. The sediment collected on the filter paper was dried at 60˚C in an oven overnight and weighed again. Total suspended solids was determined as the difference between the two dry weights (with and without sediment) divided by the volume of sample filtered. Dissolved reactive P was determined in an aliquot of the filtrate from TSS analysis with the molybdate-blue colorimetric procedure using an Alpkem rapid flow analyzer (RFA) (Alpkem method A303-S200-13, 1986). Alpkem's RFA was also used to measure ammonium and nitrate from a filtrate produced in the total suspended solids procedure (Alpkem methods A303-S021 and A303-S170, 1986). For total N and total P a 1 to 10 mL sample was digested with potassium persulfate and processed by the Alpkem RFA using the nitrate and phosphate methods previously cited (Hosomi and Sudu, 1986; Nelson, 1987).

Data Analysis

Following each storm, flow data and sample logs were collected from automated water samplers using ISCO's 581 Rapid Transfer Device (RTD). At this time, flumes and sample inlets were inspected to determine if sediment build-up in the flume or around the sampling line inlet would have contributed to erroneous flow data or a bias sample (excess sediment in sample). Back in the lab the flow data was imported into ISCO's database software (Flowlink version 5.1) and further inspected to determine the extent of potential sediment interference. Flow data with excessive interference and water samples collected from tubes submerged in sediment were flagged and omitted from statistical analysis (Table 3.4).

Flow and sample analysis data was analyzed statistically using SAS version 9.4. The water quality data did not follow a normal distribution and was therefore transformed using a square root or $\log_{10}$ transformation depending on which transformation produced the best residual plot for the component being analyzed. Runoff, DRP concentration, and DRP load were transformed using a square root transformation. Total suspended solids, sediment load, total P concentration, and total P load were transformed using a $\log_{10}$ transformation. Load (L; kg ha^{-1}), which in the scope of this thesis is synonymous with loss, was calculated from concentration (C;

mg kg^{-1}) and runoff volume according to the equation $C_i \frac{Q}{100} = L_i$ where Q is runoff (mm) and i is the analysis component (total P, DRP, or sediment). Consider the following example for total P.

$$\frac{mg\ P}{L} * Q * \frac{1\ m}{1000\ mm} * \frac{1000\ L}{1\ m^3} * \frac{10{,}000\ m^2}{1\ ha} * \frac{1\ kg}{1{,}000{,}000\ mg} = \frac{kg\ P}{ha}$$

DRP concentration was measured in µg rather than mg therefore the load output was left in units of g ha^{-1} rather than kg ha^{-1}.

$$\frac{\mu g\ DRP}{L} * Q * \frac{1\ m}{1000\ mm} * \frac{1000\ L}{1\ m^3} * \frac{10{,}000\ m^2}{1\ ha} * \frac{1\ g}{1{,}000{,}000\ \mu g} = \frac{g\ DRP}{ha}$$

Data were analyzed for treatment effects with PROC GLIMMIX using a repeated measures analysis of variance where runoff event is repeated. Events for which all three replications of a treatment were missing were excluded from factorial analysis but were used in independent analysis of variance to determine main effects of cover crop or fertilizer treatments (Table 3.4).

Results

Large amounts of erosion sometimes caused deposition of sediment in flumes and sampling channels. The sediment in the flume affected the ability of the equipment to accurately measure flow. Also, when sediment was deposited in the sampling channel it biased the water sample with extremely high sediment concentrations. Sediment interference with sample collection was assessed by visually inspecting the sample line inlet at the time of sample removal from the field. If the sample line was covered by or surrounded by sediment, then the data did not pass quality control protocols and were omitted from analysis. Of the 12 runoff events collected during the season, only five had runoff and chemical data collected from all six treatments. However, the 12 runoff events had sufficient data to analyze for main effects (Table 3.4). Therefore, main effects of fertilizer and cover crops were analyzed using data from all runoff events but interactions were analyzed using only runoff from five events (May 11, 18, 21, June 11, and September 11).

12 Event Analysis

The main effect of cover crops and the main effect of fertilizer management practice results are presented herein. These main effects were analyzed using data from all 12 runoff events (Table 3.5; Table 3.6).

Rainfall & Runoff

Approximately 250 mm of precipitation occurred between October 2014 and May 2015 but no rain event during these months produced runoff (Figure 3.5). The first runoff-producing rain event occurred in the evening of May 4, 2015 into the morning of May 5, 2015. Note that because rainfall often occurs in the evening of one day into the morning of the next day, runoff dates are marked by the day the water samples were collected not necessarily the day the rain occurred. Because samples were almost always collected within 24 hours of rainfall, there is not much, if any, difference between the date of runoff and the date of sample collection. By the end of the 2014-2015 water year (October 1 – September 30) twelve runoff producing rain events had occurred at the KAW generating an end of cycle total precipitation of 874 mm.

There was a 16% decrease in total runoff volume when cover crops were utilized (Table 3.5; Figure 3.6). The cover crop by event interaction was not statistically significant at $p < 0.05$, indicating that cover crop had similar effects of reducing runoff throughout the year (Figure 3.7). Fertilizer placement had no effect on runoff volume and there were no significant interactions. As expected when dealing with highly variable rain storms, the effect of individual runoff events is very significant but not very interesting (Table 3.7). Unless specified otherwise the main effect of event is always statistically significant.

Sediment

Sediment concentration, expressed as total suspended solids (TSS), was decreased by 46% when a cover crop was used (Figure 3.8). The trend of cover crop reducing the TSS concentration is clearly observed throughout the water year when concentrations are graphed by runoff event (Figure 3.9). A significant difference in TSS concentration was still detected on the last event that occurred on September 11, 2015.

The cover crop treatment reduced erosion (sediment load) by 56% in the 2014-2015 water year (Table 3.5; Figure 3.10). When analyzed by individual runoff event, significant differences are observed until the last two rain events of the water year. The difference in sediment loss was drastic between the cover crop and no cover crop treated plots on the first runoff event of the 2014-2015 water year where the cover crop reduced sediment loss by 56%. (Figure 3.11). Fertilizer placement had no significant effect on sediment concentration (TSS) or load (sediment loss).

Total Phosphorus

The cover crop treatment significantly reduced total P concentration in surface runoff, resulting in 38% less total P concentration when compared to the no cover crop plots (Figure 3.12). In general, treatment effects on total P concentration are similar to the effects on TSS concentration. The cover crop effect on total P concentration in runoff was observed in each event until the last two events, where no significant differences were observed (Figure 3.13).

The cover crop treatment reduced total P load by 52% when compared to the no cover treatment (Figure 3.14). Similar to the cover crop effects on total P concentration, the cover crop resulted in lower P loss for every event until August (Figure 3.15). Surprisingly, fertilizer placement had no effect on total P loss overall or at any individual event. Plots receiving P fertilizer broadcasted on the soil surface in the fall tended to have higher total P losses but these differences were not significant due to high variability (Figure 3.16).

Dissolved Reactive Phosphorus

Dissolved reactive P concentrations in surface runoff were affected by fertilizer management practice. The DRP concentration measured from the spring injected treatment was 79% less than from the fall broadcast treatment (Figure 3.17). When analyzed by event, fall broadcast had statistically greater DRP concentrations throughout the entire water year (Figure 3.18).

Fertilizer management had a significant effect on DRP loss (Figure 3.19). DRP was lost from the spring injected treatment was 76% less than that from the fall broadcast treatment. The DRP loss from the fall broadcast management practice was consistently higher than the other two practices throughout the water year. No significant differences were observed between the control and the spring injected management practices (Figure 3.20).

Overall, DRP loads were not reduced significantly by the cover crop at $p < 0.05$ (Figure 3.21). When analyzed by runoff event, the cover crop had a large reducing effect on the first runoff event where it reduced DRP loss from 176 g ha^{-1} to 63 g ha^{-1}. Many of the following events were not statistically significant but in general the trend of plots without cover producing more DRP loss persisted (Figure 3.22).

5 Event Analysis

The cover crop by fertilizer management interaction for DRP presented herein was analyzed using 5 runoff events (May 11, 18, 21, June 11, and September 11). The other 7 runoff events were excluded from this analysis because they contained at least one missing treatment.

These data only capture 39% of the total runoff that occurred during the 2014-2015 water year (Table 3.7).

Dissolved Reactive Phosphorus Interaction

Cover crop reduced DRP loads by 60% when broadcast P fertilizer was applied in the fall (Figure 3.23). Cover crop caused no significant difference in DRP loss when P fertilizer was injected or when no P fertilizer was applied. There was only a 6 g ha^{-1} $event^{-1}$ difference measured between the fall broadcast cover crop treatment and the spring injected no cover crop treatment. Although fall broadcast with a cover crop did not come out to be statistically equal to the spring injecting P fertilizer, large reductions in DRP loss were achieved by incorporating a cover crop into the management systems where P fertilizer is broadcast applied on the soil surface (Figure 3.23).

Discussion

Runoff

Runoff volume trends from one event to the next throughout the water year did not always match trends observed in precipitation amount (Figure 3.7). Rainfall amount may be the most direct and influential factor when considering surface runoff but is certainly not the only component to consider. Three large rain events occurred in the 2014-2015 water year (May 5, July 7, and September 11). May 5 and September 11 both have corresponding high runoff volumes regardless of treatment but July 7 had one of the lowest runoff volumes. It seems that the growth stage of the corn crop may have affected the amount of total runoff volume. On May 5th the corn had only emerged about a week prior and would have had little impact on runoff. On September 11th the corn hadn’t yet been harvested (harvest began on Sept. 18th) but it was completely mature and dried down, resulting in minimal runoff reduction. On July 7th the corn crop was actively growing and had canopy closure which reduced runoff volume. These results would agree with other research that concludes increased cover reduces runoff volume (Jin et al., 2009).

Soil moisture prior to the runoff producing rain event is also key. Although soil moisture was not directly measured in this research, an understanding of soil moisture conditions can be gained from the complete precipitation record (Figure 3.24). Note that precipitation values displayed in Figure 3.7 are averages from four manual rain gauges across the KAW at the time of sample collection (generally within 1 day of rain storm). The precipitation values displayed in Figure 3.24 were retrieved from a Kansas Mesonet station less than 1 km away. There was much less runoff volume on June 11th than there was on June 5th even though precipitation amounts were similar. The complete precipitation record (Figure 3.24) shows there were small rain events leading up to the June 5th event but not the June 11th event. This indicates that the soil moisture conditions prior to a runoff producing rain event is also an important factor in runoff volume.

Sediment and Total Phosphorus

Although the cover crop treatment was technically a mix, very minimal amounts of Rapeseed and Hairy vetch emerged. Therefore, the 2014-2015 cover crop was effectively monocrop wheat rather than a mix. The late planting of the cover crop likely added to the weak emergence of the rapeseed and hairy vetch. It is unlikely that limited prevalence of rapeseed and hairy vetch would have significantly changed the nutrient and sediment loss results. However, if the cover crop was planting earlier, results likely would have be influenced by additional cover crop biomass.

When looking at the cover crop effect on sediment concentration by event (Figure 3.9), all events show a significant difference between cover and no cover except the August 8th event.

The lack of difference measured on that date is likely due to the extremely small runoff volume (Figure 3.7). There was only 1.32 mm of runoff from the no cover plots and 0.71 mm from the cover. Sediment concentration differences might have been seen on August 8th if the event were slightly larger because differences were observed on the last event. Diminishing differences occurred as time from cover crop termination increased as expected due to the decomposition of the cover crop biomass. The longevity of the cover crop impact is especially interesting when considering the late plating and minimal growth of the cover crop. The cover crop was terminated on April 16th and the surface residue created by the cover crop was gone and therefore not a factor for these last few events. Perhaps some of the cover crop root system remained in the soil, resulting in better soil aggregation and this causing the effects of cover crop to be observed/detected well beyond the termination date. This trend of cover crop effect until the last two runoff events is seen in sediment concentration, sediment load, total P concentration, and total P load (Figure 3.9; Figure 3.11; Figure 3.13; Figure 3.15). Total P loss is closely linked with sediment loss because of the affinity P has to bind with the soil (Zimmer et al., 2016). Therefore, it is not surprising that total P loss was also cut in half (52%) when a cover crop was used. As expected, trends observed in sediment concentration are similar to those seen in total P concentration, and the trends observed in sediment load are similar to those seen in total P load. Reducing erosion may be the most important factor in minimizing P loss because the majority of P is bound to the soil particles that are being carried by the runoff (Gburek et al., 2005).

As predicted, P fertilizer placement had no significant impact on sediment loss. Contrary to expectations, P fertilizer placement also had no effect on total P loads (Figure 3.16). Perhaps conventional-till management and an adequate amount of small, no-runoff-producing rain events occurring over the winter and early spring helped equalize the fertilizer treatments in terms of total P loss. Coming from a conventionally tilled system, there would have been much less P stratification. Therefore, P concentrations in the surface layer of the soil would be lower than what one would expect to find in a long standing no-till system. This being the case, the soil surface had a greater capacity for binding with the fall broadcast fertilizer in this water year than it would have after several no-till cycles due to increased stratification induced by no-till management. The fall broadcast treatment's ability to react with the soil surface was facilitated by over 100 mm of light, non-runoff-producing rainfall that occurred prior to the first runoff event. Combined, these two things may have reduced the total P loss measured from the fall broadcast treatment, resulting in no significant differences from any event throughout the entire water year. Fertilizer management differences were measured however in the DRP fraction.

Dissolved Reactive Phosphorus

The DRP fraction of total P was 8, 7, 3, 12, and 4% for no cover, cover crop, control, fall broadcast, and spring injected treatments respectively (Table 3.8). The DRP fraction is readily available for algae uptake upon entering freshwater systems and should not be ignored. It may be the factor of greatest influence when considering the negative effects of eutrophication (Seo et al., 2005). Compared to the other two fertilizer management practices (spring injected and control) DRP was significantly greater in the fall broadcast treatment for both concentration and load, especially on the first runoff producing rain event (Figure 3.20; Figure 3.18). The extreme differences in DRP between fall broadcast and the other two treatments is likely due to the vulnerable position fall broadcast P is in being left on the soil surface. The rain water has the opportunity to dissolve and wash away the fall broadcast fertilizer but the spring injected fertilizer is protected below the soil surface. Although rain may have a greater tendency to cause DRP loss from surface broadcasted P, cover crops appear to prevent DRP loss particularly from surface broadcasted P treatment resulting in an interesting fertilizer management by cover crop interaction (Figure 3.23). The cover crop has no impact on DRP in the control and spring injected treatments but significantly decreased DRP loss in the fall broadcast treatment. The cover crop likely slowed the flow of runoff and increased the amount of infiltration, reducing the amount of DRP lost from the fall broadcast treatment. The spring injected treatment still had less DRP loss than fall broadcast with a cover crop but the difference the cover crop made in the fall broadcast treatment is dramatic. This result is different from what Gaynor and Findlay (1995) found. In their study cover crops proved to decrease sediment loss but increase DRP loss.

Conclusions

In conclusion a winter cover crop was shown to decrease runoff volume, sediment loss, total P loss, and DRP loss. Fertilizer management surprisingly did not have a significant effect on total P but had a major impact on DRP loss. The cover crop affected DRP loss from the fertilizer treatments differently, resulting in a fertilizer by cover crop interaction where the cover crop reduced DRP loss in the fall broadcast treatment but not in the other two treatments. Soil moisture data would be valuable for a better understanding of the effect soil moisture prior to a runoff event has on runoff volume. Equipment errors and the erosion issues were major obstacles, especially in the beginning. Research over multiple water years is an absolute must because of the various dynamic factors. Nonetheless, cover crops do hold promise as a best management practice for reducing P loss from Kansas cropland.

Table 3.1 2014-2015 field operation. Control (CN), Fall Broadcast (FB), Spring Injected (SI), No Cover Crop (NC), Cover Crop (CC).

Date	Activity	CN-NC	CN-CC	FB-NC	FB-CC	SI-NC	SI-CC	Notes
10/28/14	soil sampling	YES	YES	YES	YES	YES	YES	split 0-5 & 5-15 cm
11/7/14	tillage	YES	YES	YES	YES	YES	YES	chisel & disc
11/13/14	cover crop planting	NO	YES	NO	YES	NO	YES	wheat, hairy vetch, rapeseed
1/13/15	P fertilizer application	NO	NO	181 kg DAP ha-1, suppling 33 kg N ha-1 and 83 kg P2O5 ha-1	181 kg DAP ha-1, suppling 33 kg N ha-1 and 83 kg P2O5 ha-1	NO	NO	DAP: 18-46-0
4/14/15	cover crop biomass collection	NO	YES	NO	YES	NO	YES	18 row meters from each plot
4/16/15	herbicide application	1.89 L ha-1 Visor, 0.35 L ha-1 Duel II Magnum, 0.2 L ha-1 Calisto, 1.42 L ha-1 Glyphosate, AMS	1.89 L ha-1 Visor, 0.35 L ha-1 Duel II Magnum, 0.2 L ha-1 Calisto, 1.42 L ha-1 Glyphosate, AMS	1.89 L ha-1 Visor, 0.35 L ha-1 Duel II Magnum, 0.2 L ha-1 Calisto, 1.42 L ha-1 Glyphosate, AMS	1.89 L ha-1 Visor, 0.35 L ha-1 Duel II Magnum, 0.2 L ha-1 Calisto, 1.42 L ha-1 Glyphosate, AMS	1.89 L ha-1 Visor, 0.35 L ha-1 Duel II Magnum, 0.2 L ha-1 Calisto, 1.42 L ha-1 Glyphosate, AMS	1.89 L ha-1 Visor, 0.35 L ha-1 Duel II Magnum, 0.2 L ha-1 Calisto, 1.42 L ha-1 Glyphosate, AMS	cover crop termination & weed control
4/14/15	corn planting & P fertilizer application	Planting Only	Planting Only	Planting Only	Planting Only	174 L APP ha^{-1} suppling 83 kg P_2O_5 ha^{-1} and 25 kg N ha^{-1}	174 L APP ha^{-1} suppling 83 kg P_2O_5 ha^{-1} and 25 kg N ha^{-1}	128,000 seeds ha^{-1}
4/14/15 4/15/15 4/16/15	nitrogen fertilizer application	523 kg 28% UAN ha-1 suppling 146 kg N ha-1	523 kg 28% UAN ha-1 suppling 146 kg N ha-1	322 L 28% UAN ha^{-1} equal to 406 kg 28% UAN ha^{-1} suppling 114 kg N ha^{-1}	322 L 28% UAN ha^{-1} equal to 406 kg 28% UAN ha^{-1} suppling 114 kg N ha^{-1}	341 L 28% UAN ha^{-1} equal to 435 kg 28% UAN ha^{-1} suppling 122 kg 28% UAN ha^{-1}	341 L 28% UAN ha^{-1} equal to 435 kg 28% UAN ha^{-1} suppling 122 kg 28% UAN ha^{-1}	equalize N rates among treatments
9/10/15 9/15/15	corn hand harvest	YES	YES	YES	YES	YES	YES	see text for details
9/18/15 9/21/15	corn combine harvest	YES	YES	YES	YES	YES	YES	see text for details

Table 3.2 Label specifications for the corn hybrid planted at the Kansas Agricultural Watersheds on April 14, 2015. Plots 301, 302, and 304 were partially planted with a similar but different hybrid, DKC52-61RIB.

DKC53-56RIB				
Dekalb Brand				
(GENSS)				
Relative Maturity: Overall - 103				
Growing Degree Units Mid-Pollination:	1267			
Black Layer:	2550			
Lot No.	746M774JXG			
		Origin	Germ	Date Tested
Variety 1045177:	94.00%	IA	95%	11/14
Treatment:	WAIH2V			
Variety 1048633	5.00%	IA	95%	11/14
Treatment:	WAIH2V			
Inert Matter:	0.40%			
Weed Seed:	0.00%			
Other Crop Seed:	0.60%			
Noxious Weeds/lb:	None			
Kind:	Field Corn			
Suggested Plate	JD B7		CIH C7	

Table 3.3 Equipment error reduced corn emergence. This list contains the number of rows from each plot that had no corn emergence on May 5, 2015. These rows were replanted on May 13, 2015.

Plot No.	Notes
101	7 rows were missing
102	7 ¼ rows missing with another row being very sparsely populated
103	6 rows missing
104	good
105	there was a little overlap but otherwise good
106	1 row missing on the ridge (this might just be an abnormally wide guess row) and a little bit of a row missing in the NW corner of the plot
201	good
202	1 row missing
203	good
204	3 ¼ rows missing and another row sparsely populated
205	5 rows missing
206	4 rows (2 of these rows had plants at the ends of the plots but none in the center)
301	1 row missing and a little overlap.
302	3 rows missing
303	good
304	10 rows missing
305	good
306	3 rows missing
Total	51 ½ rows

Table 3.4 Runoff event records.

Collection Date	Runoff Range	Precipitation (mm)	Missing Runoff Points	Missing Chemical Points	Missing Treatments
5/5/15	5/4 (3 pm) – 5/5 (2 am)	74.93	0	9	CN- NC & SI-NC
5/6/15	5/6 (2 am) – (6 am)	11.49	2	6	SI-NC
5/11/15	5/7 (6 pm) – 5/10 (5 pm)	18.88	1	3	
5/18/15	5/16 (4 pm) – 5/17 (11 pm)	19.78	4	5	
5/21/15	5/20 (1 am) – (5 am)	15.97	1	4	
5/26/15	5/23 (1 pm) – 5/26 (3 am)	33.91	4	9	SI-NC
5/29/15	5/28 (3 am) – (9 am)	25.84	0	8	CN- NC
6/5/15	6/4 (8 pm) – 6/5 (8 am)	36.37	1	9	SI-NC
6/11/15	6/11 (3 am) – (12 pm)	21.91	1	5	
7/7/15	7/6 (2 pm) – (5 pm)	51.82	2	10	SI-NC
8/8/15	8/8 (3 am) – (6 am)	28.96	0	12	CN-CC & SI-NC
9/11/15	9/10 (7 pm) – 9/11 (12 am)	83.31	3	4	

Control (CN), Fall Broadcast (FB), Spring Injected (SI), No Cover Crop (NC), Cover Crop (CC). Collection date is the date in which water samples were physically collected from the field. Runoff range describes the date range in which the runoff actually occurred. Precipitation is an average of the four manual rain gauges across the research site and includes event rainfall leading up to initial runoff. The number of plots excluded from runoff and chemical analysis for each event due to quality control protocol are listed under missing runoff points and missing chemical points respectively. Treatments where all three replications were missing are recorded under missing treatments.

Table 3.5 ANOVA table containing the p-values for the main effect of cover crop using the dataset that contains all 12 runoff events.

	Runoff	Sed¥ Load	TP¥ Load	DRP¥ Load	TSS¥	TP¥	DP¥
Cover¥	0.006	<0.001	<0.001	0.053	0.001	<0.001	0.233
Event¥	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Event*Cover¥	0.919	0.103	0.022	<0.001	0.844	0.096	0.342

¥Sediment (Sed), Total P (TP), Dissolved Reactive P (DRP), Total Suspended Solids (TSS), Cover Crop (Cover), Runoff Event (Event), Runoff Event by Cover Crop Interaction (Event*Cover)

Table 3.6 ANOVA table containing the p-values for the main effect of fertilizer using the dataset that contains all 12 runoff events.

	Runoff	Sed¥ Load	TP¥ Load	DRP¥ Load	TSS¥	TP¥	DP¥
Fert¥	0.938	0.993	0.463	<0.001	0.936	0.267	<0.001
Event¥	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Event*Fert¥	0.998	0.962	0.985	<0.001	0.842	0.641	0.002

¥Sediment (Sed), Total P (TP), Dissolved Reactive P (DP), Total Suspended Solids (TSS), Fertilizer Management (Fert), Runoff Event (Event), Runoff Event by Fertilizer Management Interaction (Event*Fert)

Table 3.7 ANOVA table containing the p-values for the interactions using the dataset that contains only the 5 events without missing treatments. Runoff analysis is included using the entire 12 event dataset for comparison.

	12 events	5 complete events						
	Runoff	Runoff	Sed¥ Load	TP¥ Load	DRP¥ Load	TSS¥	TP¥	DP¥
Fert¥	0.903	0.696	0.490	0.377	<0.001	0.341	0.238	<0.001
Cover¥	0.016	0.020	0.002	0.003	0.050	0.006	0.008	0.146
Fert*Cover¥	0.797	0.588	0.433	0.455	0.023	0.335	0.923	0.057
Event¥	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.063
Event*Fert¥	0.994	0.671	0.794	0.965	0.046	0.111	0.515	0.059
Event*Cover¥	0.841	0.387	0.161	0.072	0.228	0.685	0.393	0.382
Event*Cover*Fert¥	0.079	0.954	0.151	0.640	0.977	0.012	0.461	0.903

¥Sediment (Sed), Total P (TP), Dissolved Reactive P (DP), Total Suspended Solids (TSS), Fertilizer Management (Fert), Cover Crop (Cover), Fertilizer Management by Cover Crop Interaction (Fert*Cover), Runoff Event (Event), Runoff Event by Fertilizer Management Interaction (Event*Fert), Runoff Event by Cover Crop Interaction (Event*Cover), Runoff Event by Cover Crop by Fertilizer Management Interaction (Event*Cover*Fert).

Table 3.8 The dissolved P and particulate P fraction of total P loss by treatment.

	DRP¥ Load (g ha-1)	TP¥ Load (g ha-1)	DP¥ Fraction	PP¥ Fraction
No Cover	264.32	3346.37	8%	92%
Cover Crop	114.49	1622.50	7%	93%
Control	42.36	1687.11	3%	97%
Fall Broadcast	345.37	2794.81	12%	88%
Spring Injected	82.78	2133.33	4%	96%

¥Dissolved Reactive P (DP), Total P (TP), Particulate P (PP)

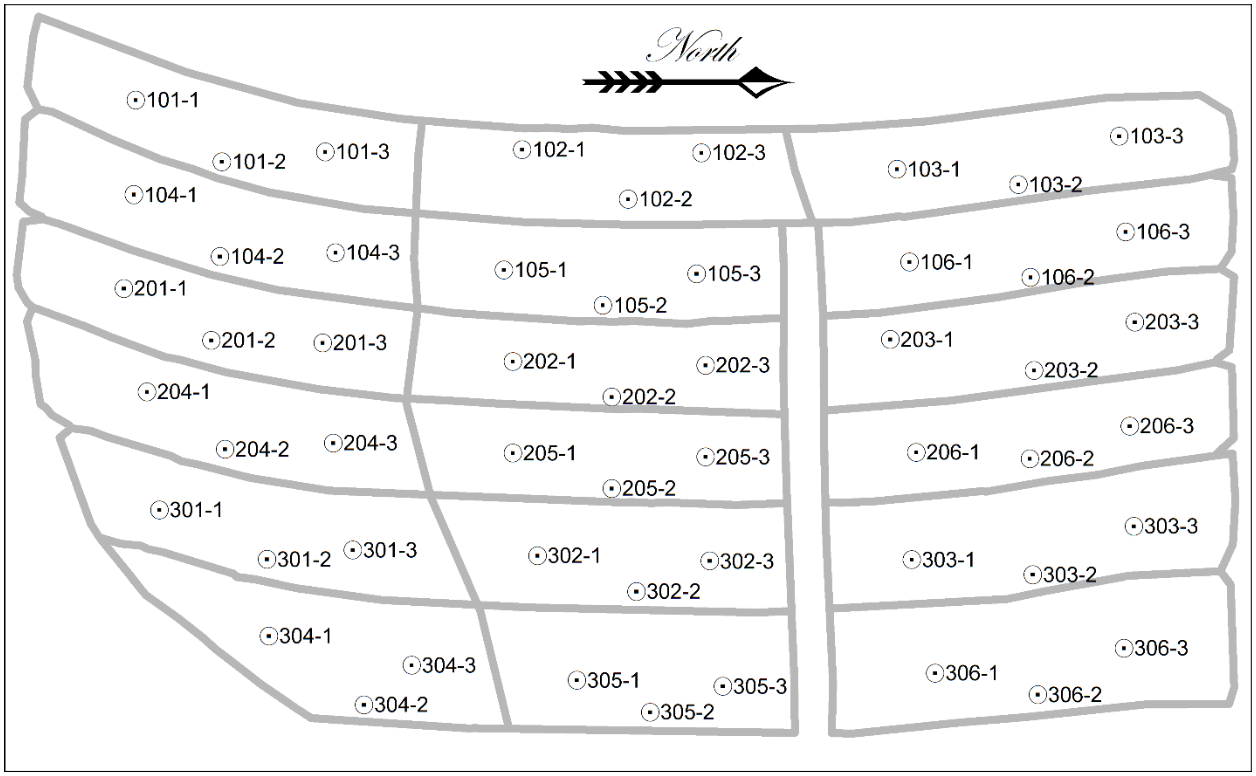

Figure 3.1 Location of sub-plot points for collection of soil, biomass, and grain samples.

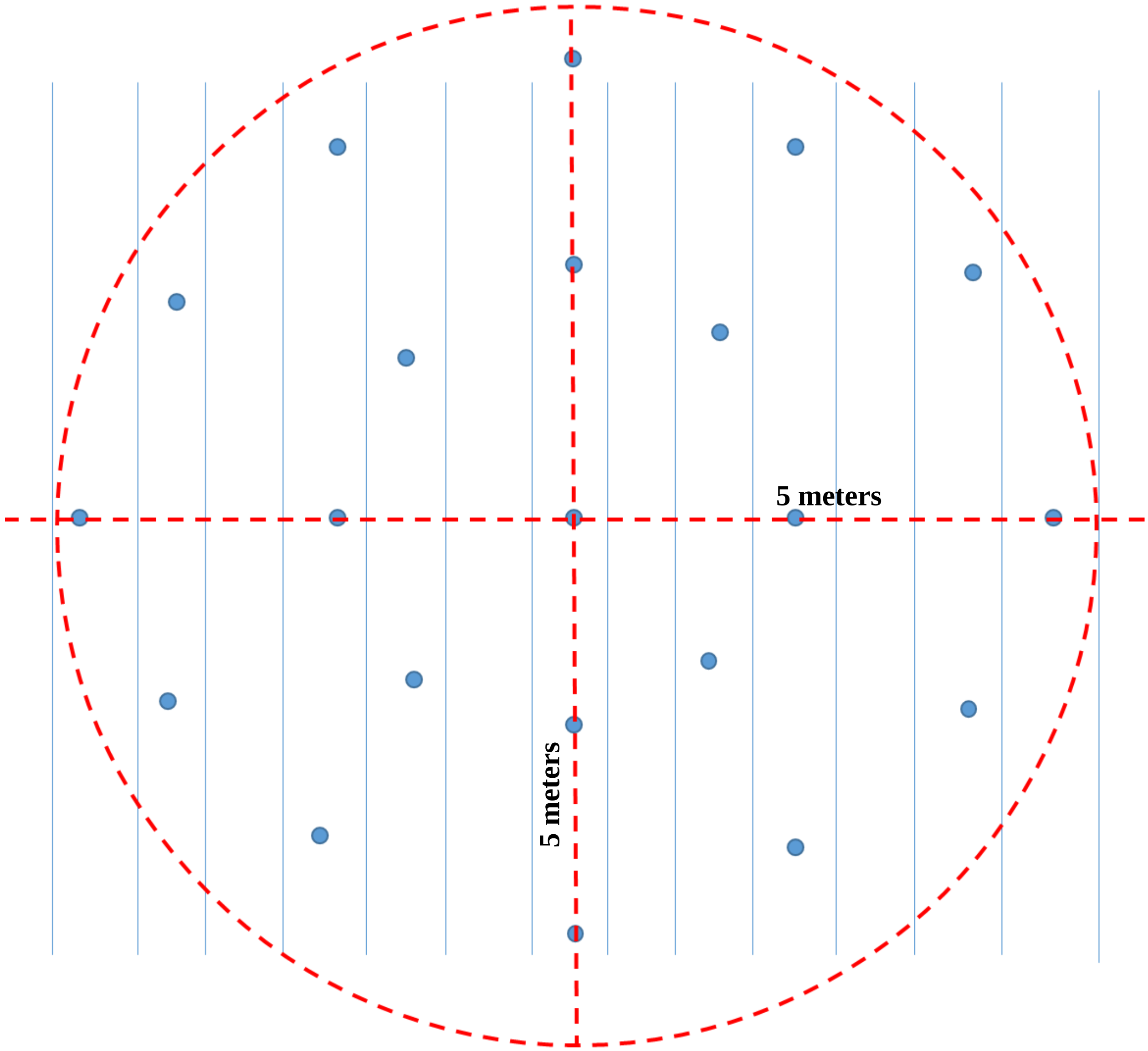

Figure 3.2 Composite soil sample pattern made up of 21 soil cores. The diameter of area sampled is approximately 10 meters.

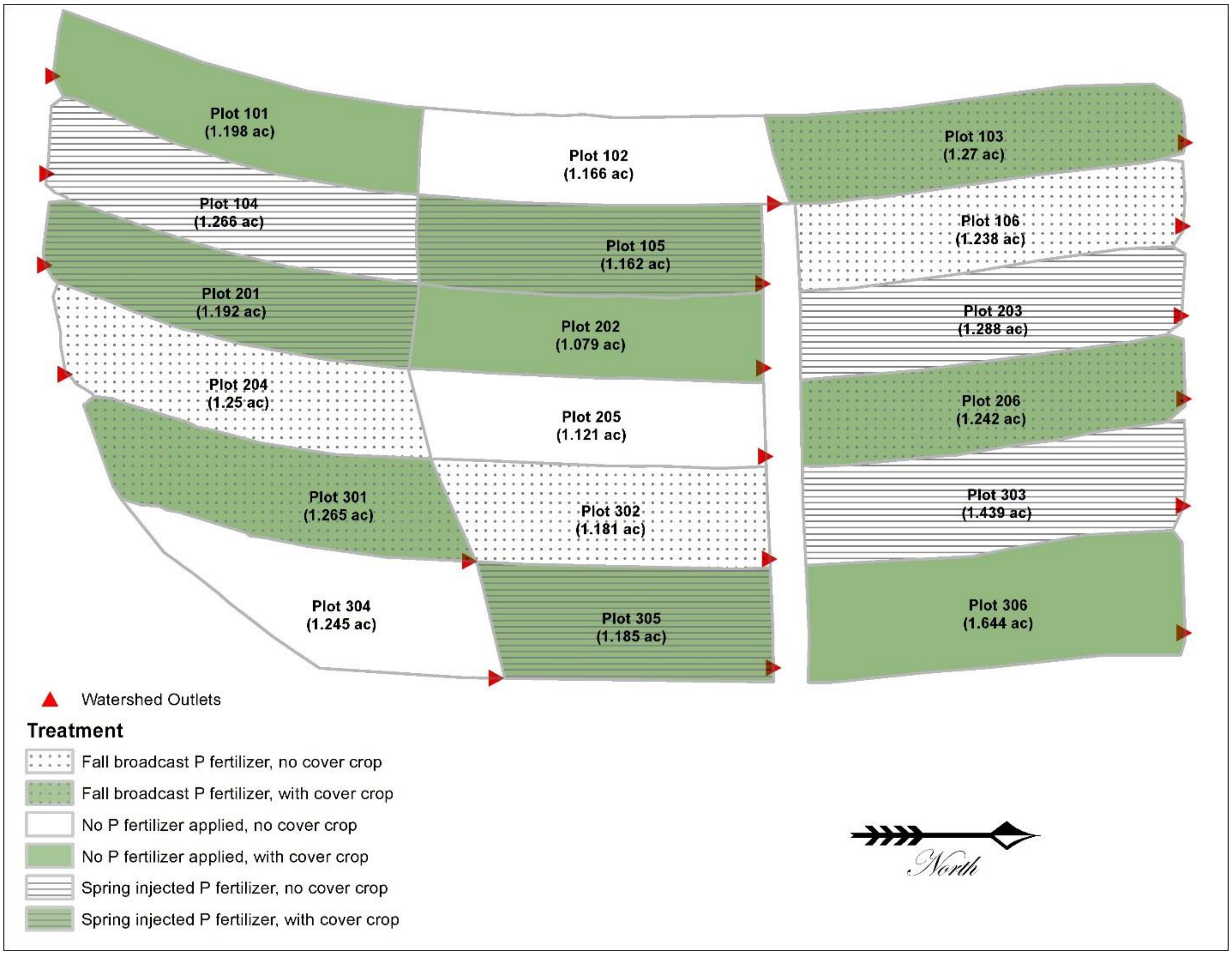

Figure 3.3 Kansas Agricultural Watershed (KAW) treatment map.

Figure 3.4 Corn being harvest with a combine after hand harvesting. Combine harvest took place at the Kansas Agricultural Watersheds on September 21, 2015.

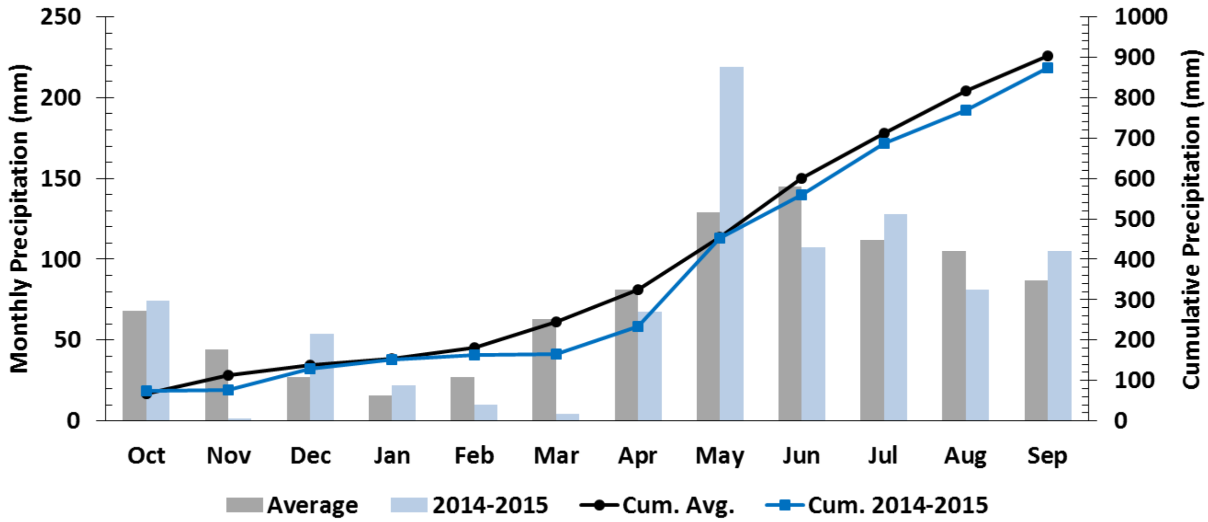

Figure 3.5 The 2014-1015 monthly (left axis) and cumulative (right axis) precipitation plotted with the 30 year average for Manhattan, KS. One water year is defined as one cycle beginning October 1 and ending September 30. The 2014-2015 data was collected from the Kansas mesonet weather station in Ashland Bottoms, KS located less than a km away from the Kansas Agricultural Watersheds research site.

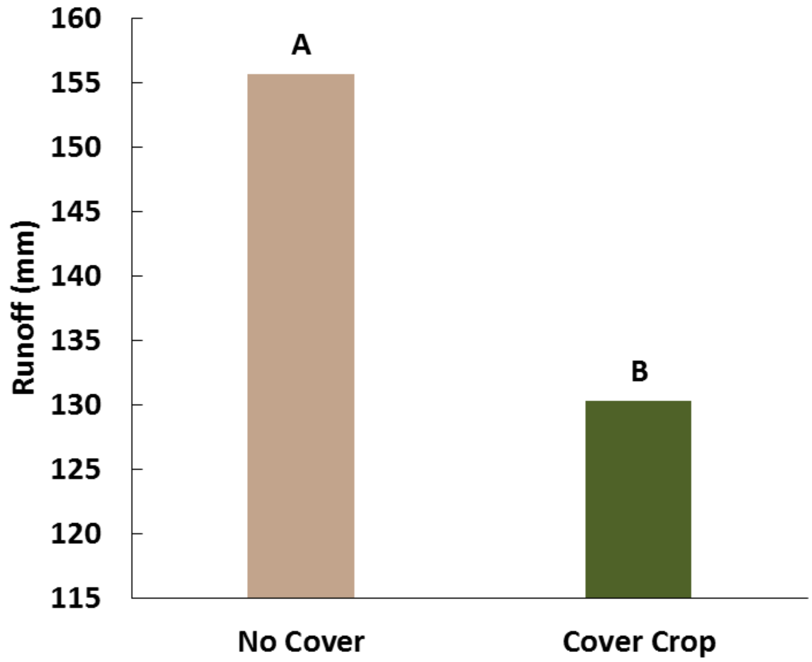

Figure 3.6 Runoff totals from cover crop and no cover treatments (with and without cover crop) for the 12 runoff events in the 2014-2015 water year. (Different letters indicate significant difference at p<0.05)

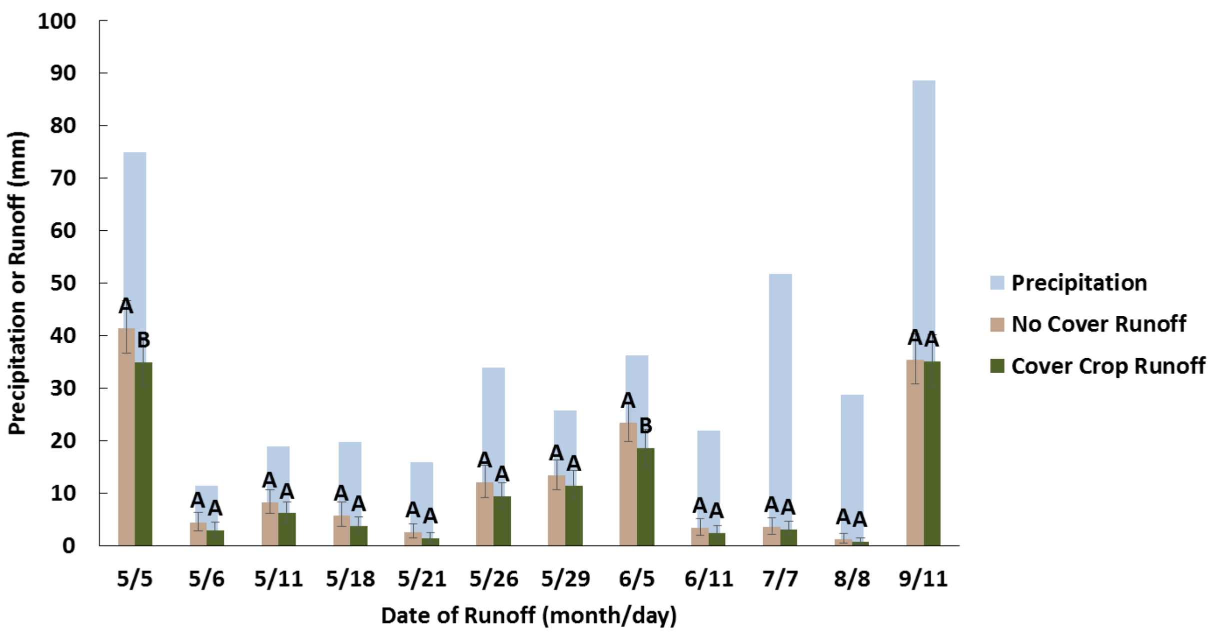

Figure 3.7 Runoff from cover crop and no cover treatments (with and without cover crop) graphed by runoff event with event precipitation. (Error bars indicate the 95% confidence intervals. Different letters indicate significant difference within event at p<0.05)

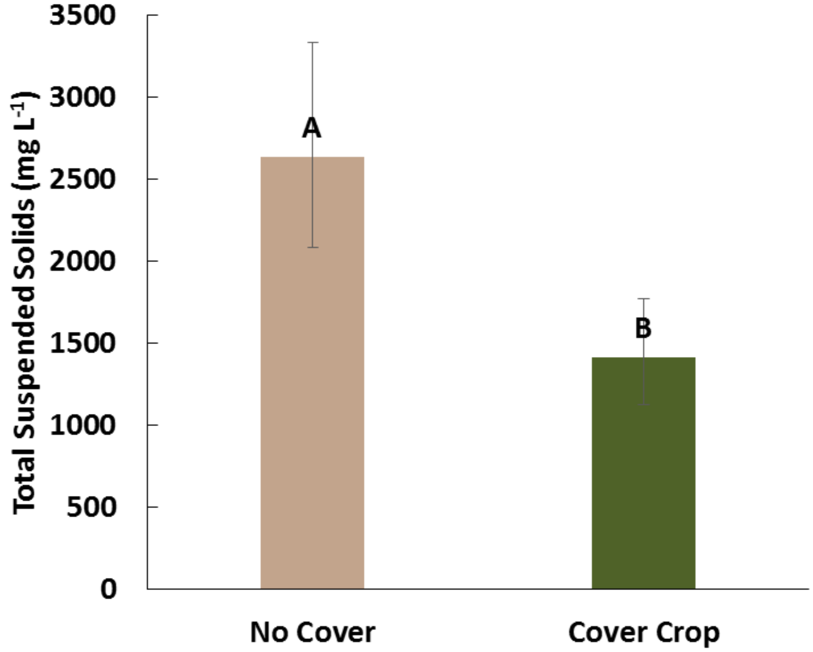

Figure 3.8 Main effect of cover crop treatment (with or without cover crop) on total suspended solid for the 12 runoff event in the 2014-2015 water year. Cover crop reduced total suspended solids by 46%. Plots not receiving a cover crop lost 2632 mg L^{-1} whereas plots that had the cover crop lost 1412 mg L^{-1}. (Error bars indicate the 95% confidence intervals. Different letters indicate significant difference at p<0.05)

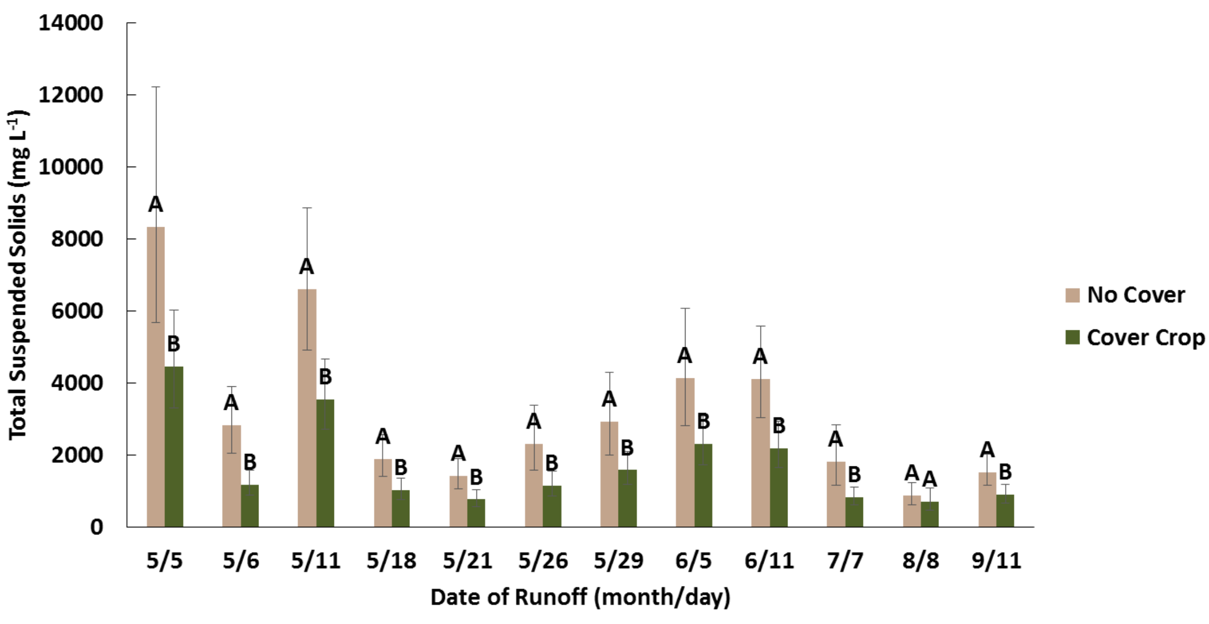

Figure 3.9 Total suspended solids from cover and no cover (with or without cover crop) graphed by runoff event. (Error bars indicate the 95% confidence intervals. Different letters indicate significant difference within event at p<0.05)

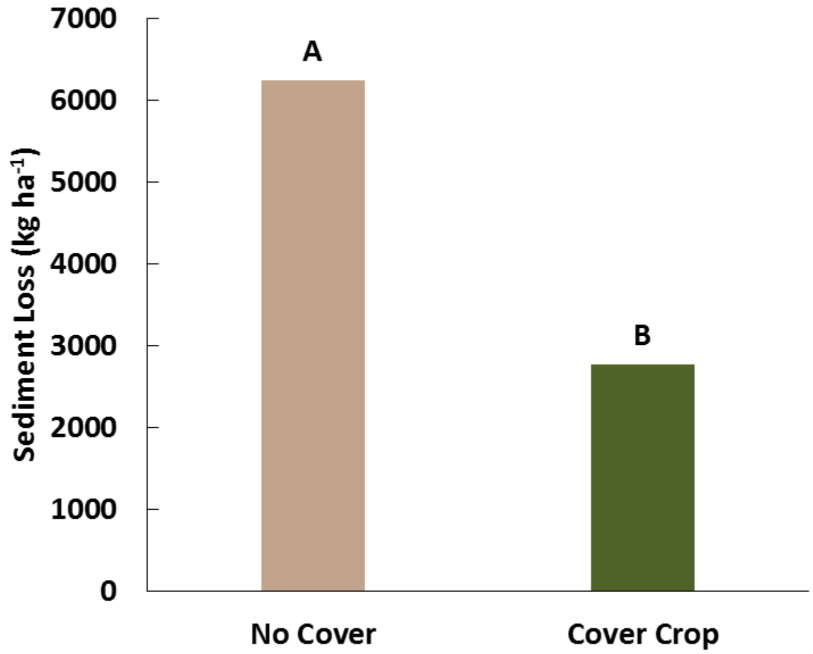

Figure 3.10 Erosion totals from cover crop and no cover treatments (with and without cover crop) for the 12 runoff events in the 2014-2015 water year. Cover crop reduced total erosion by 56%. Plots not receiving a cover crop lost 6250 kg ha^{-1} whereas plots that had the cover crop lost 2770 kg ha^{-1}. (Different letters indicate significant difference at $p<0.05$)

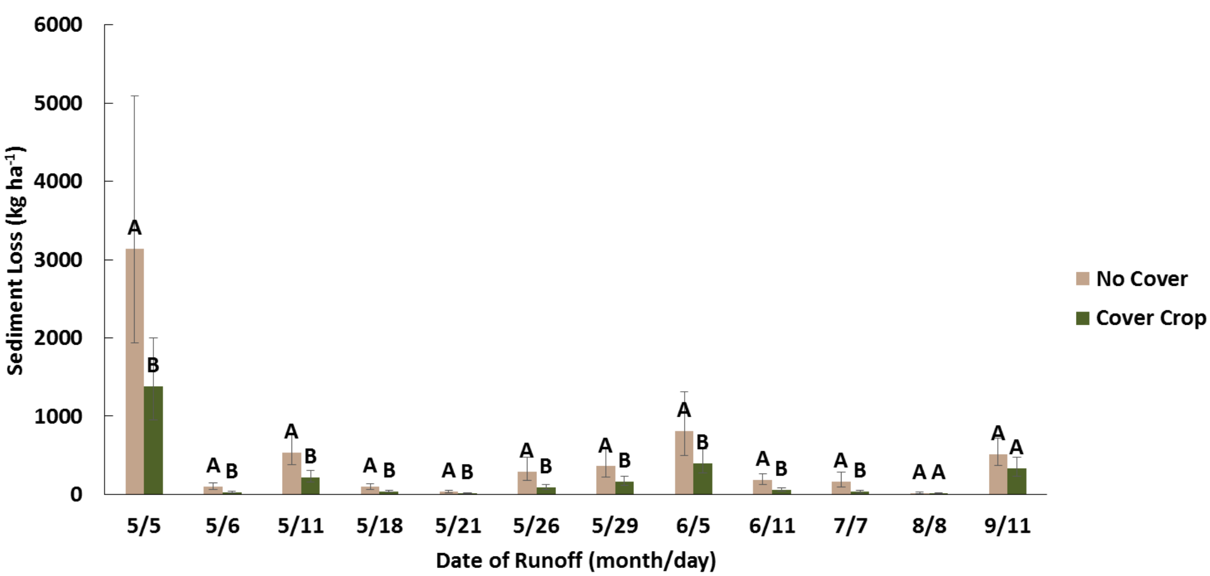

Figure 3.11 Sediment loss (erosion) from cover and no cover treatments (with and without cover crop) graphed by runoff event. (Error bars indicate the 95% confidence intervals. Different letters indicate significant difference within event at $p<0.05$)

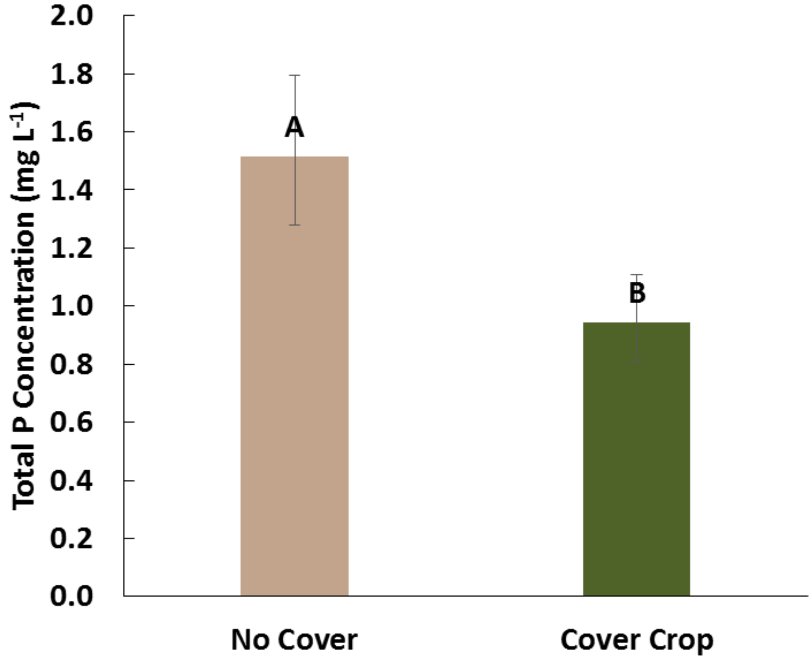

Figure 3.12 Main effect of cover crop treatment (with or without cover crop) on total P concentration for the 12 runoff events in the 2014-2015 water year. Overall cover crop reduced total P concentrations by 38%. (Error bars indicate the 95% confidence intervals. Different letters indicate significant difference at p<0.05)

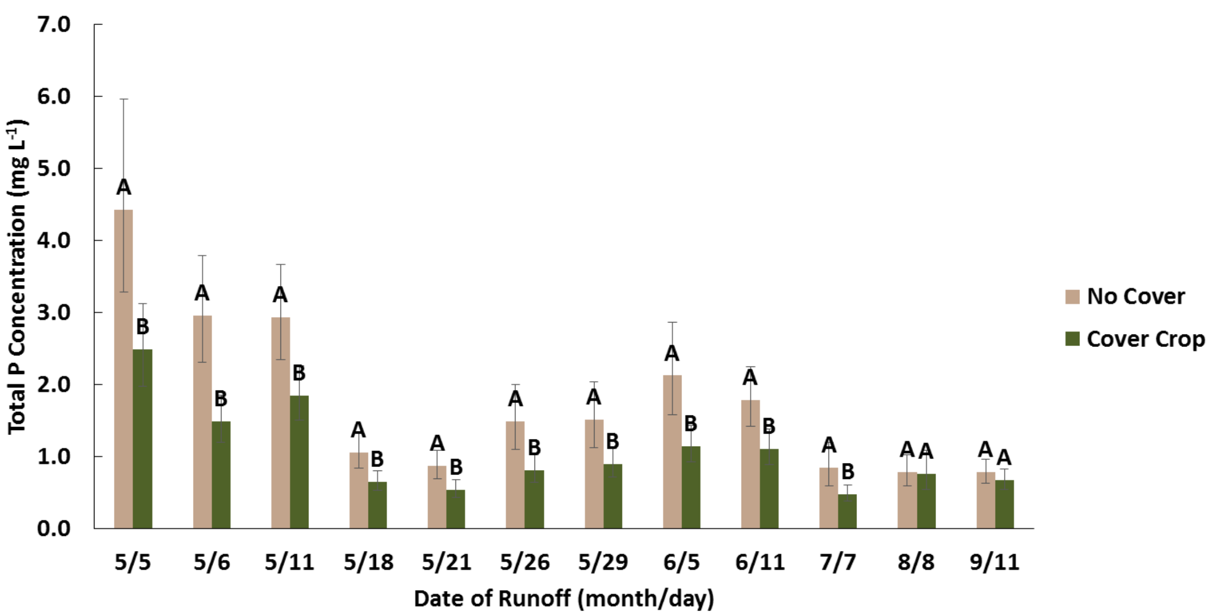

Figure 3.13 Total P concentrations from cover and no cover treatments (with and without cover crop) graphed by runoff event. (Error bars indicate the 95% confidence intervals. Different letters indicate significant difference within event at p<0.05)

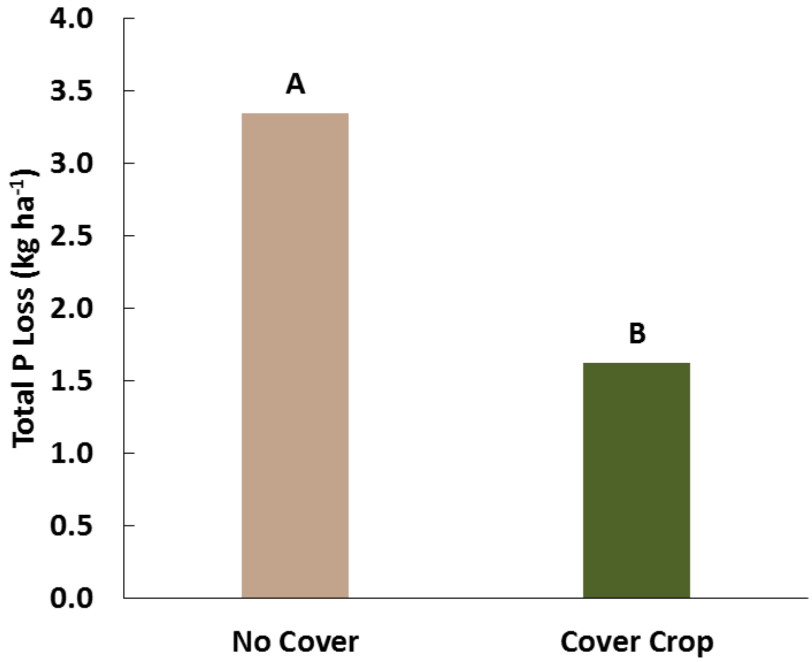

Figure 3.14 Total P totals from cover crop and no cover treatments (with or without cover crop) for the 12 runoff events in the 2014-2015 water year. Cover crop reduced total P by 52%. Plots not receiving a cover crop lost 3.35 kg ha^{-1} whereas plots that had the cover crop lost 1.62 kg ha^{-1}.(Different letters indicate significant difference at p<0.05)

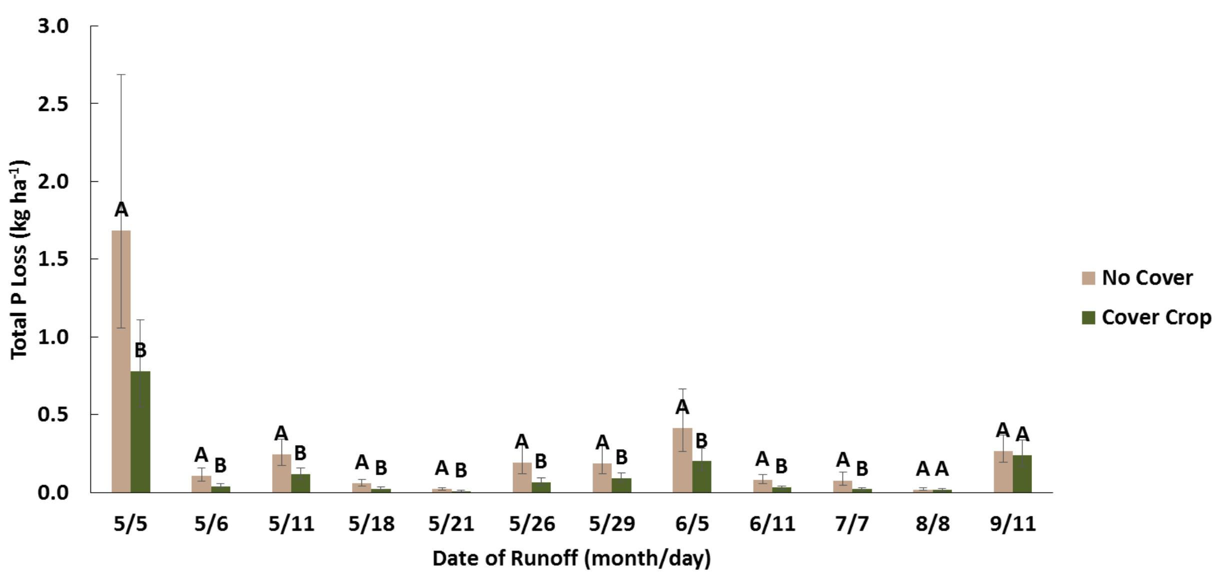

Figure 3.15 Total P loss from cover and no cover treatments (with and without cover crop) graphed by runoff event. (Error bars indicate the 95% confidence intervals. Different letters indicate significant difference within event at p<0.05)

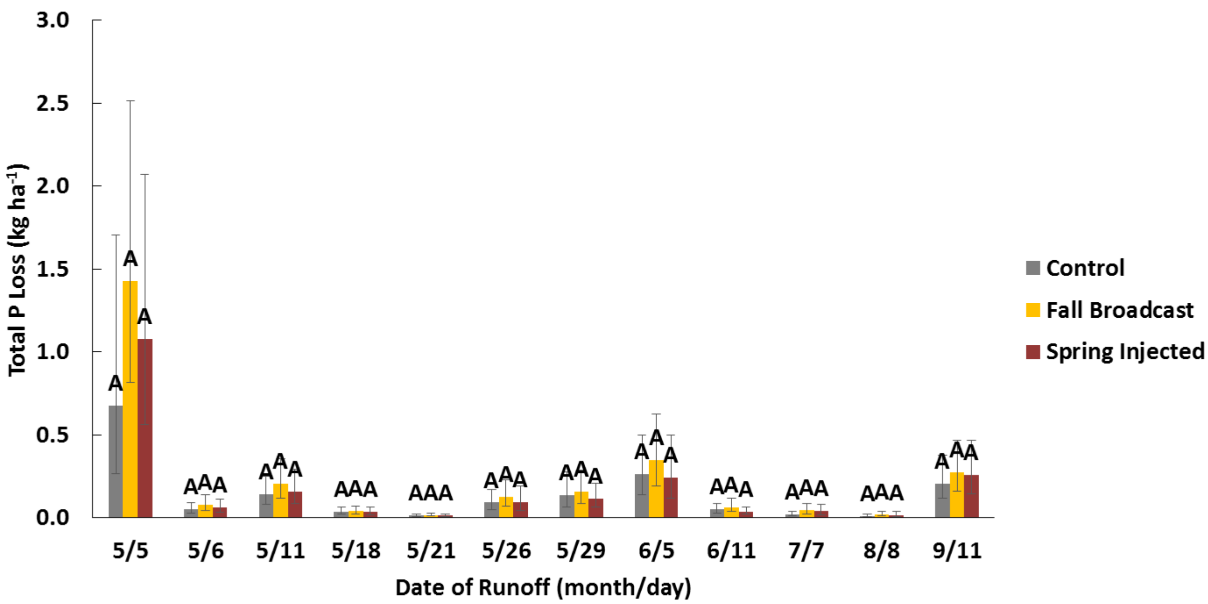

Figure 3.16 Total P loss by fertilizer management treatment (no P fertilizer [control], broadcast P fertilizer applied in the fall, and injected P fertilizer applied in the spring) by event. There was no significant effect of fertilizer management on total P loss. (Error bars indicate the 95% confidence intervals. Different letters indicate significant difference within event at p<0.05)

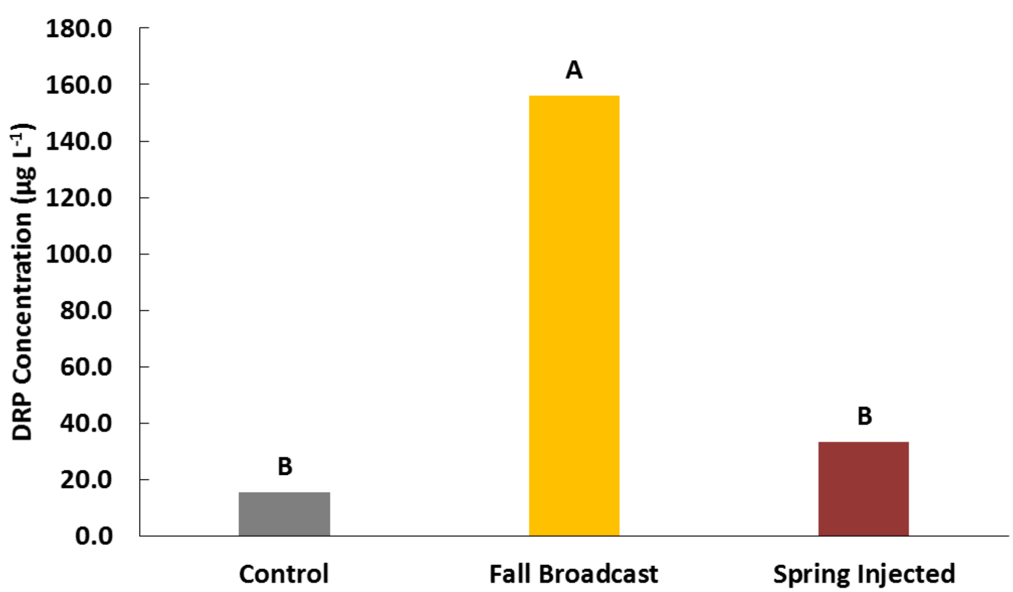

Figure 3.17 Main effect of the three P fertilizer treatments (no P fertilizer [control], broadcast P fertilizer applied in the fall, and injected P fertilizer applied in the spring) from the 12 runoff events in the 2014-2015 water year. (Error bars indicate the 95% confidence intervals. Different letters indicate significant difference within event at p<0.05)

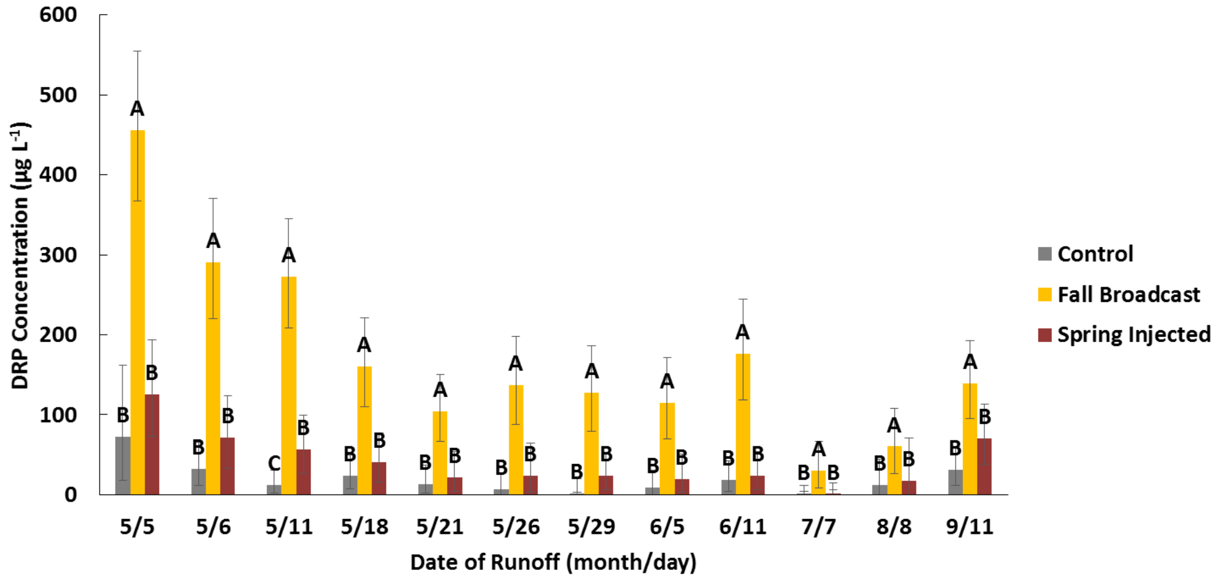

Figure 3.18 Dissolved reactive P concentrations for the three fertilizer management treatments (no P fertilizer [control], broadcast P fertilizer applied in the fall, and injected P fertilizer applied in the spring) by runoff event. (Error bars indicate the 95% confidence intervals. Different letters indicate significant difference within event at $p<0.05$)

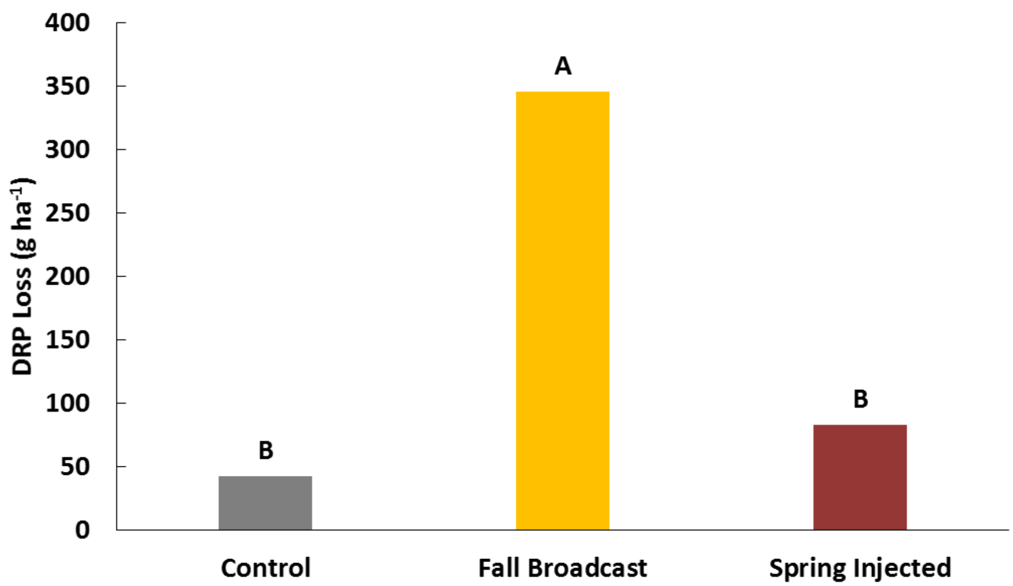

Figure 3.19 Dissolved reactive P totals from the three fertilizer treatments (no P fertilizer [control], broadcast P fertilizer applied in the fall, and injected P fertilizer applied in the spring) for the 12 runoff events in the 2014-2015 water year. Injecting P fertilizer in the spring reduced DRP loss by 76% compared broadcasting in the fall. (Different letters indicate significant difference at $p<0.05$)

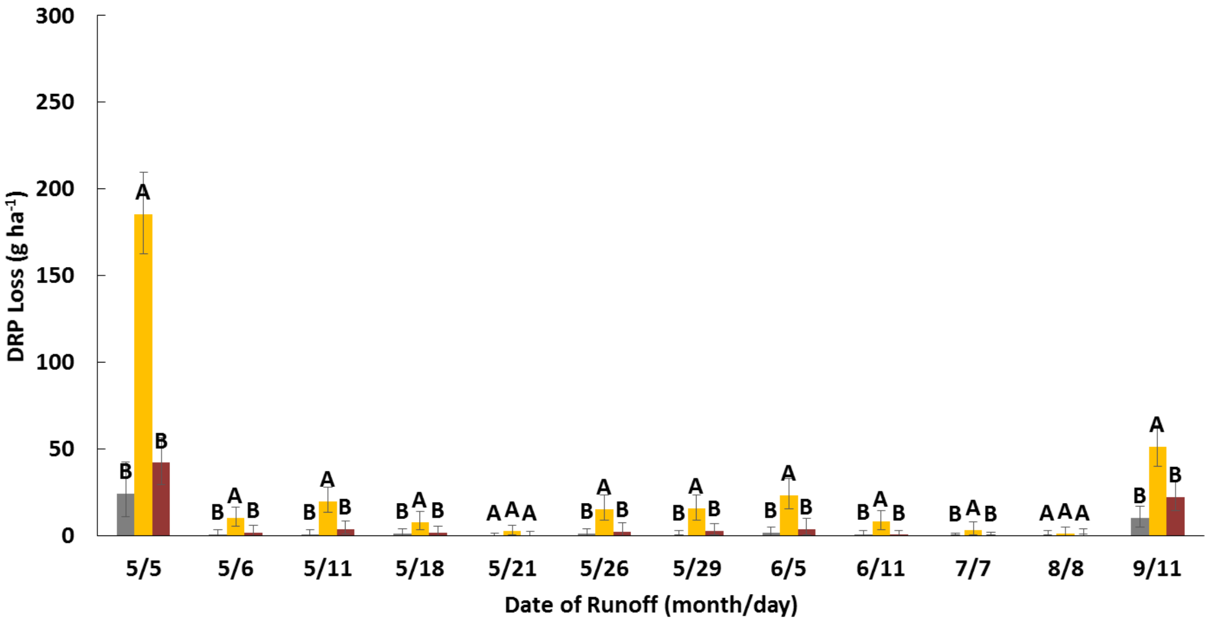

Figure 3.20 Dissolved reactive P loss for the three fertilizer management treatments (no P fertilizer [control], broadcast P fertilizer applied in the fall, and injected P fertilizer applied in the spring) by runoff event. The first runoff event after fertilizer application had much greater losses than did the other events but significant differences were still observed on the last event of the cycle. (Error bars indicate the 95% confidence intervals. Different letters indicate significant difference within event at p<0.05).

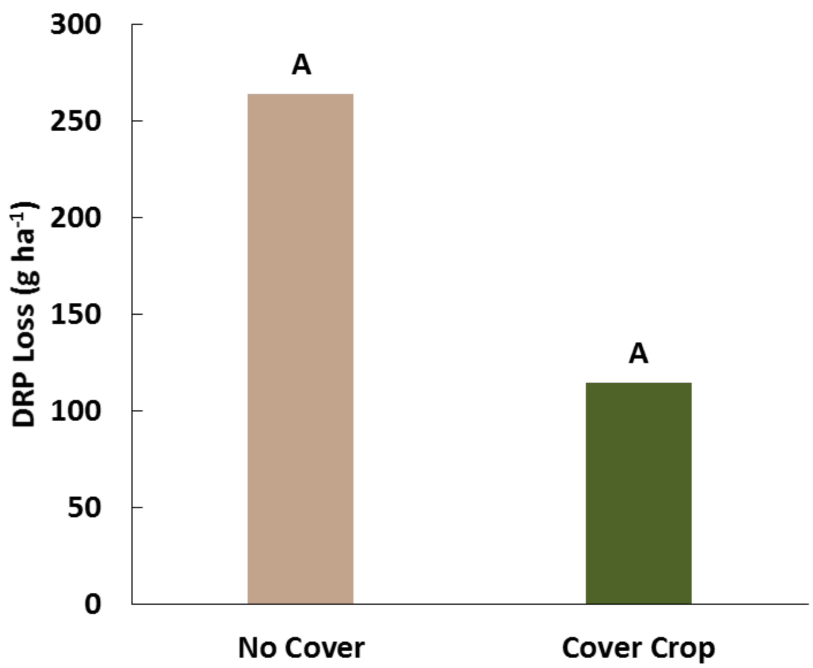

Figure 3.21 Dissolved reactive P totals from cover crop and no cover treatments (with and without cover crop) for the 12 runoff events in the 2014-2015 water year. Overall cover crop did not reduced DRP loss. (Different letters indicate significant difference at p<0.05)

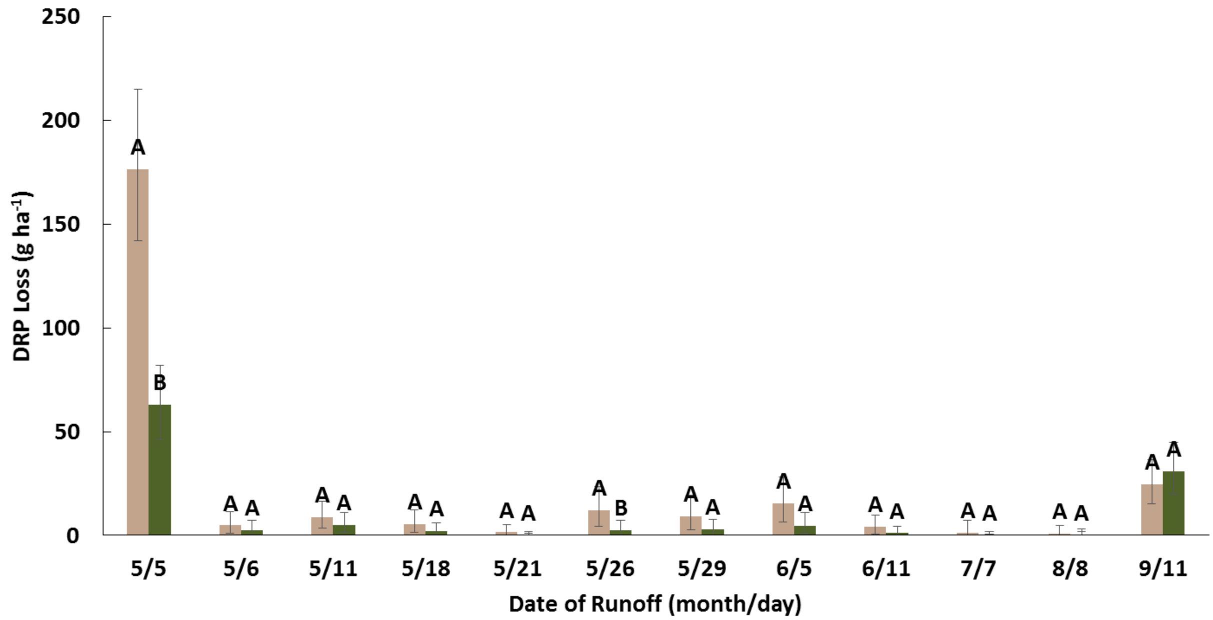

Figure 3.22 Dissolved reactive P load from cover and no cover treatments (with and without cover crop) graphed by runoff event. (Error bars indicate the 95% confidence intervals. Different letters indicate significant difference within event at p<0.05)

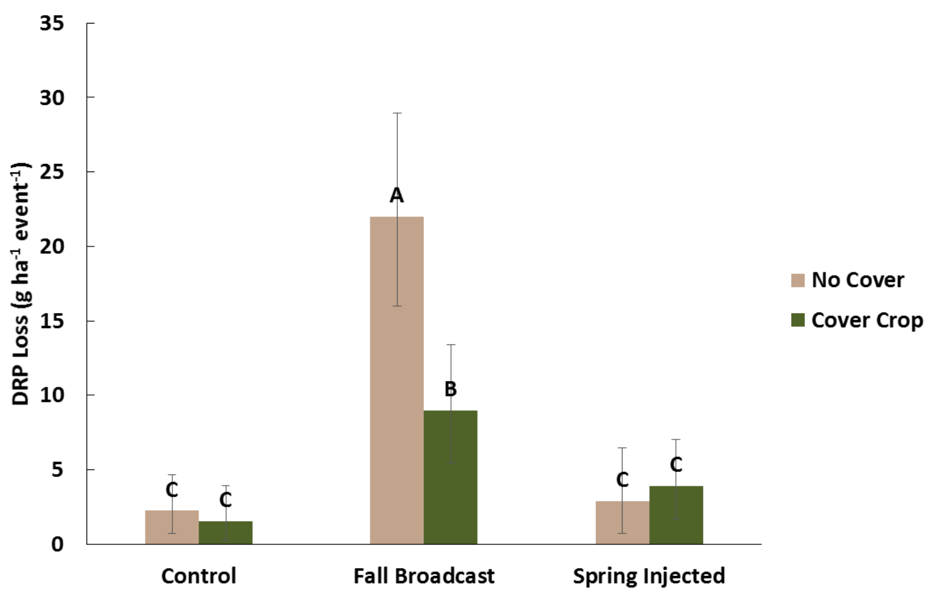

Figure 3.23 Cover crop (with or without cover crop) by P fertilizer management (no P fertilizer [control], broadcast P fertilizer applied in the fall, and injected P fertilizer applied in the spring) interaction from the 5 events with no missing treatment. The cover crop decreased DRP loss by 60% when P fertilizer was applied on the surface as a fall broadcast but had no significant effect in the other two treatments. Under fall broadcast fertilizer management, cover crop reduced DRP loss from 27 g ha^{-1} event^{-1} to 14 g ha^{-1} event^{-1}. (Error bars indicate the 95% confidence intervals. Different letters indicate significant difference within event at p<0.05)

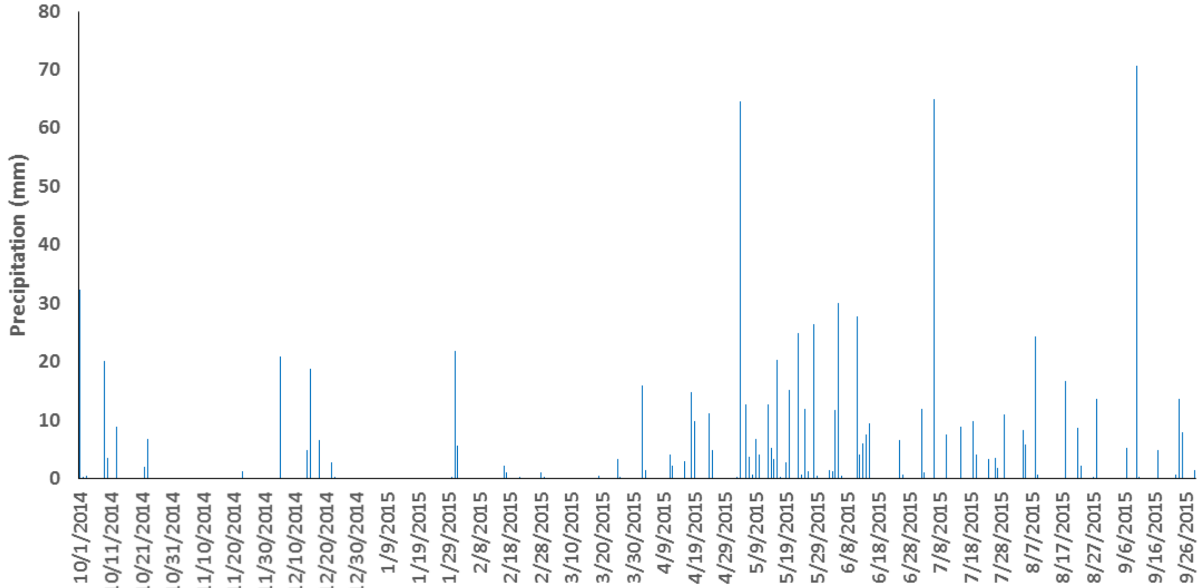

Figure 3.24 All 2014-2015 water year precipitation graphed. Precipitation data was collected from the Kansas mesonet weather station in Ashland Bottoms, KS located less than a km away from the Kansas Agricultural Watersheds research site.

Chapter 4 - Kansas Agricultural Watersheds under No-till Management

Results from Chapter 3 indicate that in conventional till agriculture, a cover crop can reduce runoff, sediment, total P, and DRP loss. The increased soil cover provided by the cover crop may be largely responsible for these effects (Dabney, 1998; Dabney et al., 2001). Increasing surface residue through no-till or conservation tillage has also been shown to reduce erosion. Gaynor and Findlay (1995) showed a 49% reduction in sediment loss when conservation tillage practices were utilized over conventional tillage. Cover crops could provide more benefits than simply physical protection of the soil surface, including improved soil properties and increases in root biomass (Nanzyo et al., 2002; Williams and Weil, 2004). Additional agronomic benefits may include increased nutrient cycling and reduced weed pressure (Hill et al., 2016). There may be agronomic and environmental benefits of using both cover crops and no-till management; however, there is not any research on the combined impacts of these two conservation practices on P loss.

The objective of this study was to quantify the effects of winter cover crops and fertilizer management practices on sediment and P loss in surface runoff from the soybean (*Glycine max)* phase of a no-till corn-soybean rotation.

Materials and Methods

The study was conducted at the Kansas Agricultural Watershed (KAW) Field Laboratory as a continuation of the experiment described in Chapter 3. The experiment design and instrumentation remained largely unchanged from the 2014-2015 water year to the 2015-2016 water year. Therefore, full details on site characteristics, treatments, water sample collection can be found in Chapter 3. The methods listed below highlight any changes and details specific to the 2015-2016 water year.

Tillage

Unlike the 2015-2016 water year describe in Chapter 3, the Kansas Agricultural Watersheds were under no-till management during the 2015-2016 water year.

Cover Crop

The cover crop used in the 2015-2016 water cycle was a monocrop of winter wheat. It was planted on September 22, 2015 and had emerged by September 28, 2016. It was planted at a seeding rate of 146 kg ha^{-1} (Table 4.1). However, the wheat variety used was Overly which has a larger than normal seed size. Adjusted to a more typical wheat size the rate would be approximately 125 kg ha^{-1}. There was a large amount of volunteer corn that emerged in the fall. The quantity of volunteer corn in block one was in part a result of the wrong combine sieves being used during harvest. Since the volunteer corn would be killed by freezing winter temperatures no herbicide was applied at this time. The wheat cover crop exhibited visual symptoms of nitrogen deficiency as chlorosis of the plant tissue and necrotic leaf tips. Nitrogen deficiency likely limited biomass growth. This is a reasonable assumption when considering no nitrogen fertilizer was applied to the wheat cover crop which followed a corn crop that was higher yielding than expected.

Fertilizer

Fall broadcast fertilizer applied as diammonium phosphate (DAP 18-46-0) began on November 10, 2015, but equipment problems prevented the entire site from being applied on this date. Along with the calibration issue described in chapter three, the gear settings that worked well during calibration were prone to slipping during actual application. The frequency of the gears slipping increased throughout the day. On November 12, 2015 the Barber spreader was recalibrated with the small cog on top and the large cog on the bottom. This provided better mechanical advantage, fixing the gear slip problem. As a result, block one had a higher rate of DAP applied to it than did blocks two and three. Block one received approximately 78 kg P_2O_5 ha^{-1} whereas blocks two and three received approximately 52 kg P_2O_5 ha^{-1} (Table 4.1).

Ammonium polyphosphate (APP 10-34-0) was applied 5 cm below and 5 cm to the side of the soybean seed at planting on June 6, 2016. Due to the DAP application issues that took place in the fall, 168 L APP ha^{-1} were applied to block one and 119 L APP ha^{-1} were applied to blocks two and three so that the P rates were consistent between fall broadcast and spring injected treatments within each block (Table 4.1).

Cover Crop Biomass

Three meters of cover crop biomass were harvested from two rows on May 5, 2016 (Table 4.1) at each of the 54 points marked in Figure 3.1. Plants were cut at the soil surface with a hand sickle and then dried at 60˚C for several days. Dry biomass was ground using a Wiley Mill and submitted to the K-State Testing Lab for analysis of N using a sulfuric peroxide digest and Ca, Mg, Zn, Fe, Cu, Mn, S, K, and P using a nitric perchloric digest.

Soybean Planting

Rain throughout May combined with the corn residue and standing cover crop biomass kept the soil moist through the month of May and delayed soybean planting until early June. Soybeans were planted at a rate of 325,000 seeds ha^{-1} on June 6, 2016 (Table 4.1). The soybean variety used was KS3406. A White 6100 four-row planter outfitted with one Yetter spoked closing wheal and one standard closing wheel on each its four rows was used for the planting/spring injected fertilizer application. Sticky soil conditions on June 6th occasionally prevented the seed slot from closing properly, but there were no major gaps in plant stand.

Deer

Significant whitetail deer grazing was observed on June 23, 2016. It was particularly concerning as the soybean crop was at the vulnerable VC growth stage (cotyledons and unifoliate are fully expanded) (

Figure 4.1). If the deer consumed below the cotyledons the soybean plant would not recover, but the deer generally grazed slightly above the cotyledons, which stunted but did not kill the plants. Action was taken for legalized control hunting at the KAW. Alex Thornburg of the Kansas Department of Wildlife granted five nuisance tags. Three of the five tags remained unfilled at the time of their expiration and deer damage persisted throughout the growing season.

Herbicide

On April 12, 2016 an herbicide mix was applied to control weeds. The cover crop plots and border areas were sprayed with a mix containing Sterling Blue, and 2,4-D LV6 at rates of 0.6 and 0.9 L ha^{-1} respectively. The plots not having a cover crop had 3.6 L ha^{-1} of glyphosate included in the mix. A 2 L scoop of AMS was also added to each 227 L tank of herbicide mix (Table 4.1).

On May 6, 2016, the wheat cover crop was chemically terminated using 3.6 L ha^{-1} of glyphosate (Table 4.1). On June 29, 2016 the plots not being treated with a cover crop were sprayed a second time for weeds. The application was an herbicide mix consisting of 3.6 L ha^{-1} of glyphosate and 0.94 L ha^{-1} of Cobra. No application was made at this time to the plots having received the cover crop treatment because the cover crop had sufficiently suppressed the weeds (Table 4.1).

Hand Harvest

Soybean biomass harvest took place on September 19, 2016 at soybean growth stage R6 (Table 4.1). Biomass was collected at this stage because the majority of nutrient uptake has occurred but most of the soybean leaves are still on the plant. Waiting until R7 allows for slightly more overall nutrient uptake but fails to capture the nutrients in the leaves due to senescence. Plants from one meter of row were collected from each of the three marked GPS points in each plot (Figure 3.1). After these plants were weighed, six plants were randomly selected from among them. The six plants were weighed and then dried at 60˚C for several days. After dry weights were determined, samples were ground in their entirety using the Wiley Mill. Ground tissue was thoroughly mixed and a sub-sample was submitted to the K-State Testing Lab for nutrient analysis.

Combine Harvest

On October 17, 2016 a plot combine was used to harvest two rows of soybean across the entire length (north/south) of each research plot (Table 4.1). Real time kinematic (RTK) GPS technology was used to measure the exact distance harvested by the combine in each plot. The grain weight from these strips was measured using the combine mounted weigh bucket. Three grain samples from each plot were collected and tested for moisture and test weight. On October 19, 2016 the remaining soybean crop was harvest with a commercial size combine (Table 4.1). Grain weight for each plot was weighed in a weigh wagon on site prior to being transport to the grain elevator. Total plot grain weight was then determined by adding the weights recorded on the two harvest dates (October 17^{th} and 19^{th}).

Water Sample Collection

No-till management helped to reduce erosion and the associated problems with flow monitoring and water sample collection discussed in chapter 3. Therefore, no data were omitted because of sediment deposition in the flumes and split PVC sampling pipes in the 2015-2016 water year. Very little changed in the method of collecting waters samples between 2014-2015 and the 2015-2016 water years. However, one key difference is that the auto-sampler program was changed to sample immediately when the 0.015 meter depth threshold was crossed (Appendix C). This change was made because under the previous programming, small events could occur without triggering a water sample due to not enough sustained flow above 0.015 meters. This program change allowed for sample collection from smaller events but introduced a new problem. Under the updated program there was potential for flow (or static in the flow reading) to cross the 0.015 m threshold multiple times over a short period thus triggering multiple samples. This kind of error was rare but did occur and may have influenced nutrient concentration results by drawing samples more often than the 1 mm flow pacing rate would dictate. Otherwise, the programming and sample collection processes were the same and is discussed in more detail in Chapter 3. Overall the 2015-2016 water year had far fewer errors in both quantity and frequency as automated equipment generally performed as expected. Water sample analysis was identical to that described in Chapter 3.

Soil sample collection

Soil samples were collected on September 28, 2015. Two composite samples made up of 21 soil cores (Figure 3.2) were taken from an area with a 5 meter radius near the three points in each plot indicated in Figure 3.1. One composite sample was composed of the surface soil layer depths 0-5 cm and the other 5-15 cm. Soil samples were analyzed for pH, buffer pH, Mehlich P, total P, potassium, nitrate, total nitrogen, and total carbon. The soil test returned an average pH of 6.7, indicating the 7.25 Mg ha^{-1} of lime applied on November 6, 2014 was successful in raising the soil pH to the desired 6.8 target level.

Data analysis

After each runoff-producing rain event, water samples and flow data were collected from each outlet. Flow data were collected using ISCO's 581 Rapid Transfer Device. These data were then imported into ISCO's database software Flowlink version 5.1. Sample analysis and flow data were analyzed statistically using SAS version 9.4. Upon visual review of residual plots produced by SAS version 9.4, the data were found to have a non-normal distribution. Runoff volume was transformed using a square root transformation. The other five parameters, total suspended solids, total P, total P load, DRP, and DRP load were transformed using a log_{10} transformation. PROC GLIMMIX with a repeated measures analysis of variance was used to analyze for treatment effects (Appendix D). Runoff event was the repeated measure for this analysis. Events that produced less than 5 mm of runoff were however omitted.

Results

Less erosion in the 2015-2016 water year and adjustments made to the auto-sampling program enabled the capture of 27 runoff events. The majority of these events (20) were however small (producing < 5 mm of runoff). These small events combined make up 16% of the total runoff for the water year (Table 4.2). The results presented herein are derived from analysis of the remaining 7 runoff events that produced more than 5 mm of runoff and account for 84% of the total runoff. As in the 2014-2015 water year, runoff events are marked by the date in which the sample was collected, which is generally within 24 hours of the event (Table 4.3).

Rainfall and Runoff

Between October 1, 2015 and September 30, 2016 (the 2015-2016 water year) there was 1143 mm of precipitation (Figure 4.2). Of the 27 total runoff events only 7 produced runoff volumes greater than 5 mm. These 7 events, caused by only 30% of the total precipitation (343.5 mm) resulted in 84% of the total runoff. The first of these 7 events occurred during the winter on December 15, 2015 and the second on April 25, 2016. Cover crop did not have a significant effect on total runoff volume overall, but there was a significant event by cover crop interaction resulting from these first two events (Table 4.4). The cover crop increased runoff by 25% on December 15 but decreased runoff by 23% on April 25. There was no statistical difference in runoff between cover and no cover plots for any of the remaining events (Figure 4.3).

There was also a fertilizer by cover by event interaction on runoff volume (Table 4.4). On December 15, 2015 the cover crop increased runoff from in the control treatment but decreased runoff in the spring injected treatment (Figure 4.4). On May 25, 2016 cover crop decreased runoff from the fall broadcast and spring injected treatments (Figure 4.5). On the May 27, 2016 cover crop increased runoff in the control treatment (Figure 4.6). After May 27th cover crop resulted in no significant difference in runoff for any of the fertilizer treatments. Over the entire year, the cover crop increased runoff volume by 29% in the control treatment but had no significant effect in the other two fertilizer treatments (data not shown).

Sediment

The cover crop treatment had a significant overall effect on sediment concentrations in surface runoff (Table 4.4). Estimates indicate a 57% reduction when compared to those plots without a cover crop. Sediment concentrations were 558 mg L^{-1} for the no cover treatment and only 239 mg L^{-1} for the cover crop treatment (Figure 4.7). An event by cover crop interaction was also observed for sediment concentration (Table 4.4). Sediment concentrations were not different between cover and no cover crop treatments on December 15^{th} and August 8^{th} (Figure 4.8).

Similar effects of cover crop are seen when looking at sediment load (erosion) as were seen in sediment concentration. The cover crop reduced sediment loss by 71% compared to treatments not receiving the cover crop (Figure 4.9). The December 15^{th} event makes for an interesting event by cover crop interaction (Figure 4.10). On December 15^{th}, plots treated with a cover crop had 53% more sediment loss than did the plots without. Although this is opposite of the effect on every other event in this water year, the total contribution to annual sediment loss from this event was very small (Figure 4.10). The increased sediment loss from cover crop plots on the December 15^{th} event was a result of greater runoff from this treatment (Figure 4.3), not increased sediment concentration (Figure 4.8).

Total Phosphorus

Cover crop had no effect on the overall total P concentration, but there was a significant event by cover crop interaction (Table 4.4). The interaction showed differences in total P concentrations between cover and no cover early in the spring (April 25 & 27) (Figure 4.11). Total P concentration was reduced by 24% and 40% on April 25^{th} and 27^{th}, respectively, but reductions did not continue throughout the water year (Figure 4.11). Similarly, differences between fall broadcast applied P and spring injected P were seen in total P concentration in the first part of the season (Figure 4.12) but equalized in the latter half resulting in no significant difference between those two treatments when looking at the whole water year overall (Figure 4.13).

Although the main effect of cover on total P load was not significant, the event by cover and event by fertilizer interactions were (Table 4.4). Differences in total P load were measured between cover and no cover plots on the first three events (December 15, April 25, and April 27). On December 15th cover increased total P load by 41% but on April 25 and 27, cover decreased total P load by 43% and 38% respectively (Figure 4.14).

Total P load was greater in fall broadcast than it was in spring injected on April 27th and May 27th by 43% and 32%, respectively (Figure 4.15). In the events prior and the events after, there were no differences between these two treatments. For the last two events (August 25 & 26), the fall broadcast treatment and the spring injected treatment had statistically greater loss than did the control (Figure 4.15). Fertilizer management made no significant difference on total P loss overall.

Dissolved Reactive Phosphorus

There was a significant increase in DRP concentration from the cover crop plots for every event analyzed (Figure 4.16). This resulted in a 46% increase in DRP concentration overall when a cover crop was used (Figure 4.17). Diminishing loss as time from application increases, is clearly seen in DRP concentrations from fall broadcast treatment (Figure 4.18). After application of the spring injected fertilizer there is no longer a significant difference in DRP between fall broadcast and spring injected treatments (Figure 4.18). Nonetheless, at the end of the water year, DRP concentrations were 43% greater overall from the fall broadcast plots compared to the spring injected. Both spring injected and fall broadcast had significantly greater loss than did the no P fertilizer control (Figure 4.19).

Cover crop had a significant effect on DRP loss overall, increasing the loss by 48% over the no cover treatment. A greater than expected fraction of total P was lost as DRP. The DRP fraction of total P was 22, 50, 20, 52, and 36% for no cover, cover crop, control, fall broadcast, and spring injected treatments respectively (Table 4.5). The year-end total of DRP loss from the no cover plots was 244 g ha^{-1} whereas the cover crop plots lost 469 g ha^{-1} (Figure 4.20). When analyzed by event, the no cover plots consistently had less DRP loss wherever there are significant differences (Figure 4.21).

Significant differences were also seen from fertilizer management practices (Table 4.4). All three fertilizer treatments, control, fall broadcast, and spring injected, had significantly different DRP loss from one another. The fall broadcast treatment was greatest, losing 677 g ha^{-1}. Spring injected was next, losing 355 g ha^{-1}. The control had the least amount of DRP loss at 171 g ha^{-1} (Figure 4.22). When analyzed by event, the fall broadcast treatment had the greatest loss for the first four events but was not different from the spring injected treatment in the last three. The spring injected treatment was equal to the control treatment in the events prior to spring injected application (first four events) then became equal to fall broadcast but different than control after application (last three events) (Figure 4.23).

Discussion

Main Effects of Cover Crop

Runoff

Cover crop resulted in no significant reduction in overall runoff volume. In terms of reducing runoff, this may suggest that there is little additional benefit from a cover crop in a no-till system. Although cover crop had no overall effect on runoff volume the first two events are interesting when analyzed individually. The cover crop made a significant increase in runoff volume on December 15, 2015 and a significant decrease on April 25, 2016 (Figure 4.3). The cover crop (winter wheat) lifecycle is likely the cause of this interaction. On December 15th the cover crop was in a dormant phase of its lifecycle. The wheat was alive and providing ground cover but not actively growing or taking up much water. Little soil moisture would be lost through transpiration, and the cover crop biomass would have reduced evaporation. This being the case, the cover crop may have kept the soil surface wetter than the no cover treatment. Increased soil moisture likely resulted in increased runoff volume from the cover crop treatments. Similarly, Zeimen et al. (2006) observed higher runoff in no-till management due to higher soil water content compared to conventional till soil. On April 25th, the wheat cover crop was no longer in the dormant phase of its life cycle. At the time of this event, the cover crop was actively growing and taking up soil moisture. This likely resulted in the soil surface of the cover crop plots being drier, which facilitated more infiltration and consequently less runoff from the cover crop treatment on the April 25th event. Various cover crop species may impact surface runoff differently. Furthermore, this research suggests that the various growth phases of a single species of cover crop has a differing effect on runoff.

Sediment

Even though cover crop had no overall effect on runoff volume there was an obvious difference when it came to sediment loss. The cover crop significantly reduced erosion (Figure 4.9) but this wasn't true for every runoff event. On December 15, 2015 the cover crop significantly increased erosion (Figure 4.10). This is a direct result of the increased runoff volume previously discussed. At this point in time, the relatively small amount of cover crop biomass had a minimal impact on reducing sediment concentration. The increased runoff volume caused from the cover crop increasing soil moisture outweighed any decrease in sediment concentration provided by the minimal cover crop biomass. The effect was different for the following four runoff events where the added biomass provided by the cover crop on those dates served to reduce both sediment concentration and loss. This was true until August 25. With the cover crop terminated on May 6, 2016, minimal cover crop residue remained on the soil surface on August 25th. Diminishing erosion reduction effect is expected as time from cover crop termination increases. Soybean planting for all treatments on June 6, 2016 also would play a major role in equalizing sediment loss from the cover and no cover treatments later in the season. On August 25th the soybean canopy was completely full, providing erosion protection for both cover and no cover crop plots.

Total Phosphorus

As it was in 2014-2015, total P loss was influenced by sediment loss. On December 15, 2015 more total P was lost from the cover crop plots (Figure 4.14). The increased total P loss is connected to the increased sediment loss, which is connected to the increased runoff on December 15th. On the following two events (April 25th and April 27th), total P loss was reduced by the cover crop as was sediment load. However, on May 27th and July 13th erosion was reduced but there was no difference in total P loss between the cover and no cover treatments. The lack of difference here could be a result of increased DRP loss resulting from cover crop termination. This is consistent with Aronson et al. (2016) where cover crops were not found to substantially reduce total P loss.

Dissolved Reactive Phosphorus

The cover crop treated plots had increased DRP concentrations on every runoff event (Figure 4.16). This suggests that the cover crop may be releasing some detectable amount of DRP throughout its life cycle and after its termination. This however does not account for the dynamic factors like runoff volume and watershed size which impact P loss. Dissolved reactive P load paints a more complete picture when considering the different phases of the cropping system. Dissolved reactive P load may have been significantly greater with a cover crop on December 15th because some of the wheat cover crop biomass was killed due to freezing temperatures. Perhaps load differences were not measured on April 25th and 27th because the cover crop was actively growing, storing P in its biomass. On May 27th however we see the greatest disparity. This could be a result of the cover crop termination. The P that was previously stored in the cover crop biomass is being released as DRP, resulting in significant differences on May 27th and July 13th (Figure 4.21).

Main Effects of Fertilizer

Total Phosphorus

There was no significant difference between fall broadcast and spring injected in total P concentration overall (Figure 4.13), but significance differences were measured from the first four events and then not from the last three (Figure 4.12). This verifies the expectation of diminishing differences with time as noted by Harmel et al. (2009). Phosphorus concentrations in surface runoff generally exhibit curvilinear decay based on time since fertilizer application (Harmel et al., 2009). This curvilinear decay may simply be caused by decreased quantities of fertilizer left on the soil surface for each consecutive runoff event but it is unlikely so straight forward. An improved P loss model developed by Vadas et al. (2008) considers also the P infiltration based on the runoff rainfall ratio. Phosphorus infiltration could further be influenced by soil temperature where warmer soil temperatures increase infiltration. Regardless, the trend clearly shows decreasing total P concentration with time.

The timing of the spring injected P fertilizer application is likely the cause behind the insignificant difference in total P loss between the fall broadcast treatment and the spring injected treatment on the last three runoff events (Figure 4.12; Figure 4.15). Total P loss from the spring injected treatment becomes different than that from the control treatment only after the spring injected fertilizer was applied. Despite its subsurface application, the data suggest that P loss still occurs through surface runoff when P fertilize is injected, and like the fall broadcast treatment, total P loss from the spring injected treatment follows curvilinear decay with time.

Dissolved Reactive Phosphorus

As seen in total P, diminishing concentrations of DRP are measured from the fall broadcast and spring injected treatment as time from these fertilizer application increases (Figure 4.18). The same rationale of decreasing fertilizer quantities remaining after each runoff event along with continual infiltration also explain the DRP decay over time. The trend is less obvious in DRP load due to differences in runoff volumes but is still noticeable (Figure 4.23). Unlike total P, there were significant differences overall between fertilizer treatments in both DRP concentration and load (Figure 4.18; Figure 4.22). Overall, fall broadcast P fertilizer application resulted in the greatest loss. Spring injected P fertilizer has less DRP loss than fall broadcast but more than the control (Figure 4.22). It is possible that the differences seen in DRP loss between fall broadcast and spring injected are a result of application timing rather than placement.

Conclusions

The objective of this study was to quantify the effects of winter cover crops and fertilizer management practices have on sediment and P loss in surface runoff from the soybean phase of a no-till corn-soybean rotation. A winter cover crop, in this case winter wheat, effectively reduced sediment loss but failed to have a significant impact on total P loss. In contradiction to my hypothesis, cover crop increased DRP loss. Although there are many potential benefits of using cover crops, the results of this study suggest that reducing P loss may not be one of them. This research supports injecting P fertilizer as the best management practice (BPM) to reduce P loss from agriculture.

Table 4.1 2015-2016 field operation. Control (CN), Fall Broadcast (FB), Spring Injected (SI), No Cover Crop (NC), Cover Crop (CC). Block 1 had different fertilizer rates than did blocks 2 and 3 due to equipment problems during the fall broadcast application of DAP. No additional nitrogen was applied to equalize the amounts of nitrogen applied with the P fertilizer because this fertilizer preceded a soybean crop.

Date	Activity	CN-NC	CN-CC	FB-NC	FB-CC	SI-NC	SI-CC	Notes
9/28/15	soil sampling	YES	YES	YES	YES	YES	YES	Split 0-5 & 5-15 cm
9/22/2015	cover crop planting	NO	YES	NO	YES	NO	YES	Winter wheat 146 kg ha^{-1}
11/12/15	P fertilizer application	NO	NO	Block 1: 169 kg DAP ha^{-1}, suppling 30 kg N ha^{-1} and 78 kg P_2O_5 ha^{-1} Block 2&3: 113 kg DAP ha^{-1}, suppling 20 kg N ha^{-1} and 52 kg P_2O_5 ha^{-1}	Block 1: 169 kg DAP ha^{-1}, suppling 30 kg N ha^{-1} and 78 kg P_2O_5 ha^{-1} Block 2&3: 113 kg DAP ha^{-1}, suppling 20 kg N ha^{-1} and 52 kg P_2O_5 ha^{-1}	NO	NO	DAP = 18-46-0
4/12/16	herbicide application	0.6 L ha^{-1} Sterling Blue, 0.9 L ha^{-1} 2,4-D LV6, 3.6 L ha^{-1} glyphosate, AMS	0.6 L ha^{-1} Sterling Blue, 0.9 L ha^{-1} 2,4-D LV6, AMS	0.6 L ha^{-1} Sterling Blue, 0.9 L ha^{-1} 2,4-D LV6, 3.6 L ha^{-1} glyphosate, AMS	0.6 L ha^{-1} Sterling Blue, 0.9 L ha^{-1} 2,4-D LV6, AMS	0.6 L ha^{-1} Sterling BluFe, 0.9 L ha^{-1} 2,4-D LV6, 3.6 L ha^{-1} glyphosate, AMS	0.6 L ha^{-1} Sterling Blue, 0.9 L ha^{-1} 2,4-D LV6, AMS	Weed control
5/5/16	cover crop biomass collection	NO	YES	NO	YES	NO	YES	18 row meters from each plot
5/6/16	herbicide application	NO	3.6 L ha^{-1} glyphosate	NO	3.6 L ha^{-1} glyphosate	NO	3.6 L ha^{-1} glyphosate	Cover crop termination
6/6/16	soybean planting & P fertilizer application	Planting Only	Planting Only	Planting Only	Planting Only	Block 1: 168 L APP ha^{-1} suppling 23 kg N ha^{-1} and 79 kg P_2O_5 ha^{-1} Block 2&3: 119 L APP ha^{-1} suppling 17 kg N ha^{-1} and 56 kg P_2O_5 ha^{-1}	Block 1: 168 L APP ha^{-1} suppling 23 kg N ha^{-1} and 79 kg P_2O_5 ha^{-1} Block 2&3: 119 L APP ha^{-1} suppling 17 kg N ha^{-1} and 56 kg P_2O_5 ha^{-1}	325,000 seeds ha^{-1} APP = 10-34-0 (1.39 kg L^{-1})

Date	Activity	CN-NC	CN-CC	FB-NC	FB-CC	SI-NC	SI-CC	Notes
6/29/16	herbicide application	3.6 L ha^{-1} glyphosate, 0.94 L ha^{-1} Cobra	NO	3.6 L ha^{-1} glyphosate, 0.94 L ha^{-1} Cobra	NO	3.6 L ha^{-1} glyphosate, 0.94 L ha^{-1} Cobra	NO	Weed control
9/19/16	soybean hand harvest	YES	YES	YES	YES	YES	YES	Growth stage: R6
10/17/16	soybean plot combine harvest	YES	YES	YES	YES	YES	YES	2 rows from each plot
10/19/16	soybean combine harvest	YES	YES	YES	YES	YES	YES	

Table 4.2 ANOVA table for analysis of fifteen small events (<5mm runoff) and had no missing treatments. These fifteen events produced 14% of the total runoff from the 2015-2016 water year.

	Runoff	TSS¥	Sed¥	TP¥	TP¥ load	DRP¥	DP¥ load
Fert¥	0.401	0.265	0.861	<0.001	0.355	<0.001	0.031
Cover¥	0.566	0.004	0.092	0.084	0.090	<0.001	0.002
Fert*Cover¥	0.208	0.243	0.265	0.512	0.694	0.028	0.099
Event¥	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Event*Fert¥	0.193	0.273	0.468	<0.001	0.070	0.010	0.309
Event*Cover¥	<0.001	0.027	0.082	0.046	<0.001	0.404	0.004
Event*Cover*Fert¥	<0.001	0.245	0.485	0.247	0.272	0.323	0.169

¥Sediment (Sed), Total P (TP), Dissolved Reactive P (DRP), Total Suspended Solids (TSS), Fertilizer Management (Fert), Cover Crop (Cover), Fertilizer Management by Cover Crop Interaction (Fert*Cover), Runoff Event (Event), Runoff Event by Fertilizer Management Interaction (Event*Fert), Runoff Event by Cover Crop Interaction (Event*Cover), Runoff Event by Cover Crop by Fertilizer Management Interaction (Event*Cover*Fert).

Table 4.3 Runoff event records.

Collection Date	Runoff Range	Runoff >5 mm	Precipitation (mm)	Number of Plots Missing Runoff Data	Number of Plots Missing Concentration Data	Missing Treatments¥
11/19/15	11/17 (4 am) – 11/17 (9 am)		32.51		16	CC-NC, FB-CC, SI-CC, SI-NC
12/1/15	11/26 (9 am) – 11/27 (2 am)		38.10		5	
12/15/15	12/13 (1 am) – 12/14 (6 am)	YES	63.25		2	
4/21/16	4/20 (2 am) – 4/20 (3 pm)		28.45	1	17	CN-CC, CN-NC, FB-CC, FB-NC, SI-CC
4/25/16	4/24 (9 pm) – 4/25 (5 am)	YES	52.92	2	2	
4/27/16	4/26 (3 pm) – 4/27 (10 am)	YES	76.45	1		
5/2/16	4/29 (3 pm) – 4/30 (3 pm)		18.46	1	15	FB-CC, FB-NC, SI-CC
5/23/16	5/23 (11 am) – 5/23 (2 pm)		2.29		18	ALL
5/24/16	5/24 (3 am) – 5/24 (2 pm)		24.81		13	FB-CC, FB-NC, SI-CC
5/25/16	5/24 (11 pm) – 5/25 (9 am)		14.39	1	1	
5/26/16	5/25 (8 pm) – 5/26 (7 am)		16.09	1	1	
5/27/16	5/26 (3 pm) – 5/27 (9 am)	YES	62.57	2	2	
5/28/16	5/27 (6 pm) – 5/28 (4 am)		11.68	1	1	
6/29/16	6/28 (5 am) – 6/28 (11 am)		21.34	3	10	
7/4/16	7/2 (3 am) – 7/3 (1 pm)		22.18		2	
7/7/16	7/7 (6 am) – 7/7 (9 am)		7.45	1	10	FB-CC
7/12/16	7/12 (3 am) – 7/12 (7 am)		26.08		1	
7/13/16	7/13 (8 am) – 7/13 (1 pm)	YES	23.88	1	1	
8/8/16	8/7 (5 am) – 8/7 (7 am)		14.67		9	CN-CC, SI-CC
8/12/16	8/11 (9 pm) – 8/12 (12 am)		20.45	1	9	CN-CC, SI-CC
8/20/16	8/19 (5 pm) – 8/19 (9 pm)		46.61	2	3	
8/25/16	8/25 (6 am) – 8/25 (1 pm)	YES	37.59			
8/26/16	8/26 (5 am) – 8/26 (1 pm)	YES	26.86			
8/27/16	8/27 (3 am) – 8/27 (10 am)		8.76			
9/13/16	9/13 (2 am) – 9/13 (11 am)		43.37		2	
9/14/16	9/14 (2 am) – 9/14 (12 pm)		14.48		1	
9/25/16	9/24 (3 pm) – 9/25 (10 am)		30.67		2	

¥Control (CN), Fall Broadcast (FB), Spring Injected (SI), No Cover Crop (NC), Cover Crop (CC). Collection date is the date in which water samples were physically collected from the field. Runoff range describes the date and time range in which the runoff actually occurred. Precipitation is an average of the four automated tipping bucket rain gauges across the research site and includes event rainfall leading up to initial runoff. The number of plots excluded from runoff and chemical analysis for each event due to quality control protocol are listed under missing runoff points and missing chemical points respectively. Treatments where all three replications were missing are recorded under missing treatments.

Table 4.4 ANOVA table for analysis over the seven large events (>5mm runoff) that produced 84% of the total runoff from the 2015-2016 water year.

	Runoff	TSS¥	Sed¥	TP¥	TP¥ load	DP¥	DP¥ load
Fert¥	0.327	0.967	0.709	0.002	0.076	<0.001	<0.001
Cover¥	0.778	<0.001	<0.001	0.485	0.725	<0.001	0.003
Fert*Cover¥	0.027	0.702	0.372	0.657	0.638	0.396	0.206
Event¥	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Event*Fert¥	0.107	0.392	0.175	<0.001	0.002	<0.001	<0.001
Event*Cover¥	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Event*Cover*Fert¥	0.003	0.368	0.168	0.469	0.320	0.127	0.807

¥Sediment (Sed), Total P (TP), Dissolved Reactive P (DRP), Total Suspended Solids (TSS), Fertilizer Management (Fert), Cover Crop (Cover), Fertilizer Management by Cover Crop Interaction (Fert*Cover), Runoff Event (Event), Runoff Event by Fertilizer Management Interaction (Event*Fert), Runoff Event by Cover Crop Interaction (Event*Cover), Runoff Event by Cover Crop by Fertilizer Management Interaction (Event*Cover*Fert).

Table 4.5 The DRP and particulate P fraction of total P loss by treatment for the 2015-2016 water year.

	DP¥ Load (g ha-1)	TP¥ Load (g ha-1)	DRP¥ Fraction	PP¥ Fraction
No Cover	244	1119	22%	78%
Cover Crop	469	943	50%	50%
Control	171	833	20%	80%
Fall Broadcast	677	1298	52%	48%
Spring Injected	355	981	36%	64%

¥Dissolved Reactive P (DRP), Total P (TP), Particulate P (PP)

Figure 4.1 Soybean damage cause by deer grazing on June 23, 2016. Generally, VC plants were chewed above the cotyledons as depicted.

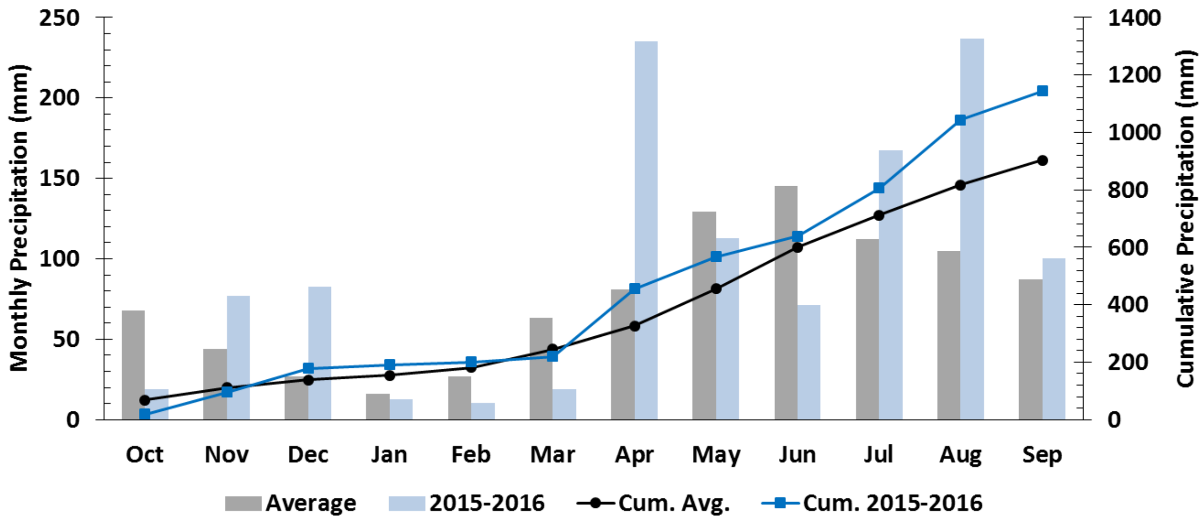

Figure 4.2 The 2015-2016 monthly (left axis) and cumulative (right axis) precipitation plotted with the 30 year average for Manhattan, KS. One water year is defined as one cycle beginning October 1 and ending September 30. The 2015-2016 data is an average of four automated rain gauges dispersed across the Kansas Agricultural Watersheds research site. Precipitation data from a Kansas mesonet weather station located less than a km away was spliced in to account for precipitation occurring over the winter months when on site rain gauges were not out.

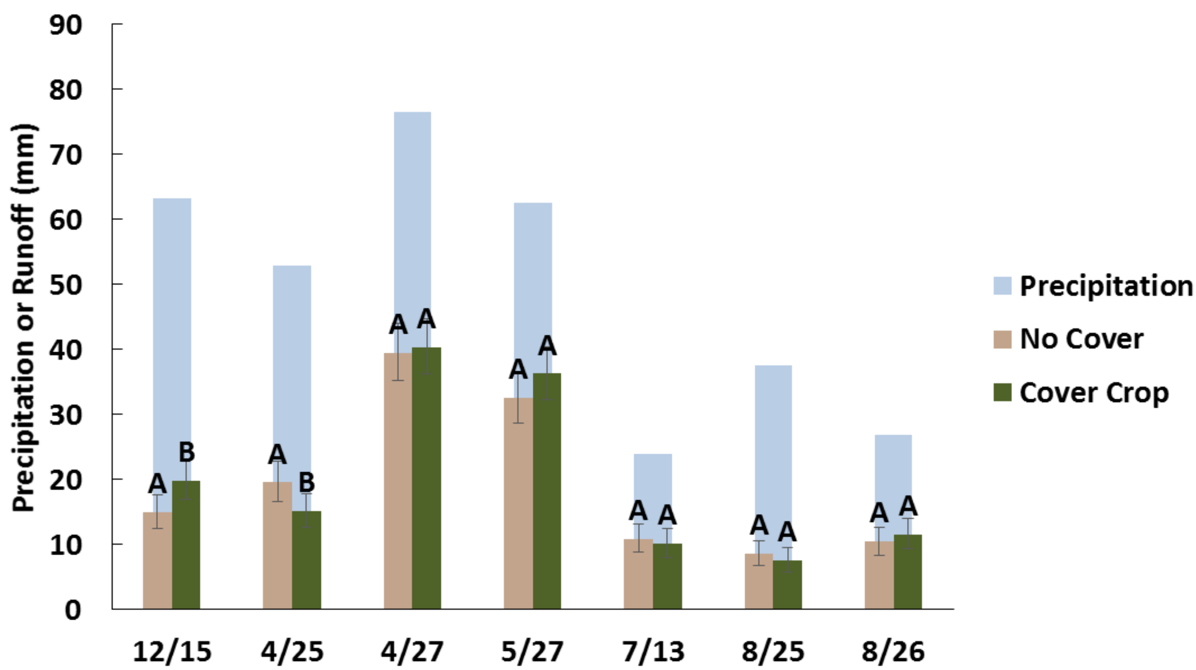

Figure 4.3 Runoff from cover crop and no cover plots graphed by runoff event with event precipitation. (Error bars indicate the 95% confidence intervals. Different letters indicate significant difference within event at $p<0.05$)

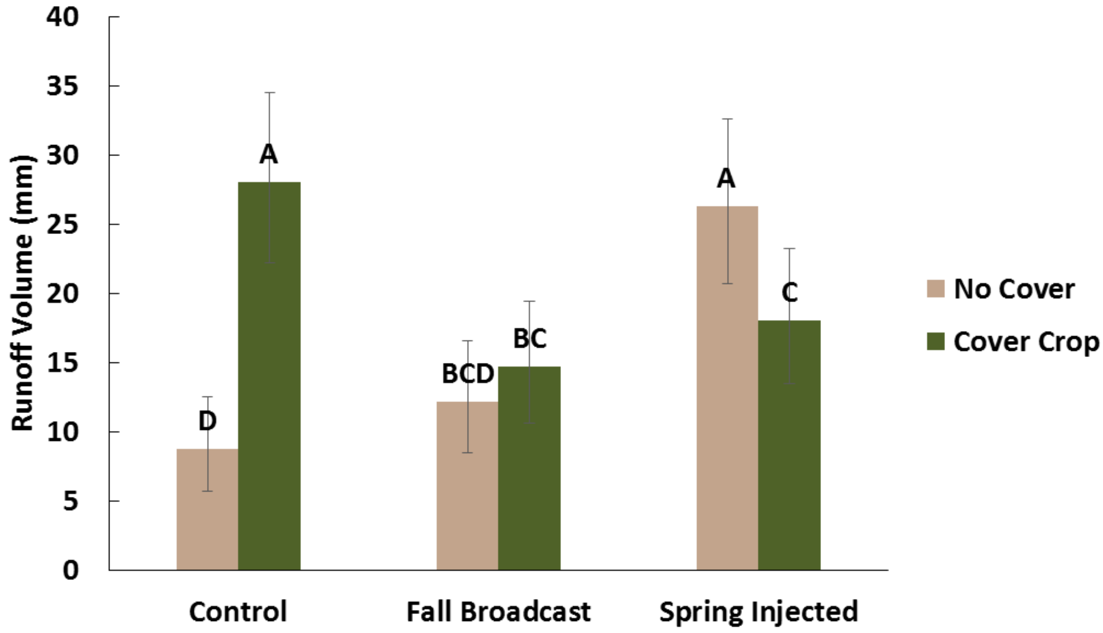

Figure 4.4 Fertilizer by cover by event interaction for runoff volume occurring on December 15, 2015. At this time cover crop significantly increased runoff volume in the control treatment and decreased runoff volume in the spring injected treatment. (Error bars indicate the 95% confidence intervals. Different letters indicate significant difference at $p<0.05$)

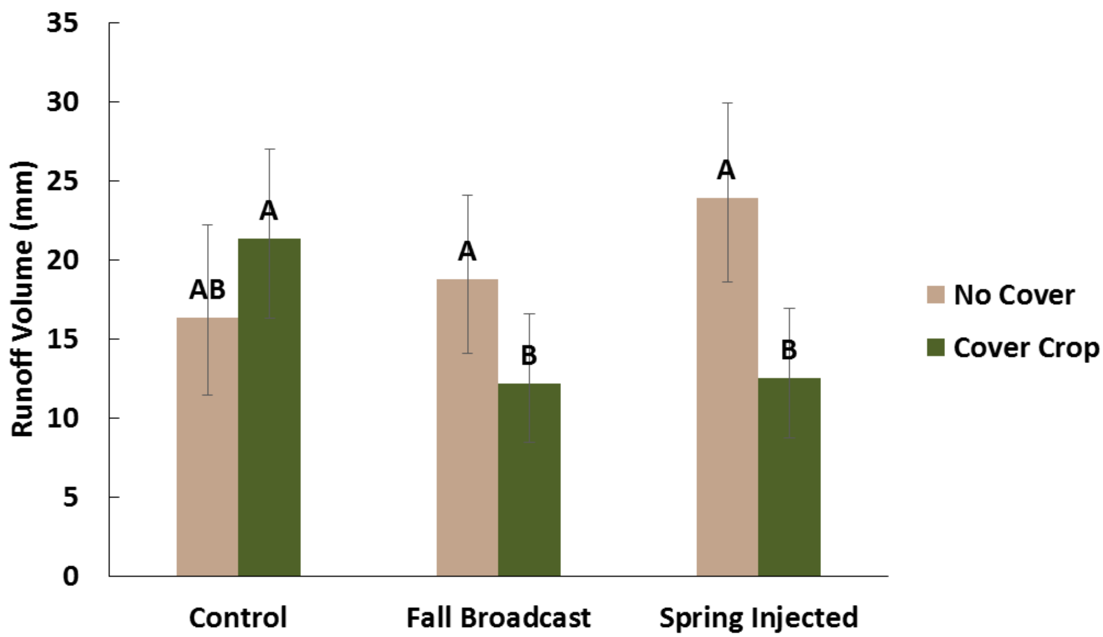

Figure 4.5 Fertilizer by cover by event interaction for runoff volume occurring on May 25, 2015. At this time cover crop significantly decreased runoff volume in the fall broadcast and spring injected plots. (Error bars indicate the 95% confidence intervals. Different letters indicate significant difference at $p<0.05$)

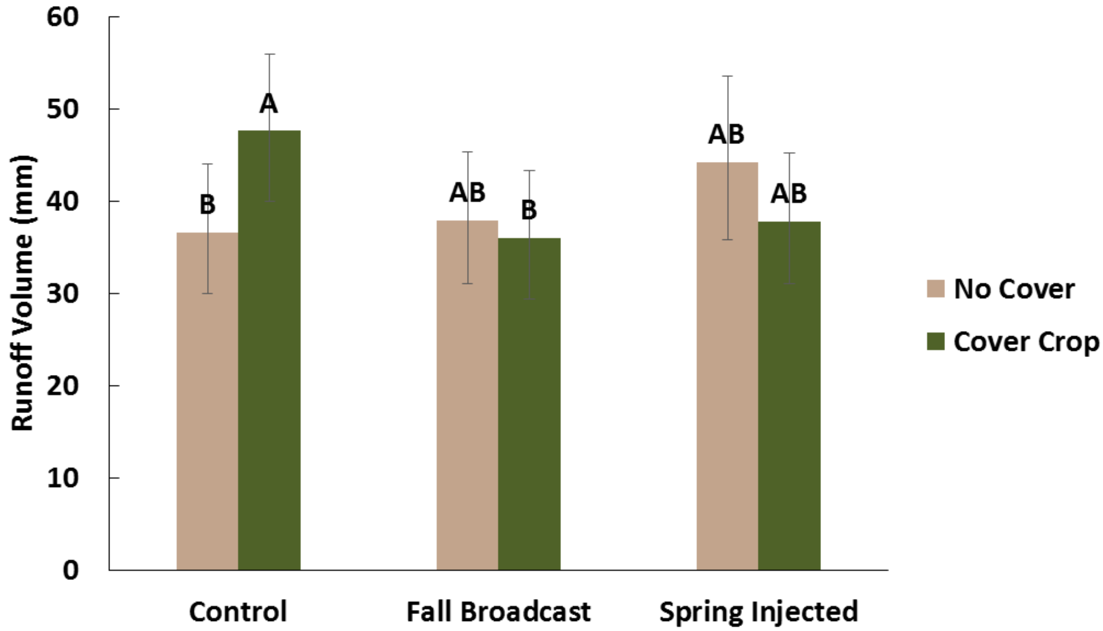

Figure 4.6 Fertilizer by cover by event interaction for runoff volume occurring on May 25, 2015. At this time cover crop significantly increased runoff volume in the control treatment. (Error bars indicate the 95% confidence intervals. Different letters indicate significant difference at p<0.05)

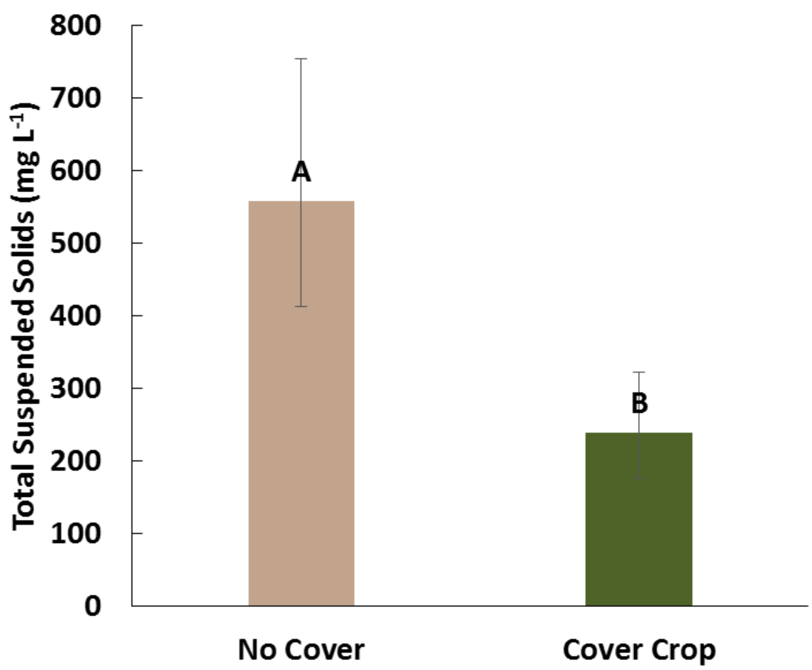

Figure 4.7 Main effect of cover crop on sediment concentrations from the seven largest runoff events (> 5 mm). (Error bars indicate the 95% confidence intervals. Different letters indicate significant difference at p<0.05)

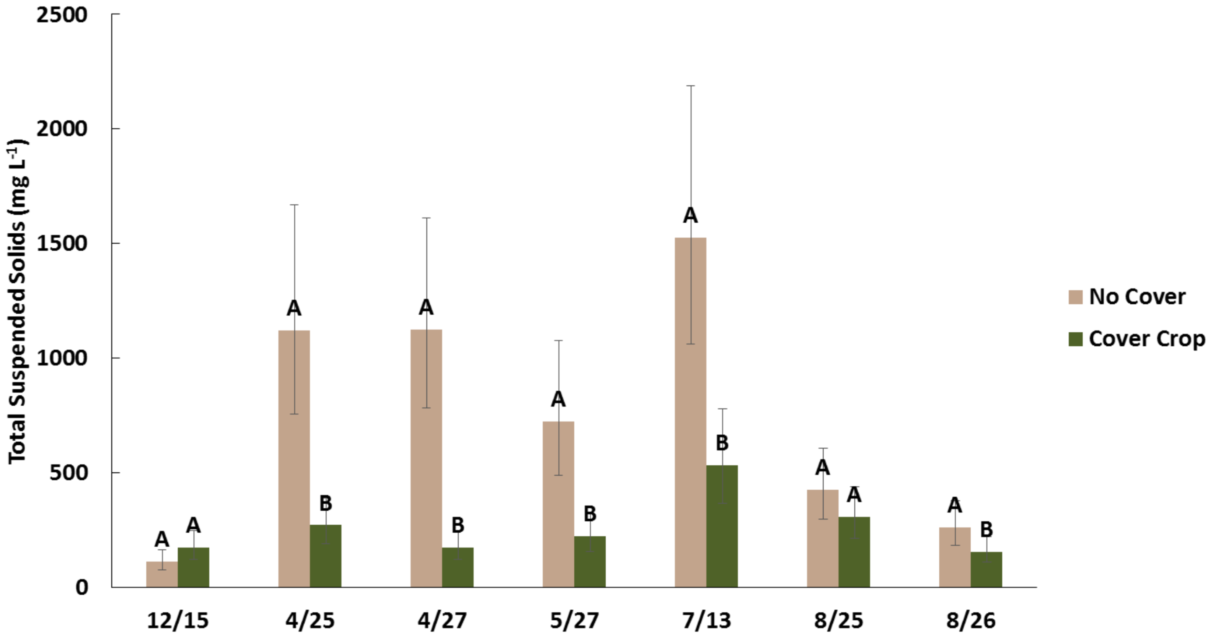

Figure 4.8 Sediment concentrations graphed for no cover and cover crop treatments (with or without cover crop) by runoff event. (Error bars indicate the 95% confidence intervals. Different letters indicate significant difference within event at $p<0.05$)

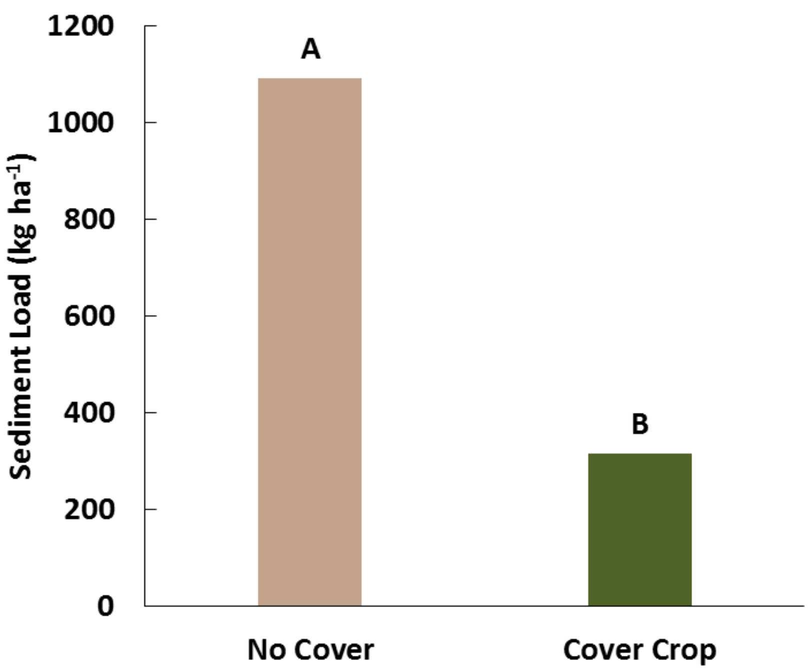

Figure 4.9 Sediment load (erosion) totaled from the seven largest runoff events (> 5 mm) for cover and no cover crop treatments (with or without cover crop). (Error bars indicate the 95% confidence intervals. Different letters indicate significant difference at $p<0.05$)

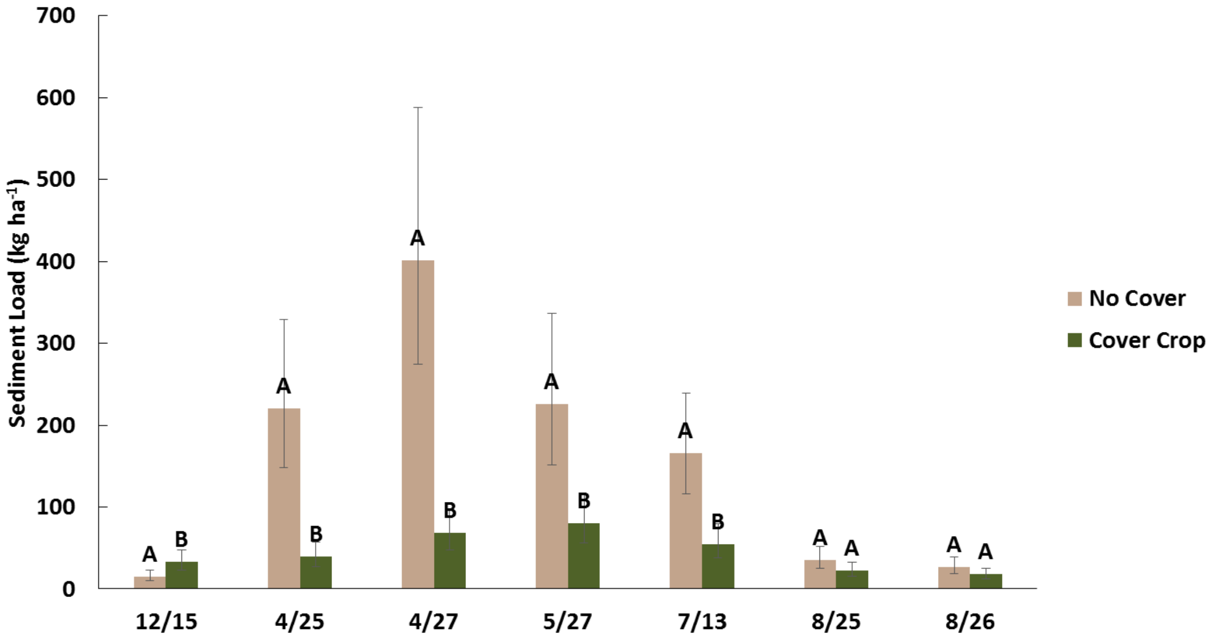

Figure 4.10 Sediment load graphed for no cover and cover crop treatments (with or without cover crop) by runoff event. (Error bars indicate the 95% confidence intervals. Different letters indicate significant difference within event at $p<0.05$)

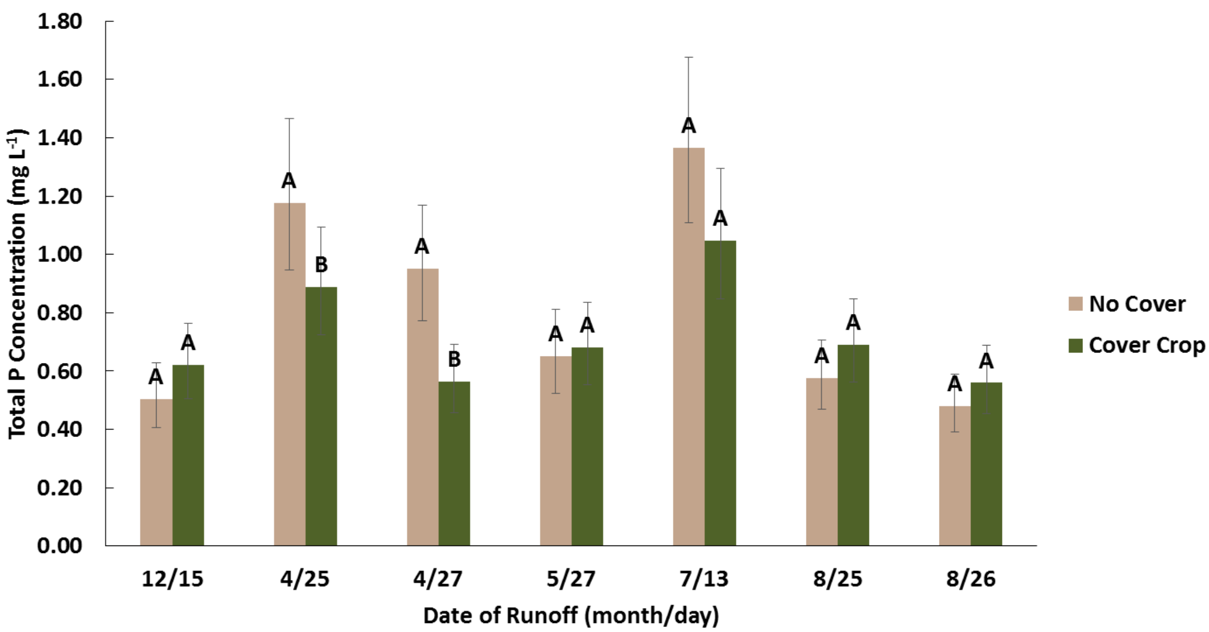

Figure 4.11 Total P concentration graphed for no cover and cover crop treatments (with or without cover crop) by runoff event. (Error bars indicate the 95% confidence intervals. Different letters indicate significant difference within event at $p<0.05$)

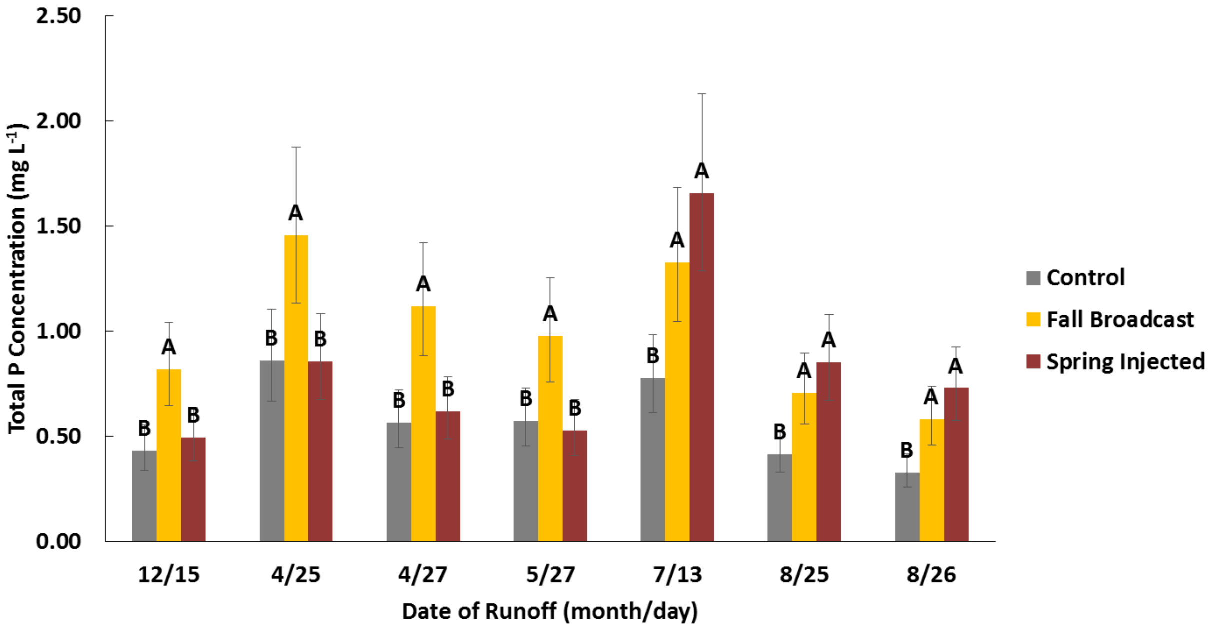

Figure 4.12 Total P concentration graphed for the three fertilizer application treatments (no P fertilizer [control], broadcast P fertilizer in the fall, and injecting P fertilizer in the spring) by runoff event. (Error bars indicate the 95% confidence intervals. Different letters indicate significant difference within event at $p<0.05$)

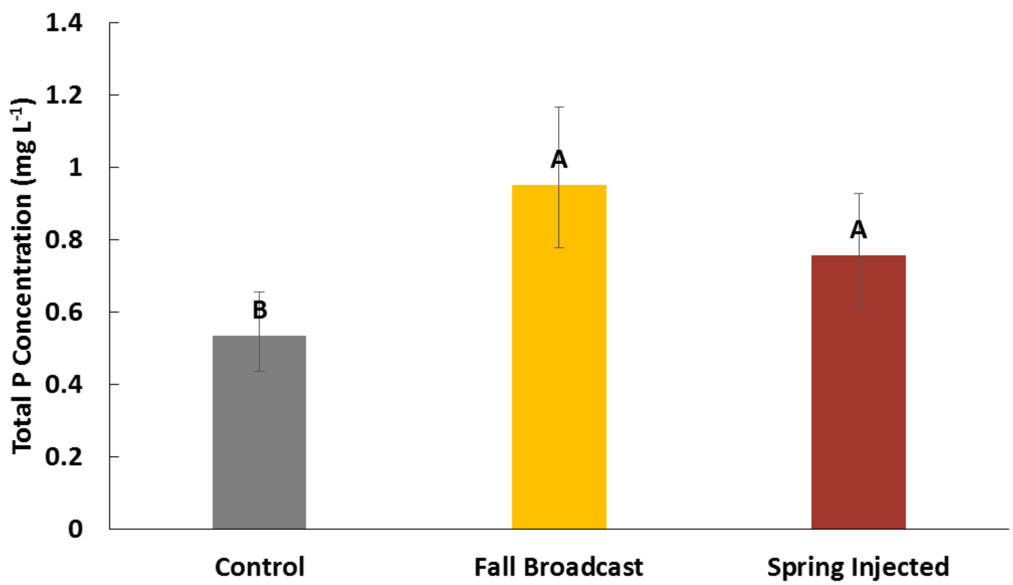

Figure 4.13 Main effect of fertilizer application treatments (no P fertilizer [control], broadcast P fertilizer in the fall, and injecting P fertilizer in the spring) on total P concentration from the seven largest runoff events (> 5 mm). (Error bars indicate the 95% confidence intervals. Different letters indicate significant difference at $p<0.05$)

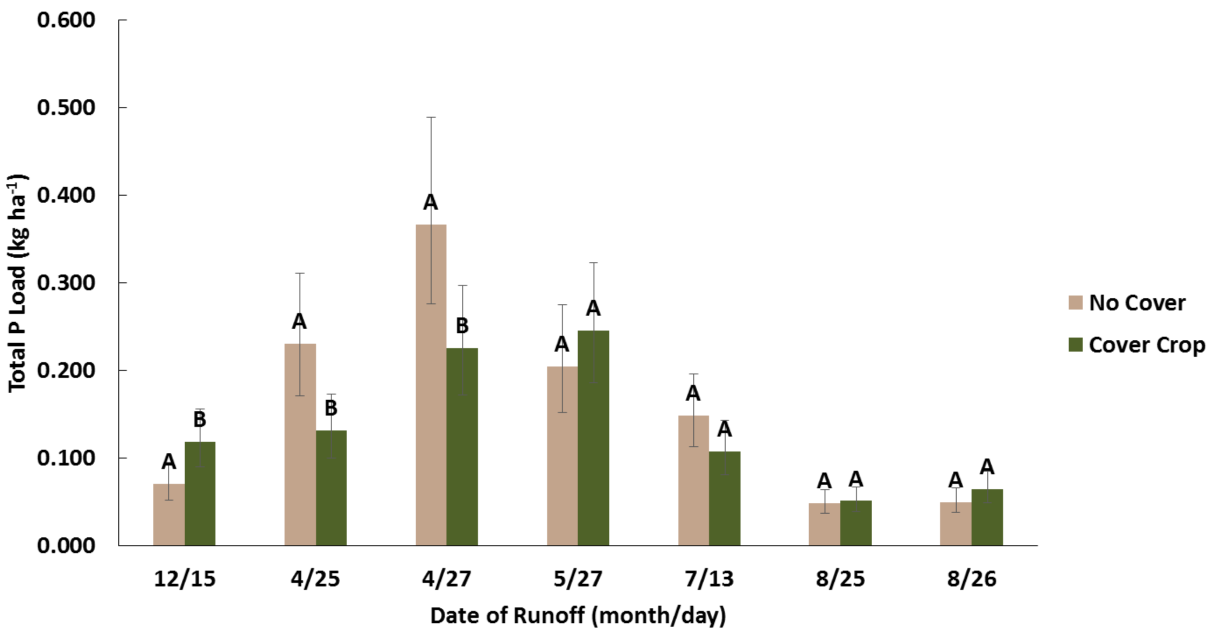

Figure 4.14 Total P load graphed for no cover and cover crop treatments (with or without cover crop) by runoff event. (Error bars indicate the 95% confidence intervals. Different letters indicate significant difference within event at p<0.05)

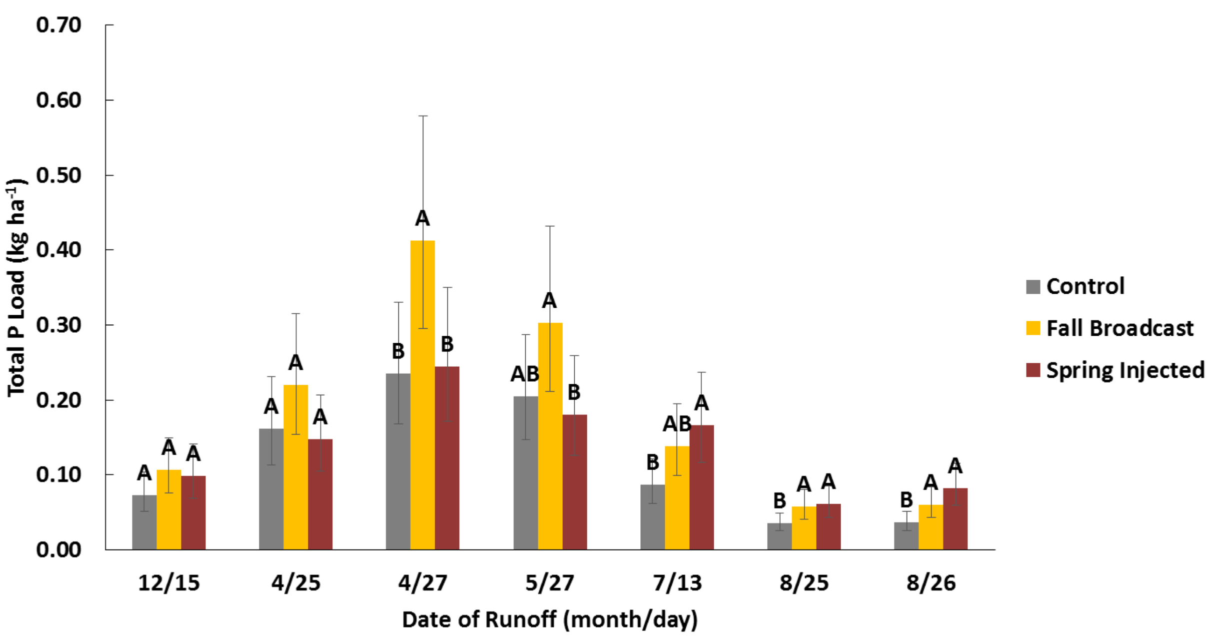

Figure 4.15 Total P load graphed for fertilizer application treatments (no P fertilizer [control], broadcast P fertilizer in the fall, and injecting P fertilizer in the spring) by runoff event. (Error bars indicate the 95% confidence intervals. Different letters indicate significant difference within event at p<0.05)

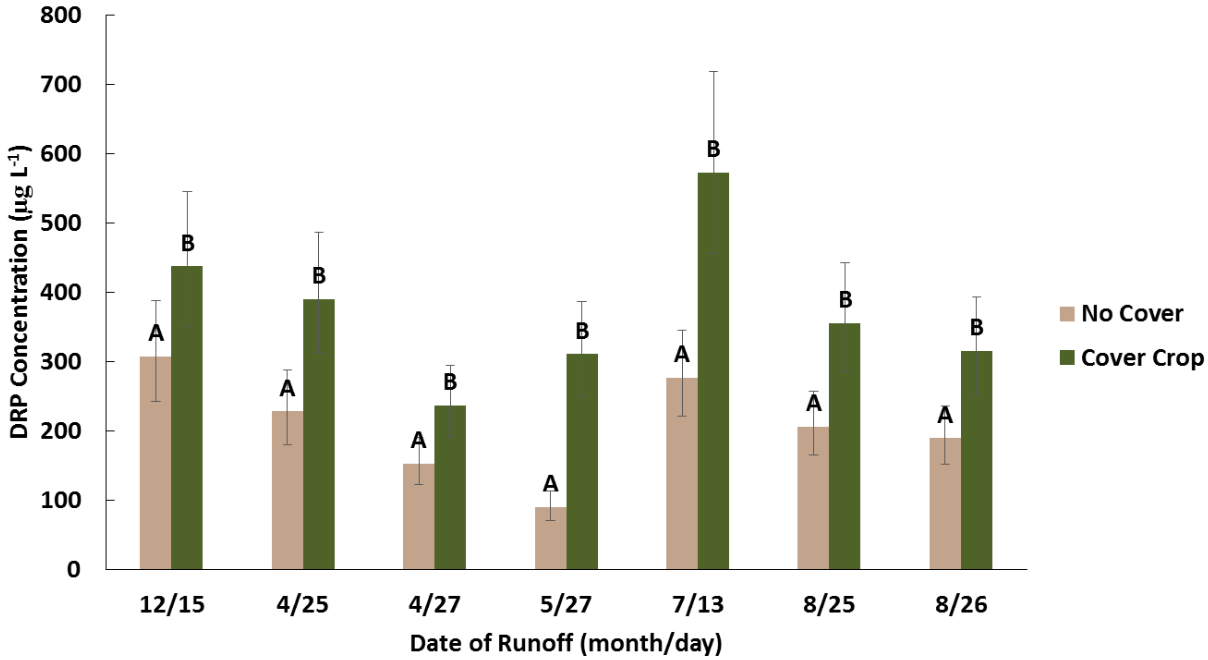

Figure 4.16 Dissolved reactive P concentration graphed for no cover and cover crop treatments (with or without cover crop) by runoff event. (Error bars indicate the 95% confidence intervals. Different letters indicate significant difference within event at p<0.05)

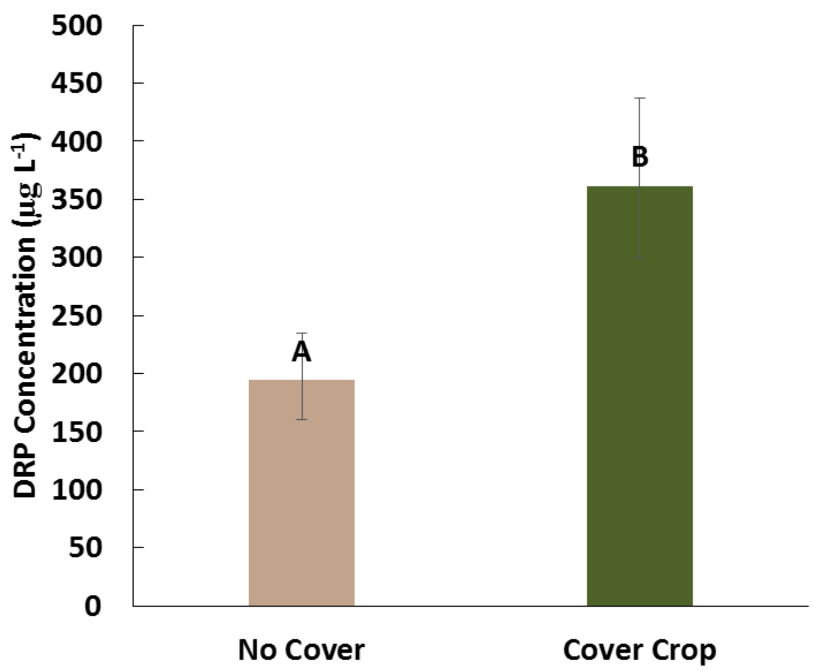

Figure 4.17 Main effect of cover crop treatment (with or without cover crop) on DRP concentration from the seven largest runoff events (> 5 mm). (Error bars indicate the 95% confidence intervals. Different letters indicate significant difference at p<0.05)

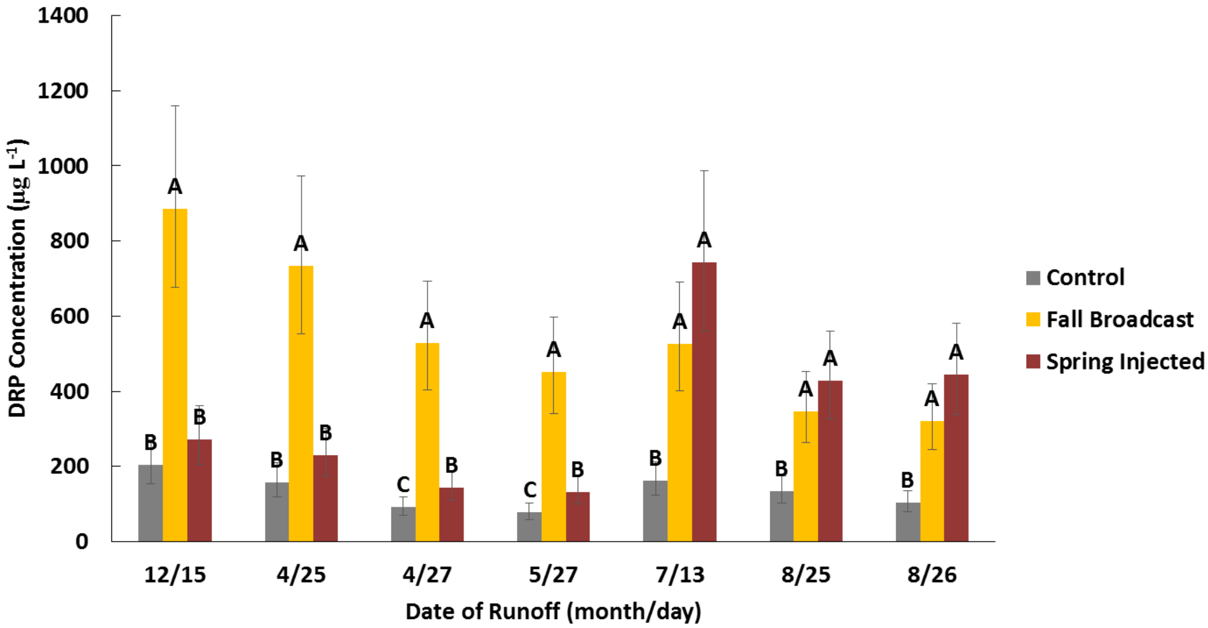

Figure 4.18 Dissolved reactive P concentration graphed for fertilizer application treatment (no P fertilizer [control], broadcast P fertilizer in the fall, and injecting P fertilizer in the spring) by runoff event. (Error bars indicate the 95% confidence intervals. Different letters indicate significant difference within event at p<0.05)

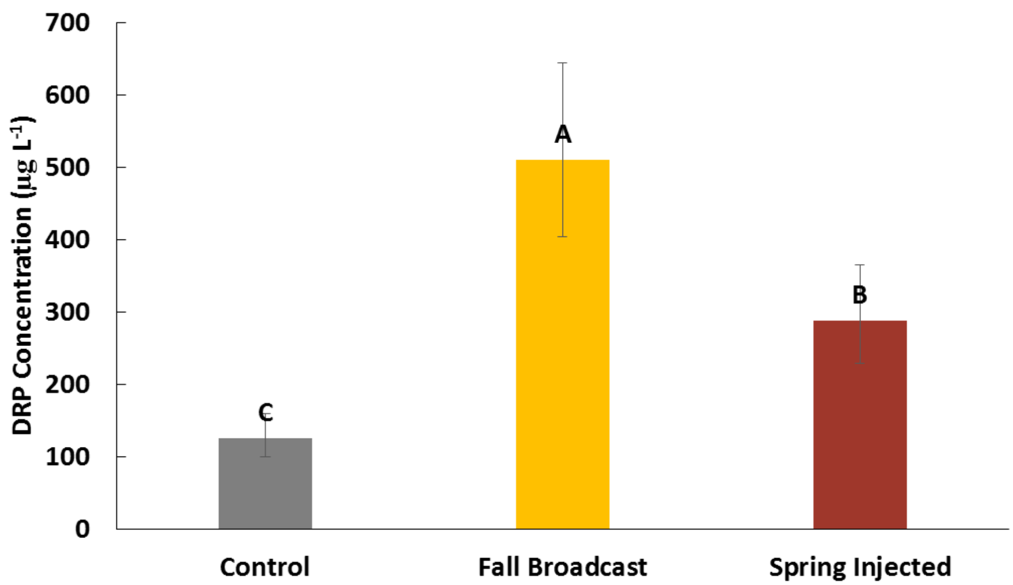

Figure 4.19 Main effect of P fertilizer application treatment (no P fertilizer [control], broadcast P fertilizer in the fall, and injecting P fertilizer in the spring) on DRP concentration from the seven largest runoff events (> 5 mm). (Error bars indicate the 95% confidence intervals. Different letters indicate significant difference at p<0.05)

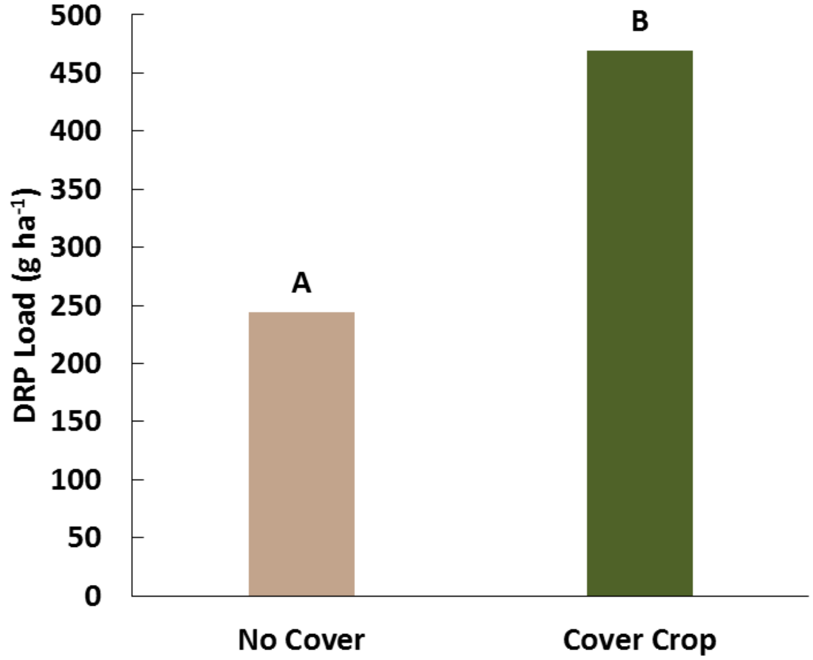

Figure 4.20 Dissolved reactive P load totaled for cover and no cover crop treatments (with or without cover crop) from the seven largest runoff events (> 5 mm). (Error bars indicate the 95% confidence intervals. Different letters indicate significant difference at $p<0.05$)

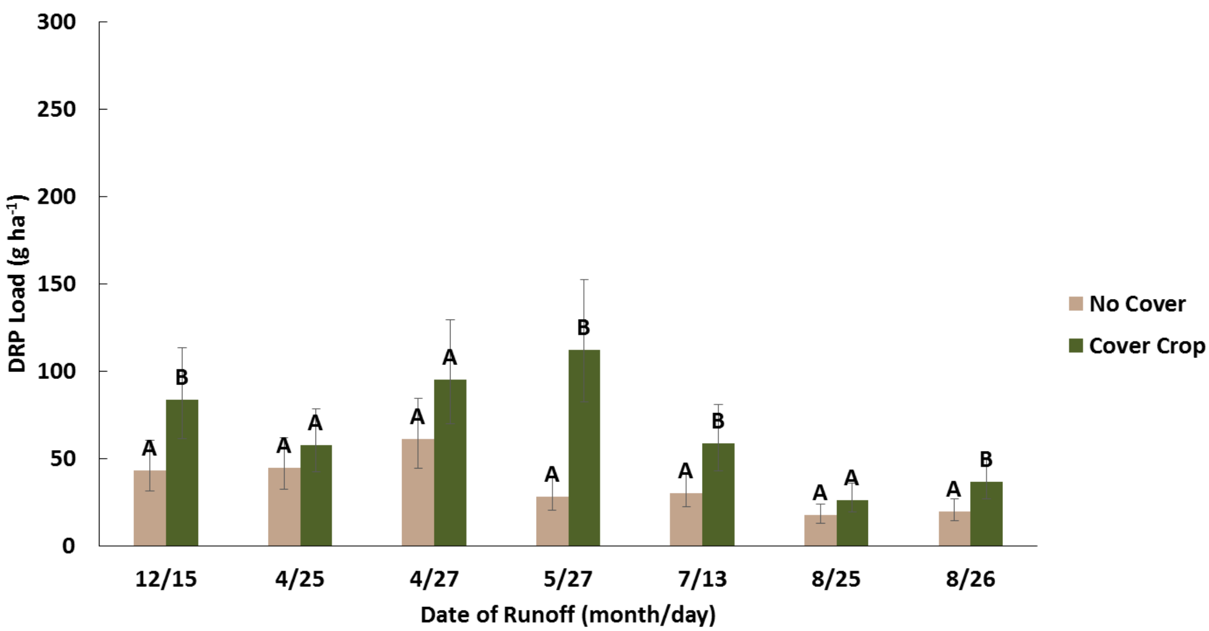

Figure 4.21 Dissolved reactive P load graphed for no cover and cover crop treatments (with or without cover crop) by runoff event. (Error bars indicate the 95% confidence intervals. Different letters indicate significant difference within event at $p<0.05$)

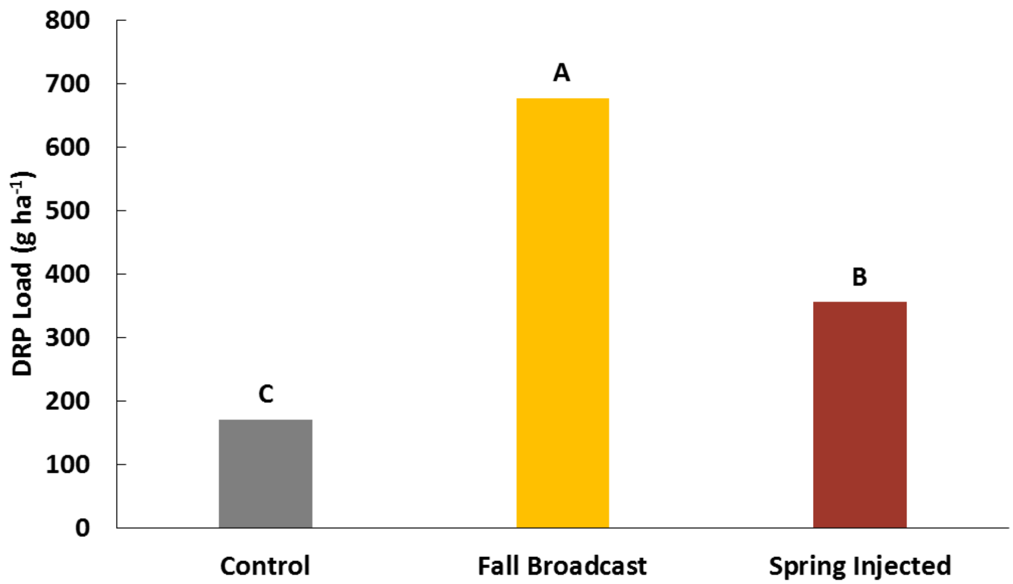

Figure 4.22 Dissolved reactive P load totaled for P fertilizer application treatment (no P fertilizer [control], broadcast P fertilizer in the fall, and injecting P fertilizer in the spring) from the seven largest runoff events (> 5 mm). (Different letters indicate significant difference at $p<0.05$)

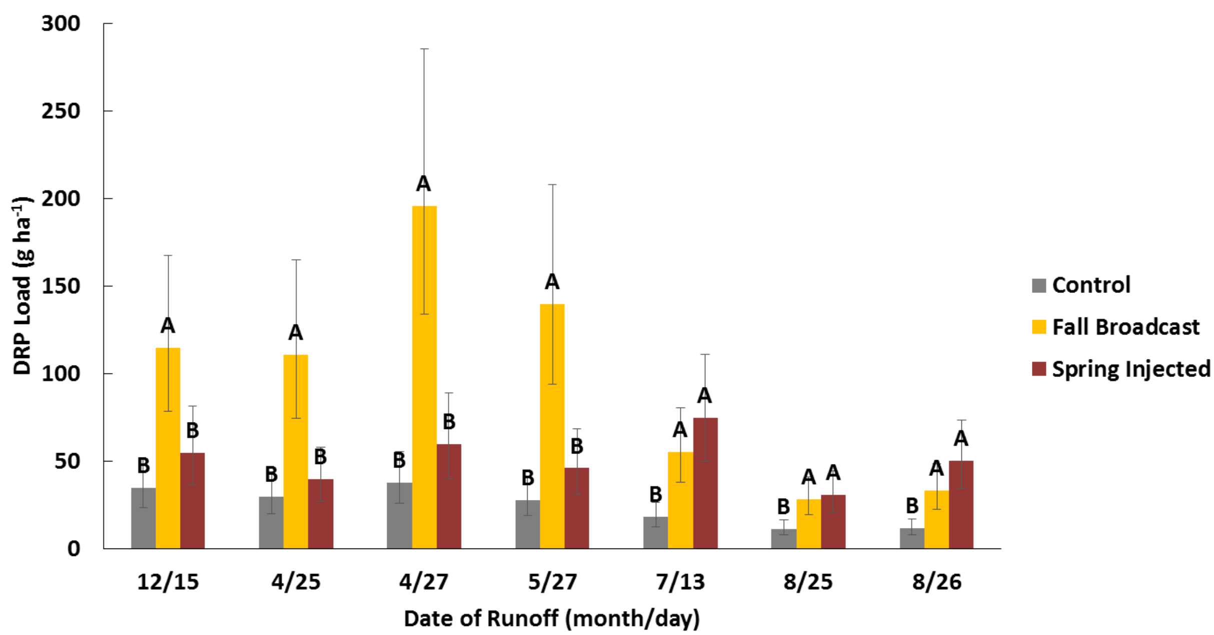

Figure 4.23 Dissolved reactive P load graphed for fertilizer application treatment (no P fertilizer [control], broadcast P fertilizer in the fall, and injecting P fertilizer in the spring) by runoff event. (Error bars indicate the 95% confidence intervals. Different letters indicate significant difference within event at $p<0.05$)

Chapter 5 - Conclusion

A producer's specific management goals should influence his decision about cover crop use. One cover crop species could be a detriment where another may be a benefit, depending on the water drawdown behavior of the particular species. Soil moisture in summer cover crop (sorghum sudangrass and forage soybean) plots was not significantly different than chemical fallow at spring planting in Ashland Bottoms, KS in 2016, but significant differences were measured for winter cover crops (tillage radish and crimson clover) and double-crop soybean (Figure 2.12). Soil water deficits may be present at spring planting following a cover crop if an insufficient amount of time and precipitation occur between cover crop termination and spring planting.

An over wintering cover crop will likely reduce sediment loss (erosion). This research however was inconclusive about how a cover crop might affect P loss. Phosphorus loss results were inconsistent between the first and second water year. In 2014-2015 with tillage, the cover crop reduced runoff, erosion, and P loss. In 2015-2016 without tillage, the cover crop reduced erosion, had no effect on runoff or total P loss, and increased dissolve P loss. Differences may have been caused by management changes, weather variability, or differences in main crop (corn vs soybean) uptake between the two years. Long term research at the field scale is needed to understand how cover crops effect P loss from agriculture.

Subsurface placement of P fertilizer in the spring will likely reduce DRP loss compared to broadcasting P fertilizer in the fall. Regardless of application method, concentrations of P in surface runoff can be expected to exhibit curvilinear decay as time from application increases. Phosphorus fertilizer application method effects on total P loss were more complex and will require more data in the no-till system to fully understand. Without more conclusive cover crop data, this research supports the generally accepted best management practice of subsurface application of P fertilizer to reduce P loss irrespective of cover crop use.

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Appendix A- Total Soil Moisture SAS Code

```
*proc print data = LTCC;
* Transpose dataset to make it easy to get results from multiple variables;
proc sort data=LTCC; by rep Species tube;
proc transpose data=LTCC
     out=aaa (rename=(_Name_=date) rename=(col1=XXX));
   var a42201 a42215 a42227 a42243 a42256 a42286 a42321 a42348 a42382 a42419
a42447 a42492;
   by rep Species tube;
run;
*proc print data = aaa;
proc sort data=aaa; by date;
*proc print data = aaa;
*/* Repeated measures (date repeated);
PROC GLIMMIX DATA=aaa;
 CLASS rep Species date;
 MODEL XXX = Species|date/DDFM=SATTERTH;
 RANDOM rep;
 random date/subject=rep*species type=cs residual;
 LSMEANS species|date/slice=date simplediff=date;

 ods output test3=ANOVA1 lsmeans=means1 diffs = pdiffs1;

*/*CONTRASTS - species*date;
estimate "cf vs cc 12" species 1 -1 0 0 0 0
                      species*date 0 0 0 0 0 0 0 0 0 0 0 1
                                       0 0 0 0 0 0 0 0 0 0 0 -1
                                       0 0 0 0 0 0 0 0 0 0 0 0
                                       0 0 0 0 0 0 0 0 0 0 0 0
                                       0 0 0 0 0 0 0 0 0 0 0 0
                                       0 0 0 0 0 0 0 0 0 0 0 0;
estimate "cf vs dcs 12" species 0 -1 1 0 0 0
                      species*date 0 0 0 0 0 0 0 0 0 0 0 0
                                       0 0 0 0 0 0 0 0 0 0 0 -1
                                       0 0 0 0 0 0 0 0 0 0 0 1
                                       0 0 0 0 0 0 0 0 0 0 0 0
                                       0 0 0 0 0 0 0 0 0 0 0 0
                                       0 0 0 0 0 0 0 0 0 0 0 0;
estimate "cf vs fs 12" species 0 -1 0 1 0 0
                      species*date 0 0 0 0 0 0 0 0 0 0 0 0
                                       0 0 0 0 0 0 0 0 0 0 0 -1
                                       0 0 0 0 0 0 0 0 0 0 0 0
                                       0 0 0 0 0 0 0 0 0 0 0 1
                                       0 0 0 0 0 0 0 0 0 0 0 0
                                       0 0 0 0 0 0 0 0 0 0 0 0;
estimate "cf vs ss 12" species 0 -1 0 0 1 0
                      species*date 0 0 0 0 0 0 0 0 0 0 0 0
                                       0 0 0 0 0 0 0 0 0 0 0 -1
                                       0 0 0 0 0 0 0 0 0 0 0 0
                                       0 0 0 0 0 0 0 0 0 0 0 0
                                       0 0 0 0 0 0 0 0 0 0 0 1
                                       0 0 0 0 0 0 0 0 0 0 0 0;
estimate "cf vs tr 12" species 0 -1 0 0 0 1
                      species*date 0 0 0 0 0 0 0 0 0 0 0 0
```

```
                                            0 0 0 0 0 0 0 0 0 0 0 -1
                                            0 0 0 0 0 0 0 0 0 0 0 0
                                            0 0 0 0 0 0 0 0 0 0 0 0
                                            0 0 0 0 0 0 0 0 0 0 0 0
                                            0 0 0 0 0 0 0 0 0 0 0 1;
estimate "cf vs sum" species 0 -3 1 1 1 0
                      species*date 0 0 0 0 0 0 0 0 0 0 0 0
                                            0 0 0 0 0 0 0 0 0 0 0 -3
                                            0 0 0 0 0 0 0 0 0 0 0 1
                                            0 0 0 0 0 0 0 0 0 0 0 1
                                            0 0 0 0 0 0 0 0 0 0 0 1
                                            0 0 0 0 0 0 0 0 0 0 0 0;


estimate "cf vs cc 5" species 1 -1 0 0 0 0
                      species*date 0 0 0 0 1 0 0 0 0 0 0 0
                                            0 0 0 0 -1 0 0 0 0 0 0 0
                                            0 0 0 0 0 0 0 0 0 0 0 0
                                            0 0 0 0 0 0 0 0 0 0 0 0
                                            0 0 0 0 0 0 0 0 0 0 0 0
                                            0 0 0 0 0 0 0 0 0 0 0 0;
estimate "cf vs dcs 5" species 0 -1 1 0 0 0
                      species*date 0 0 0 0 0 0 0 0 0 0 0 0
                                            0 0 0 0 -1 0 0 0 0 0 0 0
                                            0 0 0 0 1 0 0 0 0 0 0 0
                                            0 0 0 0 0 0 0 0 0 0 0 0
                                            0 0 0 0 0 0 0 0 0 0 0 0
                                            0 0 0 0 0 0 0 0 0 0 0 0;
estimate "cf vs fs 5" species 0 -1 0 1 0 0
                      species*date 0 0 0 0 0 0 0 0 0 0 0 0
                                            0 0 0 0 -1 0 0 0 0 0 0 0
                                            0 0 0 0 0 0 0 0 0 0 0 0
                                            0 0 0 0 1 0 0 0 0 0 0 0
                                            0 0 0 0 0 0 0 0 0 0 0 0
                                            0 0 0 0 0 0 0 0 0 0 0 0;
estimate "cf vs ss 5" species 0 -1 0 0 1 0
                      species*date 0 0 0 0 0 0 0 0 0 0 0 0
                                            0 0 0 0 -1 0 0 0 0 0 0 0
                                            0 0 0 0 0 0 0 0 0 0 0 0
                                            0 0 0 0 0 0 0 0 0 0 0 0
                                            0 0 0 0 1 0 0 0 0 0 0 0
                                            0 0 0 0 0 0 0 0 0 0 0 0;
estimate "cf vs tr 5" species 0 -1 0 0 0 1
                      species*date 0 0 0 0 0 0 0 0 0 0 0 0
                                            0 0 0 0 -1 0 0 0 0 0 0 0
                                            0 0 0 0 0 0 0 0 0 0 0 0
                                            0 0 0 0 0 0 0 0 0 0 0 0
                                            0 0 0 0 0 0 0 0 0 0 0 0
                                            0 0 0 0 1 0 0 0 0 0 0 0;


estimate "cf vs cc 7" species 1 -1 0 0 0 0
                      species*date 0 0 0 0 0 0 1 0 0 0 0 0
                                            0 0 0 0 0 0 -1 0 0 0 0 0
                                            0 0 0 0 0 0 0 0 0 0 0 0
                                            0 0 0 0 0 0 0 0 0 0 0 0
                                            0 0 0 0 0 0 0 0 0 0 0 0
```

```
                                                   0 0 0 0 0 0 0 0 0 0 0 0;
estimate "cf vs dcs 7" species 0 -1 1 0 0 0
                      species*date 0 0 0 0 0 0 0 0 0 0 0 0
                                                   0 0 0 0 0 0 -1 0 0 0 0 0
                                                   0 0 0 0 0 0 1 0 0 0 0 0
                                                   0 0 0 0 0 0 0 0 0 0 0 0
                                                   0 0 0 0 0 0 0 0 0 0 0 0
                                                   0 0 0 0 0 0 0 0 0 0 0 0;
estimate "cf vs fs 7" species 0 -1 0 1 0 0
                      species*date 0 0 0 0 0 0 0 0 0 0 0 0
                                                   0 0 0 0 0 -1 0 0 0 0 0
                                                   0 0 0 0 0 0 0 0 0 0 0 0
                                                   0 0 0 0 0 0 1 0 0 0 0 0
                                                   0 0 0 0 0 0 0 0 0 0 0 0
                                                   0 0 0 0 0 0 0 0 0 0 0 0;
estimate "cf vs ss 7" species 0 -1 0 0 1 0
                      species*date 0 0 0 0 0 0 0 0 0 0 0 0
                                                   0 0 0 0 0 0 -1 0 0 0 0 0
                                                   0 0 0 0 0 0 0 0 0 0 0 0
                                                   0 0 0 0 0 0 0 0 0 0 0 0
                                                   0 0 0 0 0 0 1 0 0 0 0 0
                                                   0 0 0 0 0 0 0 0 0 0 0 0;
estimate "cf vs tr 7" species 0 -1 0 0 0 1
                      species*date 0 0 0 0 0 0 0 0 0 0 0 0
                                                   0 0 0 0 0 0 -1 0 0 0 0 0
                                                   0 0 0 0 0 0 0 0 0 0 0 0
                                                   0 0 0 0 0 0 0 0 0 0 0 0
                                                   0 0 0 0 0 0 0 0 0 0 0 0
                                                   0 0 0 0 0 0 1 0 0 0 0 0;

run;
quit;
```

Appendix B- Soil Moisture by Depth SAS Code

```
*proc print data = PROFILE;
* Transpose dataset to make it easy to get results from multiple variables;
proc sort data=PROFILE; by rep Species D1 D2 tube;
proc transpose data=PROFILE
     out=aaa (rename=(_Name_=date) rename=(col1=XXX));
   var a42201 a42215 a42227 a42243 a42256 a42286 a42321 a42348 a42382 a42419
a42447 a42492;
   by rep Species D1 D2 tube;
run;
*proc print data = aaa;
proc sort data=aaa; by date D1;
*proc print data = aaa;

*/* Split-plot (depth as sub-plot);
PROC GLIMMIX DATA=aaa; by date;
 CLASS rep Species D1;
 MODEL XXX = Species|D1/DDFM=SATTERTH;
 RANDOM rep rep*species;
 LSMEANS species|D1/LINES cl pdiff;
 ods output tests3=ANOVA lsmeans=means diffs=pdiffs lsmlines=mcp;
*/*;

*/* print datasets to an excel file;
data means; set means; cl=upper-estimate;
proc export data = WORK.ANOVA DBMS=XLSX
  outfile = "C:\Users\dabel\My Documents\My SAS Files\9.4\PROFILE\2015-2016
Water Use.xlsx" replace;
  sheet=tests;
proc export data = WORK.means DBMS=XLSX
  outfile = "C:\Users\dabel\My Documents\My SAS Files\9.4\PROFILE\2015-2016
Water Use.xlsx" replace;
  sheet=means;
proc export data = WORK.pdiffs DBMS=XLSX
  outfile = "C:\Users\dabel\My Documents\My SAS Files\9.4\PROFILE\2015-2016
Water Use.xlsx" replace;
  sheet=diffs;
proc export data = WORK.mcp DBMS=XLSX
  outfile = "C:\Users\dabel\My Documents\My SAS Files\9.4\PROFILE\2015-2016
Water Use.xlsx" replace;
  sheet=lines;
*/*;
run;
quit;
```

Appendix C– Site Establishment and Research Equipment

Prior to site establishment, the field had an existing parallel terrace system, with terraces draining to waterways on the north and south edges of the field. The slope of terrace ridges and channels was measured with a Leica Rugby_{100} Laser Level. Measurements were taken every 6.1 m along all the terrace ridges and in all the terrace channels. This information was used in July of 2014 when earthmoving contractors were hired to create a new waterway, build berms, and regrade terrace channels to create 18 small watersheds that would each drain to a unique outlet (Figure C.1). Terrace channels were graded at a 0.3% slope. In two of the Southernmost plots (301 & 304) water naturally flowed toward the north instead of into the nearest waterway to the south. Since reversing the natural flow would have required extensive earthmoving, 30-cm pipe outlets were installed at the outlet of these two plots. Bromegrass (*Bromus inermis)* was seeded in the waterway immediately after its construction. After brome seeding Tensar VMAX SC250 turf reinforcement mat was installed to control erosion until bromegrass establishment. Unfortunately, the turf reinforcement mat was damaged during a tillage operation, which decreased its efficacy for erosion prevention.

A 0.46 m H-flume from Plasti-Fab (Appendix E) was installed anchored to concrete slabs (1.4 x 1.5 x 0.1 m) at the outlet of each watershed (Figure C.2). To ensure stability a 0.3 x 0.9 m hole was augured in the center of the concrete form as a footing for the pad before the concrete was poured. Rebar and remesh typical of concrete work was used for reinforcement in these pads. A second concrete pad (1.5 x 1.8 x 0.1 m) was poured 0.1 m below the flume outlet, also with a 0.3 x 0.9 m hole augured as a footing for stability. A 0.1 m PVC pipe split in half lengthwise was set in the center of the second concrete pad to receive and concentrate runoff exiting the flume and enable sample collection during low-flow events. An endcap (also split) was glued to the end of the PVC pipe with a hole drilled to allow water to drain. A third concrete pad was poured at each watershed outlet for a shelter to house automated water sampling equipment. Two PVC conduit pipes were laid below ground to facilitate the sampler hose and bubbler hose connection between the sampling equipment and flume area. Aluminum wings (0.6 x 3.0 m) were connected to the flume to help direct water flow and decrease the risk of water tunneling under soil berms surrounding the flume. The aluminum wings were cut and bent so that it secures flush with the inlet of the flume and extends below the soil surface 0.15 m (Figure C.3).

By using the H-flume, depth of water can accurately be correlated to flow rate (Q) because of the precise flume design. The equation needed to make this conversion between depth in meters (H_m) for the 0.46 m H-flumes used in this research is: $Q = -0.00396436 – 0.07231968 H_m^{0.5} + 79.89379128 H_m^{1.5} + 900.3765227 H_m^{2.5}$.

A Teledyne ISCO 6712 or 6700 automated water sampler equipped with a 730 bubbler module was installed at each watershed outlet to measure water depth in the flume and collect water samples. The 730 Bubbler Module uses a differential pressure transducer to measure the depth of water in the fume. Since water depth is linearly correlated to pressure we know that for every 1 m increase in depth there would be a 10 kPa increase. As water level increases, more pressure is required to push the bubble out of the bubbler tube at the bottom of the flume. The water sampler automatically converts pressure to depth and records the data. The full program used for water samplers can be found in Appendix F. There are a few differences in sampler programing between sites. Most notably is that the flow pacing interval changes based on the specific plot dimension. Actual plot sizes range from 0.44 to 0.67 ha. Samplers are programed to collect flow-weighted composite samples, collecting a 200-mL sub-sample for each 1 mm of runoff. Therefore, the volume of runoff is set to equal 1 mm from each plot. Other program differences include the site description, the amount of suction line, and the amount of suction head which are specific to each location. Samplers were programed to be “enabled” when initial water level exceeds 0.015 m. In the 2014-2015 water year samplers programed to “not sample at enable.” Therefore, the first sub sample was collected after the first 1 mm of runoff occurred following the sampler enable. This function was changed on May 24, 2016 to sample at enable and every 1 mm of runoff thereafter. This was changed to ensure sample collection from small runoff events did not have enough sustained flow above the enable point of 0.015 m to trigger a sample. Water samplers were powered by a 12V marine battery maintained by an 18 watt Coleman solar panel. Vincon tubing (inside diameter of 0.32 cm and outside diameter of 0.64 cm) was used to connect the ISCO 730 bubbler module to the bubbler pipe assembly shown in Appendix E as item #4. Vincon tubing (1.0 cm inside diameter and a 1.6 cm outside diameter) was used as sample collection line for the 6712 automated water sampler. It was conveyed through the PVC conduit and into the split PVC pipe from which water samples are collected. The sample hose is secured in the split PVC pipe with stainless steel wire to keep it from washing out during large runoff events. A 15.24 cm long metal tube was inserted in to the end of the sample hose predominantly for weight as this tube has no filtering function. (Figure C.2).

The equipment shelters for plots 104, 304, 105, and 303 are equipped with Campbell Scientific CR200 Series dataloggers for remote monitoring. These four sites are also equipped with automated tipping-bucket rain gauges (Model TR-5251, 0.254 mm per tip; Texas Electronics, Inc., Dallas, TX) that have a funnel diameter of 15.2 cm. Total precipitation for each event was recorded manually at these same locations with gauges (Stock No. 88991; Forestry Suppliers, Inc., Jackson, MS) that have a funnel diameter of 10 cm. These four pairs of rain gauges are intentionally spread out to ensure that any variability in rainfall across the KAW research area is captured in the data. Due to freeze-thaw conditions over winter, rain gauges are brought indoors to avoid damage. Precipitation data for the winter months is provided by the Kansas Mesonet weather station located less than 1 km away. This weather station is equipped with a heated siphon tipping bucket rain gauge (Hydrological Services America, Lake Worth, FL) for capturing precipitation as snowfall over the winter months. Automated water samplers are put into a standby status over winter. On standby samplers will not draw water samples but continue to measure flow. This is done to prevent water from freezing in the lines and breaking the sampler pumps. If a potential runoff event is anticipated and temperatures are projected to remain above freezing, the samplers are temporarily set to active status for the duration of the event.

Lime application

Four field-scale composite soil samples collected in April of 2014 had an average pH of 5.9 (5.6 to 6.1) with an average buffer pH of 6.4. On November 6, 2014, agricultural lime was applied at 6.7 to 7.8 Mg ha^{-1}. The lime moisture content was 3.7% and the effective calcium carbonate was 62% based on analysis from the KSU soil testing lab. This provided 4710 kg ECC ha^{-1}, which would have been sufficient to raise the pH to 6.5 to 6.8. The lime was tilled in on November 7, 2014 with a chisel followed by a disk operation.

Figure C.1 Satellite image of water way construction and slope regrading at the Kansas Agricultural Watersheds. The earth work required for the installation of tile drainage outlets for plots 301 and 304 is not shown in this image.

Figure C.2 Complete outlet installation for plot 105. The bubbler hose runs from the flume to the equipment shelter through the flexible conduit shaped like a question mark. The sampling hose runs through the flexible conduit resting in the split PVC pipe below the outlet of the flume. In the background you can see the tipping bucket and manual rain gauges on the field goal shaped stand. In this photo the aluminum flanges, solar panel, battery, and datalogger are not visible.

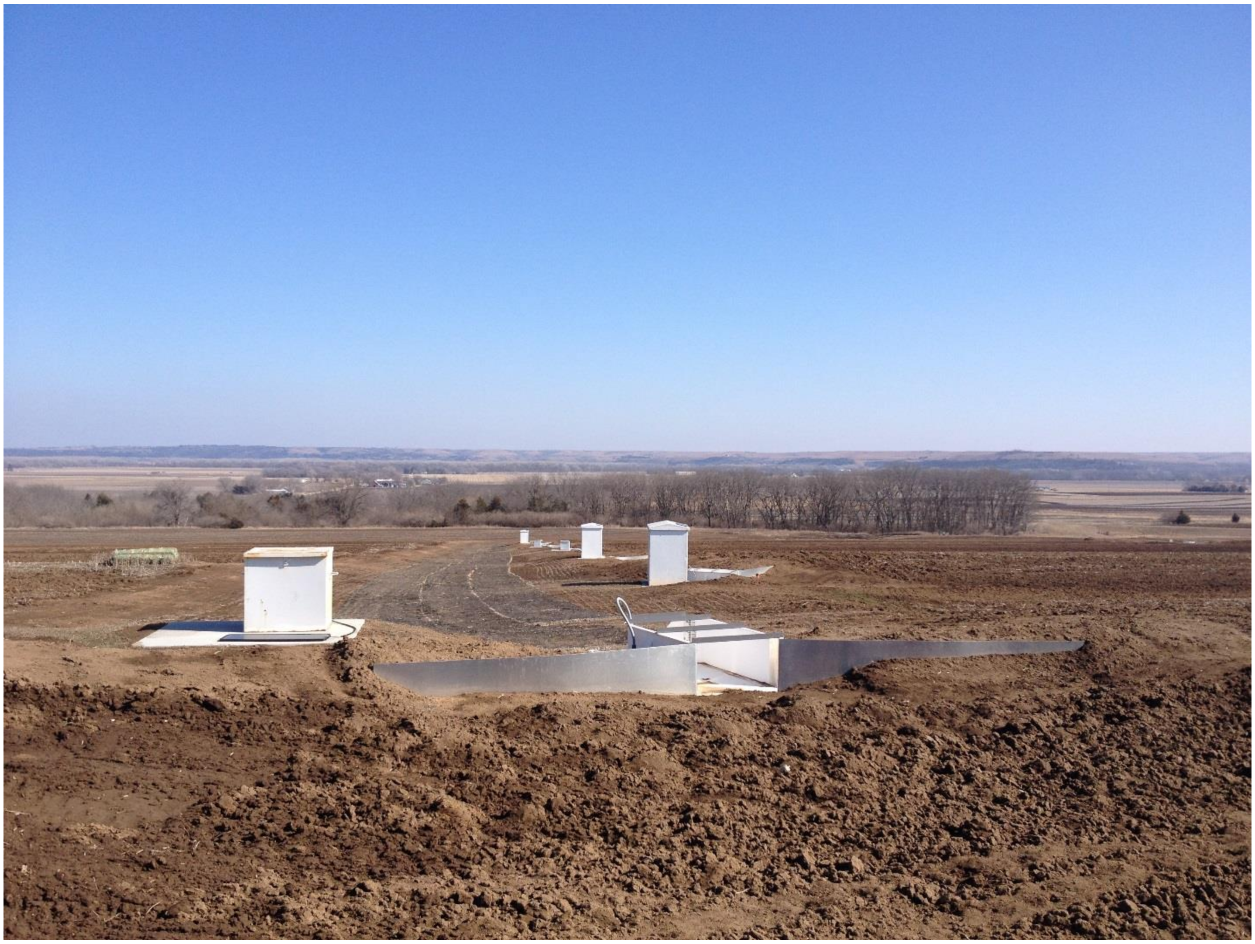


Figure C.3 Installation at site 102 looking east down the waterway. Berm reinforcing flanges made of aluminum are seen attached to the inlet of the flume. Erosion control mat can be seen extending down the waterway. The shelters at the outlets of plots 102, 105, 202, 205, 302, 305 extend into the distance respectively.

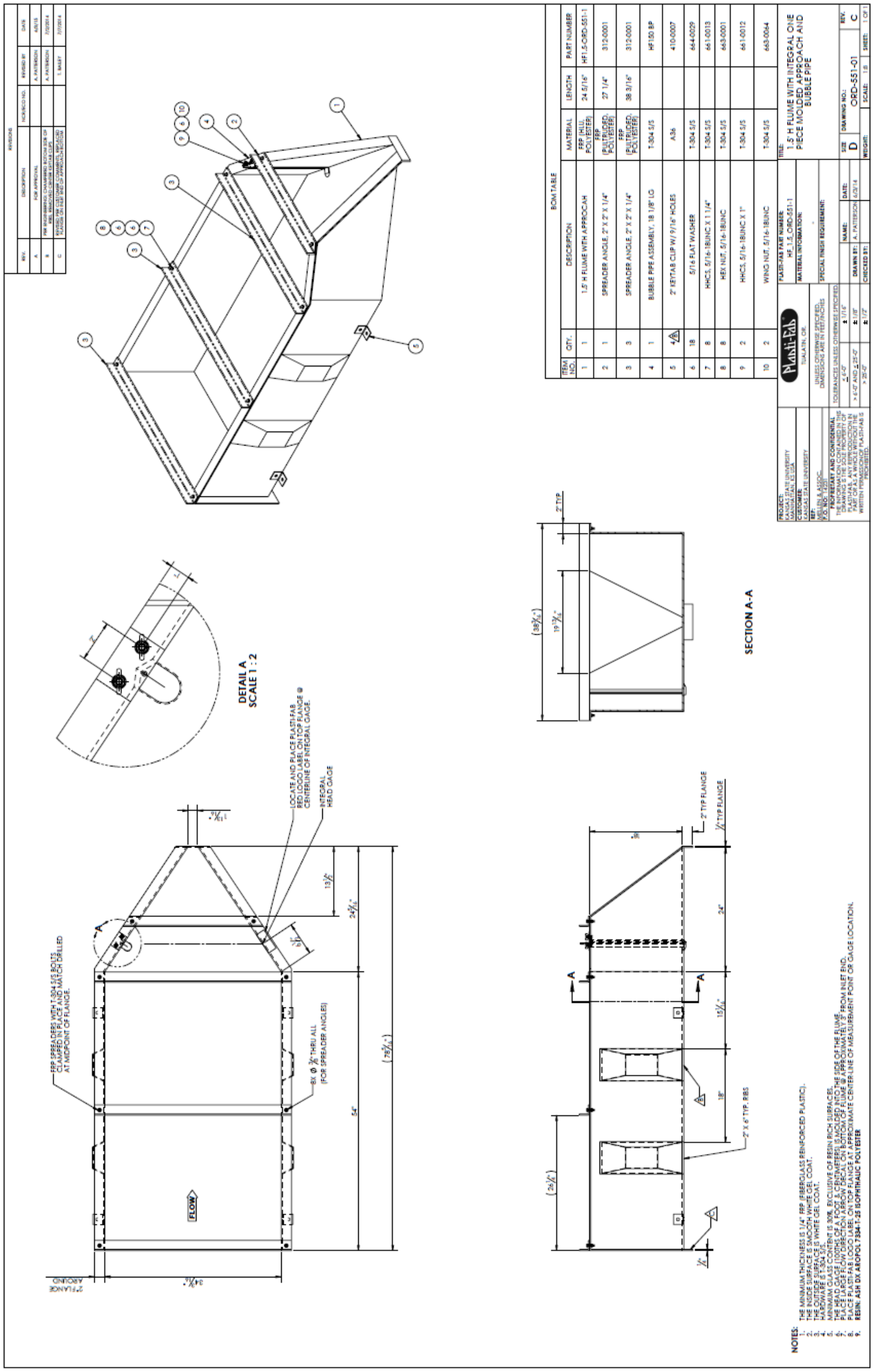
Appendix D- Water Analysis SAS Code

```
*/*********** Analysis of interaction effects on chemical concens. and loads ******;
proc glimmix data = ccc;
class rep EventID fert1 cover1;
model tTSS = fert1|cover1|EventID/ddfm = satterth;
random rep;
random EventID/subject=rep*cover1*fert1 type=CS residual;
lsmeans fert1|cover1|eventID/lines cl;
ods output tests3=tANOVA lsmeans=tmeans diffs=tpdiffs;
run; quit;

       */* use this for log-transformed variables ;
       data tmeans;
       set tmeans; * put the name of the file that contains Estimate and SE;
       Est=exp(log(10)*Estimate);  * Estimate in original scale;
       LCI=Est-exp(log(10)*lower);      * 95% Lower confidance interval in original
scale;
       UCI=exp(log(10)*upper)-Est; * 95% Lower confidance interval in original scale;
       proc print data = tmeans; run;

       /* use this for square-root transformed variables ;
       data tmeans;
       set tmeans;
       Est=Estimate**2;    * Estimate in original scale;
       LCI=Est-(lower**2); * 95% Lower confidance interval in original scale;
       UCI=(upper**2)-Est; * 95% Upper confidance interval in original scale;
       proc print data = tmeans; run;
       */*;
       proc export data = WORK.tANOVA DBMS=XLSX
         outfile = "C:\Users\dabel\My Documents\My SAS Files\9.4\KAW Field
Lab\output\KAWdataout.XLSX" replace;
         sheet=tANOVA;
       proc export data = WORK.tmeans DBMS=XLSX
         outfile = "C:\Users\dabel\My Documents\My SAS Files\9.4\KAW Field
Lab\output\KAWdataout.XLSX" replace;
         sheet=tmeans;
*/*;
run; quit;
```

Appendix E- H-flume Specifications



Appendix F - Automated Water Sampler Program

```
SAMPLER ID# 2274289525  11:20 12-JUL-16
*********** PROGRAM SETTINGS ***********
          ----------
        PROGRAM NAME:
         "KAW        "
      SITE DESCRIPTION:
         "305        "
          ----------
        UNITS SELECTED:
          LENGTH: ft


          ----------
        UNITS SELECTED:
         FLOW RATE: cfs
       FLOW VOLUME: cf

          ----------
        BUBBLER MODULE:
            FLUME
             1.5'
              H
          ----------

          1 MINUTE
        DATA INTERVAL

          ----------
        1, 10.0 lit BTLS
      25 ft SUCTION LINE
       4 ft SUCTION HEAD
    1 RINSES, 0 RETRIES
          ----------

       ONE-PART PROGRAM


          ----------
           PACING:
         FLOW, EVERY
           171.5 cf
    NO SAMPLE AT START
          ----------
          COMPOSITE:

          45 SAMPLES

          ----------
           VOLUME:

        200 ml SAMPLES

          ----------
           ENABLE:

       LEVEL >0.050 ft

          ----------
           ENABLE:
      REPEATABLE ENABLE
    NO SAMPLE AT DISABLE
       SAMPLE AT ENABLE
          ----------
           ENABLE:
       SAMPLE INTERVAL
       RESET AT ENABLE

          ----------
           ENABLE:
      0 PAUSE & RESUMES
```

```
          ----------

      NO DELAY TO START


          ----------
          ----------
          ----------
       LIQUID DETECT ON

         NO RAIN GAGE

          ----------

          NO YSI 600


          ----------
       MASTER/SLAVE OFF
     BTL FULL DETECT OFF
       TIMED BACKLIGHT

          ----------

       EVENT MARK SENT
      DURING PUMP CYCLE

          ----------
       PUMP COUNTS FOR
      EACH PURGE CYCLE:
       100 PRE-SAMPLE
      AUTO POST-SAMPLE
          ----------
      I/O1= NONE
      I/O2= NONE
      I/O3= NONE

          ----------
       0 ANALOG OUTPUTS

         NO PERIODIC
        SERIAL OUTPUT
----------------------------------------|
```