Winter Rye Cover Cropping to Improve Water Quality in Corn-based Cropping Systems

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Level K

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Consultant's Report

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Introduction

Maintenance of soil quality and health is challenging in corn-based cropping systems with the emergence of biofuel production and increases in precipitation across the contiguous United States. Cellulosic biofuel production will increase demands of biomass, specifically corn residue, because it is readily available and harvesting technologies are well established. Maintaining residue requirements to reduce soil erosion risks while harvesting corn stover has been a focal point in a number of studies, dating back to the work of Lindstrom et al. (1979), who concluded that the amount of corn stover needed to maintain residue requirements to reduce soil erosion risks should be site specific in the US Corn Belt. More recently, Thomas et al. found that removal of corn stover at rates of 38, 52.5, and 70% all statistically increase annual soil erosion (2011). Continued research in this area will enhance our ability to maintain soil conservation practices while still being able to harvest corn stover once 2nd generation (cellulosic) biofuel production becomes more readily available as an additional energy fuel.

Climate change has also been a major focus within the scientific community in recent decades. Increases in atmospheric carbon dioxide and other greenhouse gases have resulted in rising mean global surface temperatures, which have been coupled with an increase in mean atmospheric water vapor (Frei et al, 1998). This has coincided with a higher frequency and intensity of storm events throughout the contiguous U.S. A century ago, the most extreme storms contributed only 1% of total annual rainfall. Now extreme storms contribute 20% of total rainfall in the continental U.S. while total precipitation has only increased by 7% over the past century

(Rosenzweig et al, 2000). Heavy and intense rainfall can be devastating to cropland because of induced soil erosion, nutrient loss, and flooding. The rainfall erosion index component of the Universal soil-loss equation tries to quantify the effects of rainfall events on soil loss. Rainfall erosion potential is greatly affected by rainfall intensity and less by amount of rainfall produced (Wischmeier, 1959). Since extreme storm events are occurring more frequently and with higher intensity, there is a need to provide some mitigation management tools to prevent excessive losses of sediment and nutrients from cropland.

In addition to soil quality declines associated with loss of topsoil, offsite nutrient transport also threatens surface water quality. Nutrients are lost in surface runoff in both dissolved and particulate form. Nitrogen fractions lost in surface runoff include NH_4^+ and NO_3^- (Ruiz Diaz, D.A. et al, 2010; and Pauer and Auer, 2000). Excessive nitrate concentrations in coastal waters lead to algal blooms that cause hypoxia, damaging coastal ecosystems (David et al., 2010 and Rabalais et al., 2001). Phosphorus (P) is a major contributing factor to eutrophication of fresh waters. In agricultural landscapes, manure and chemical fertilizers are major contributors to phosphorus buildup in the soil (Hart et al., 2004). Once phosphorus reaches excessive levels in the soil, the excess P can be a source for non-point pollution when water erosion occurs (Hart et al., 2004 and Sims et al., 1998). P lost in surface runoff can be quantified and reported as total dissolved phosphorus, total phosphorus, PO_4^-, and particulate phosphorus (He, et al, 2006). Sediment, when deposited in rivers and lakes through surface runoff can change the dynamics of water flow and ecosystems within those freshwater areas. Once sediment settles in rivers or lakes in large amounts, navigation can be affected, necessitating costly removal. Thus, a key component of climate change mitigation will involve actions to avoid these negative consequences of intense precipitation. Winter cover crops provide one potential tool.

Due to its cold tolerance, winter rye cover cropping is a suitable practice during dormant periods in corn-soybean cropping systems of the Upper Midwest. Winter rye is winter hardy, suppresses weeds, provides cover to minimize soil erosion and offsite transport of nutrients in surface runoff, and reduces nitrate leaching to ground water. Winter rye can also increase nitrogen use efficiency. The mechanism is twofold: winter rye helps to reduce soil erosion thus keeping the organic matter in the top soil, and also scavenges nitrate that would otherwise be lost through the system via leaching (Hively, 2009). A meta-analysis found a 70% average reduction in nitrate leaching when cover crops were used (Tonitto, 2006). Staver and Brinsfield found that winter rye reduced nitrogen loads by 80% in subsurface groundwater and in deeper aquifers under corn rotations (1998). In another study, winter rye cover crops reduced nitrate concentrations in Canadian groundwater by 70% (Ball Coelho, 2005). However, the uptake of nitrogen by winter rye is dependent upon both early establishment of winter rye in the fall and robust spring biomass accumulation (Hively, 2009 and Feyereisen, 2006).

Four studies were conducted to evaluate winter rye following soybeans, corn silage, and corn for grain (in the latter study aerially seeded winter rye was not successful in standing corn grain, so this became a corn stover management experiment). Two of the studies were small plot studies that utilized a rainfall simulator to simulate a 6.34 cm hr^{-1} storm event over a 60 minute period. The other two studies were field scale research in the form of paired watershed studies. One study evaluated surface runoff in a corn silage system where one watershed was conventional practices and the other was drilled with winter rye. The other study had unsuccessful establishment of winter rye using broadcasting seeding methods from a helicopter. This was converted into a corn stover management experiment where conventional no-till practices were used in one watershed and in the other watershed, corn stover was baled and removed.

Effect of Winter Rye Seeding Methods on Surface Runoff under a Simulated Rainfall Event

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Abstract

The potential for soil erosion following soybeans (*Glycine max L.*) is higher than after corn (*Zea mays L.*) for grain harvest in agricultural landscapes. Winter rye cover crops can provide plant cover to mitigate soil losses and can be established more easily following soybeans than corn for grain in the Upper Mississippi River Basin. The objective of this study was to evaluate winter rye (*Secale cereale* L.) seeding methods and their potential to minimize the effects of high rainfall rates on surface runoff and sediment and nutrient transport from agricultural landscapes by providing winter rye cover during the fall and spring dormant periods following soybean harvest. A simulated rainfall event of 6.34 cm hr^{-1} for 60 minutes was applied to rye and fallow treatments in fall 2010 and spring 2011 at the University of Minnesota Experimental Research Station in Rosemount, MN. Treatments were rye seeded by broadcast spreader, by airflow spreader, aerially by helicopter. Rye biomass accumulation was greatest in spring with broadcast seeding, followed by aerial, and airflow having the lowest. Rye provided 74, 78, 83% ground cover in the spring for aerial, airflow, and broadcast, respectively, compared to fallow, which had 49% cover. Winter fallow treatments produced the highest volumes of surface runoff, nutrient concentrations, and sediment losses in both the fall and spring compared to winter rye treatments. Compared with winter fallow, total surface runoff in the fall was reduced by 78, 96, and 63% in aerial, airflow, and broadcast treatments, respectively, and by 100, 96, and 97%

in the spring. NO_3-N losses in surface runoff in the fall were reduced by 80% for winter rye treatments however, no differences were observed. NO_3-N losses in surface runoff in the spring were reduced by 100, 96, and 97% in aerial, airflow, and broadcast treatments, respectively, compared with winter fallow. Compared with winter fallow, NH_4-N was reduced by 72, 53, and 53% in aerial, airflow, and broadcast treatments in the fall, respectively, and by 100, 100, and 99% in the spring. Total phosphorus was reduced by 86, 99, and 83% in aerial, airflow, and broadcast treatments in fall, respectively, and by 100, 98, and 98% in spring respectively, compared to fallow. Sediment was reduced by 78, 91, and 67% in aerial, airflow, and broadcast treatments in fall, respectively, and by 100, 97, and 98% in spring respectively, compared to fallow. This study shows that seeding winter rye into soybeans can reduce soil erosion and nutrient runoff in both fall and spring with spring having the greatest environmental benefits of additional cover.

Introduction

Corn and soybean acreage in Minnesota was estimated at 15 million acres from 2007 to 2012 (USDA). These two crops consist of about half the total farmed acres in Minnesota. Corn and soybean crop rotations have the potential to leach NO_3-N into rivers, streams, and lakes through overland flow and subsurface drainage. Winter cover crops provide nitrate retention through translocation of nitrogen during dormant periods. A meta-analysis found a 70% average reduction in nitrate leaching when cover crops were used (Tonitto, 2006). Staver and Brinsfield found that winter rye reduced nitrogen loads by 80% in subsurface groundwater and in deeper aquifers under corn rotations (1998).

Soil erosion during the dormant period is another concern with corn-soybean crop rotations, especially for the soybean part of the rotation. Soil erosion can increase by 35% after soybeans compared with corn for grain because of low residue production and faster decomposition of soybean residue (Laflen and Moldenhauer, 1979). Winter cover crops can provide the necessary erosion control after soybean harvest. A study by Kessavalou and Walters showed that ground cover increased by 30% when winter rye was planted after soybeans compared to just fallow (1997). The increase in ground cover minimized soil erosion potential before a corn canopy (corn-soybean rotation) could be established in early summer the following year.

Winter cover crops are sometimes challenging to establish after rowcrops in the Upper Midwest because of the short growing season. The early soybean harvest in Minnesota can make for a better window of time for getting such crops established, when compared with the later corn grain harvest. Soybean harvest in Minnesota usually occurs in late September and October during normal growing conditions, whereas, harvesting corn for grain can continue into November (USDA, 1997). Winter cover crops, especially winter rye, can be planted in late August to mid-September in Minnesota, when soybeans are showing 10% or more leaf yellowing or leaf drop. This provides adequate solar radiation for newly germinating winter rye seeds. Winter rye can be seeded into soybeans using several different methods. These methods of seeding include aerial application from airplane or helicopter, broadcast seeding from tractor, and seeding through a manure spreader. Timing of planting, seeding rates, method of seeding, and soil moisture play crucial roles in the success of establishing winter rye into soybeans in late August or September.

We hypothesized that a winter rye cover crop seeded into standing soybeans can reduce non-point source pollution through surface runoff and minimize soil erosion by adding additional surface cover along with soybean residue. The objective of this study was to evaluate winter rye seeding methods and their potential to minimize the effects of high rainfall rates on surface runoff, sediment and nutrient transport from agricultural landscapes by providing cover during the fall and spring dormant periods following soybean harvest.

Materials and Methods

Location Description, Date, and winter rye

The study was conducted on field I-10 at the University of Minnesota Outreach, Research and Education (UMore) Park located in Rosemount, MN (44.706^0 N, 93.067^0 W) on 2, 3, and 4 November 2010 and on 28, 29 April 2011 and 2 May 2011. In both fall and spring, simulations occurred on the same field, on land with a 3% slope. The soil series was Waukegan Silt Loam (fine-silty over sandy, mixed, superactive, mesic Typic Hapludolls) and Urban Land-Waukegan Complex (fine-silty over sandy, mixed, superactive, mesic Typic Hapludolls). This study consisted of four treatments with two replications in a completely randomized design. Originally there were three replications for each treatment; however, the third replication site was an outlier and had uncharacteristic winter rye stands and soil composition compared with the other two replications. For these reasons, only two replications were analyzed. The treatments were fallow, aerial, airflow, and broadcast. Winter rye cultivar "Rymin" was seeded at rates of 112 kg ha^{-1}, 112 kg ha^{-1}, 224 kg ha^{-1}, and 89 kg ha^{-1}, respectively; in strips across a 40 acre field using a bucket spinner attached to a helicopter, a Gandy airflow spreader attached to a tractor, a bucket spreader with spinning plate attached to a tractor, and drilled in 17.78 cm rows, respectively. Dates of seeding were 9 September 2010, 14 September 2010, 14 September 2010, and 14 October 2010, respectively. The target seeding rate for all treatments was meant to be 112 kg ha^{-1}; however, calibration of controlling rate for broadcast treatments was unsuccessful. These treatments were also used for a larger research study evaluating winter rye seeding rates on establishment of winter rye. Seeding rates will be a confounding factor for determining the effect of ground cover and biomass on surface runoff. Fallow treatments were prepared by chemical termination of rye in the drilled strips using glyphosate (Roundup Ready solution at a rate of 1 kg acid equivalent ha-1) soon after rye germination on 22 October 2010. The field management consisted of no-tilling practices. New fallow treatments had to be established prior to spring simulations since no-till practices were used in the larger field making previous fallow plots unusable. Additional chemical treatment of glyphosate occurred on 21 March 2011 to create fallow treatments. All winter rye treatments were terminated using glyphosate in late-May prior to corn silage planting.

Plot sizes were 4.8 m wide by 7.6 m long, with the longer side running down the slope. Galvanized steel sheets (1.52 m long by 0.152 m wide) were pounded 0.076 m into the ground to create treatment borders. A galvanized steel catchment (1.52 m long by 0.3048 m wide) was used to capture surface runoff, which drained though a pipe on the back end of the steel catchment. The rainfall simulations were conducted in the center of each treatment, leaving 0.9 m on each side of the treatments for access to the rainfall simulator. A Norton Ladder type Purdue Rainfall Simulator constructed by

Advanced Design and Machine (Clarks Hill, IN) was used to apply simulated rainfall. The simulator used a pressurized nozzle with an oscillating boom. Because time constraints prevented completion of all simulations in one day, simulations were spread over three days (2, 3, 4 November 2010 and 28, 29 April 2011 and 2 May 2011). UMore Park well water was hauled in tanks and used to perform the surface runoff experiment. Water was pumped from the reservoir to the simulator using a Honda 5000 generator (Honda Power Equipment, Alpharetta, GA) and septic water pump (Goulds Pumps, Seneca Falls, NY). Water was transferred to a polyvinyl chloride (PVC) manifold that transferred the water to three inlets on top of the rainfall simulator. The three inlets allowed the water to flow through six floodjet 3/8K SS45 nozzles (Spraying Systems Co. Wheaton, IL) that evenly dispersed the simulated rainfall to the different treatments.

Winter Rye Biomass Determination

Winter rye biomass was collected on 4 November 2010 and 2 May 2011 after rainfall simulations were conducted. Winter rye biomass yield was determined by harvesting an area of 0.25 m^3 three times for each treatment in a location adjacent to each treatment plot. Samples were dried at 65^0C for 72 h and dry matter was calculated. A subsample was ground, passed through a 1 mm sieve, and analyzed for total N (TKN), neutral detergent fiber, and phosphorus by wet analysis by Stearns DHIA Laboratories, Sauk Centre, MN.

Water Samples

Water samples were collected in 1 L polypropylene bottles (Teledyne ISCO Inc., Lincoln, NE) every 10 minutes after initial surface runoff occurred in each simulation.

Between samples, a bucket was used to collect all water to determine total surface runoff volume from the treatment. The water samples were immediately placed in a cooler with ice. Samples were filtered using a 0.2 μ filter with a non-surgical syringe (120 ml was filtered from each bottle) (VWR International, Chicago, IL). Filtered samples were analyzed for NO_3-N, NH_4-N, and dissolved reactive phosphorus (DRP) using a Quikchem 8500 Lachat Ion analyzer (Hach Company, Loveland, CO). Other filtered samples were analyzed for total dissolved phosphorus (TDP) (University of Minnesota Soil Testing Laboratory) using rapid flow analyzer (RFA) method with Alpkem RFA 300 (RFA, 1986 and Astoria-Pacific, Clackamas, OR). Unfiltered samples were analyzed for total suspended solids (TSS), sediment carbon, sediment nitrogen, and total phosphorus (TP). TSS was determined with ESS Method 340.2 (U.S. Environmental Protection Agency). TP analysis was performed by the University of Minnesota Soil Testing Laboratory using RFA method with Alpkem RFA 300 (RFA, 1986 and Astoria-Pacific, Clackamas, OR). Sediment carbon and sediment nitrogen were determined using Elementar Vario EL combustion analyzer (Elementar Americas, Inc., Mt. Laurel, NJ).

Soil Samples

On 4 November 2010 and 2 May 2011, soil samples were collected from the simulation treatments plots to a depth of 90 cm using a Giddings probe (5.08 cm diameter) mounted on a truck. One core was collected at the upslope, mid slope, and downslope positions of each treatment, for a total of three cores per treatment. These cores were subsampled by depth in the following increments: 0-15, 15-30, 30-60 and 60-90 cm, and composited by depth for each plot. Soil samples were subsampled (approximately 200 g per sample) for physical analysis and were dried at 105^{0}C to determine gravimetric water content and bulk density. The bulk of the soil sample was dried at 37^{0}C, ground through a <0.5 mm sieve, and analyzed for soil NO_3-N, NH_4-N, and Mehlich III P using a Quikchem 8500 Lachat Ion analyzer (Hach Company, Loveland, CO). Additional soil sampling to a depth of 0-15 cm was used to calculate antecedent soil moisture conditions at the time of rainfall simulations. There was no statistical difference in antecedent moisture between treatments. Average antecedent moisture was 0.20 for fall and 0.22 θg (gravimetric water content) for spring.

Ground Cover

Ground cover data were collected on 2 November 2010 and 28 April 2011. At the time of simulations, three digital photographs were taken of each treatment using a camera mounted on a stand facing downward at a height of 1.2 m. The photographs were analyzed using USDA Sample-Point Measurement Software 1.48 (Booth, 2006). This software allows for a 100-point grid to be placed over each photograph. Average ground cover is determined by visual observation at each point.

Calibration of Rainfall Simulator

The Rainfall Simulator was calibrated on 19 May 2010 and 19 May 2011. A control setting for field simulations was chosen to roughly represent a 5 cm hr^{-1} storm event, corresponding to a rain event with a 10-year return frequency in Rochester, MN. For these calibrations, 40 uniform jars were arranged between the simulator nozzles and under the simulator nozzles within one treatment. Rain intensity was determined from the volume of water collected in each jar and the duration of the event. Average rainfall rate using the jar method was 6.34 cm

hr^{-1} for both calibrations. Ten rain gauges were used in every treatment during rainfall simulations for comparison to the calibration used at the field. Average rain gauge measurement for 2010 was 5.60 cm and 5.85 cm for 2011.

Statistical Analysis

Data in the study were subjected to a two-way ANOVA (Rweb version 2.20.1., R core Team, 2009) and statistical significance was evaluated at the $p< 0.05$. In fall, there was no treatment effect for runoff, winter rye biomass, ground cover, soil nutrient concentrations (except for ammonium which was significant for depth), nutrient losses, and sediment. In spring, effect of treatment was statistically significant for runoff, nitrate losses, ammonium losses, sediment losses, and ground cover. There was no treatment effect in soil nutrient concentrations for spring. Interaction of Biomass and ground cover had an effect on runoff for spring but not in fall. Runoff had significant effect on NO_3-N losses, phosphorus losses and on sediment. Least significant difference (LSD) testing was used to observe differences between treatments. LSD test confidence interval of 0.05 was used throughout the analysis.

Results and Discussion

Rye Biomass, Ground Cover, Soil Composition

Ground cover provided by soybean residue decreased from fall to spring for all treatments because of residue decomposition. In the fallow treatment, ground cover from soybean residue decreased by 47% between fall and spring, where as winter rye treatments decreased by 16% (Table 1). Rye significantly increased ground cover compared with winter fallow for all treatments. Ground cover is important to preventing wind and water erosion in agricultural landscapes following soybean harvest in the

Upper Mississippi River Basin because of rapid decomposition of soybean residue during the dormant period.

Winter rye biomass accumulation was greater in spring than in fall. Between fall and spring, winter rye biomass increased by 83, 43, and 73% for aerial, airflow, and broadcast, respectively (Table 1). Differences in biomass accumulation may be due to differences in seeding methods. In airflow seeding it is essential to have higher airflows to control uniformity in seed distribution, however higher air flows can cause seed blowouts at the open end of the seeder causing decreased uniformity across the field. Controlling uniformity in seeding winter rye is essential to having successful seed distribution across the field.

Soil NO_3-N, NH_4-N and mehlich-III phosphate (MIII-P) did not vary by treatment for either fall or spring (Fig 1), and differences across time were not observed. NO_3-N concentrations decreased from fall to spring in all treatments. Fallow treatments were initially drilled winter rye that had chemical termination prior to simulations. Fall preparation of fallow treatments had winter rye terminated after germination, however spring termination of drilled winter rye for fallow treatment preparation occurred after snowmelt where winter rye plants had substantial growth. The presence of the rye is the reason for uptake of NO_3-N in the fallow treatments in the spring. Aerial and airflow treatments had decreased soil NO_3-N from fall to spring but broadcast treatments appeared the same. This implies that winter rye treatments did scavenge nitrate nitrogen between fall and spring. NH_4-N concentrations in fall were significantly different between depths. NH_4-N concentrations were greater in the 0 to 30 cm depth than the 30 to 90 cm depth.

Total Water Volume

In spring, winter rye treatments had 100, 96, 97% less runoff than fallow, respectively (Table 2). The aerial, airflow, and broadcast treatments produced less runoff than fallow in the spring but not in the fall (Table 2). No differences were observed in fall surface runoff. Differences in surface runoff were observed in spring, where fallow had the highest amount of runoff. Winter rye treatments were similar in runoff (Table 2). Presence of winter rye and increase of ground cover in winter rye treatments were the major contributing factors to decrease in runoff compared to fallow for spring simulations.

NO_3-N, NH_4-N, and Phosphorus loss in Surface Runoff

In both fall and spring, winter rye treatments reduced NO_3-N and NH_4-N losses in surface runoff compared to fallow. Reductions of NO_3-N and NH_4-N losses in winter rye treatments were greater in spring than fall simulations. For fall simulations, aerial, airflow and broadcast reduced nitrate-N losses by 81, 96, and 64% respectively compared to fallow (Table 3). Aerial, airflow, and broadcast were similar in reducing NO_3-N in fall, with fallow having the most NO_3-N loss. In the spring NO_3-N losses were reduced by 100, 96, and 97% for aerial, airflow, and broadcast, respectively compared to fallow (Table 3). NH_4-N losses followed similar pattern as NO_3-N losses for the spring, but no treatment effect was observed in the fall. In spring, NH_4-N losses were reduced by 100, 100, and 99%, in aerial, airflow, and broadcast, respectively, compared to fallow. Aerial, airflow, and broadcast were similar in reducing NH_4-N with fallow having the greatest loss of NH_4-N. Water was the driving force behind increases in NO_3-N and NH_4-N losses with greater amounts of runoff resulted in higher losses of

NO_3-N and NH_4-N. Concentrations of NO_3-N in runoff for all treatments ranged from 4.84 mg L^{-1} to 7.66 mg L^{-1} in fall. In spring, NO_3-N concentrations ranged from 6.11 mg L^{-1} to 8.96 mg L^{-1}. These concentrations are below the EPA water quality standard of 10 mg L^{-1} in drinking water (EPA 2012). This standard of 10 mg L^{-1} in drinking water was established to prevent human infant deaths caused by blue-baby syndrome. Blue-baby syndrome is an environmental-caused health disorder where the blood lacks the ability to carry enough oxygen to vital tissues and organs (Knobeloch et al., 2000).

Phosphorus losses followed a similar trend in terms of NO_3-N and NH_4-N losses for the four treatments. In the fall there was no difference in losses for any of the P fractions measured (Table 4). Differences were observed in spring loss of P with fallow having the highest loss of P for several measured P fractions, and no differences existing between rye seeding treatments (Table 4). Reduction in TP for spring was 100, 98, and 98% for aerial, airflow, and broadcast, respectively, compared to fallow. Broadcast, aerial, and airflow were similar in TP loss. Majority of P losses for all treatments were in the form of PP for both fall and spring where PP was 50 to 78% of total P lost in surface runoff (Table 4). This is not surprising since many soils in their natural state are low in dissolved phosphorus and majority of P lost in surface runoff come in the form of PP (Hart et al., 2004). Catchment studies conducted in New Zealand found that PP contributed 62 to 91% of total phosphorus fractions (Gillingham and Thorrold, 2000). Phosphorus losses were impacted by increase in runoff. Concentrations of TP in runoff for all treatments ranged from 0.13 mg L^{-1} to 0.22 mg L^{-1} in fall. In spring TP concentrations ranged from 0.15 mg L^{-1} to 0.22 mg L^{-1}. Phosphorus is the limiting nutrient for organisms in freshwater ecosystems, when in excess can cause eutrophication. Eutrophication accelerates when 0.025 mg L^{-1} is added to lakes and rivers (EPA). The maximum concentration of phosphorus in rivers is 0.1 mg L^{-1} and in lakes is 0.05 mg L^{-1} (EPA). The phosphorus in the runoff from the rainfall simulations is higher than the maximum recommendation for waterways; however, these concentrations came from the upland area of a field and were not directly running off into rivers or lakes. Phosphorus losses decrease with increased distance between field and waterways. Phosphorus losses can also decrease with additional buffer strips that would prevent sediment bound P or particulate phosphorus from reaching rivers or lakes (Dougherty et al, 2004).

Sediment Loss

In the fall sediment losses were reduced by 78, 91, and 67% in aerial, airflow, and broadcast respectively compared to fallow. In the spring reductions in sediment losses were 100, 97, and 98% for aerial, airflow, and broadcast, respectively compared to fallow (Table 5). In both fall and spring, differences were seen between treatments with fallow having the highest loads of sediment compared to winter rye treatments. Winter rye treatments in both fall and spring were similar to each other (Table 5). These differences in sediment loss between treatments is due to greater runoff totals from fallow for both fall and spring since sediment movement is caused by overland flow of water in this study and not by wind erosion, which is another factor causing translocation of top soil in agricultural landscapes. Since greater loss of sediment occurred in fallow, as expected, there was a greater loss of total N and total C compared to winter rye treatments (Table 5). Sediment losses were higher in fallow treatments for both fall and spring and majority of phosphorus loss was in the form of sediment bound phosphorus or particulate phosphorus (Table 4).

Conclusions

The potential for soil erosion following soybeans is higher than after corn for grain harvest in agricultural landscapes. Winter rye cover crops can provide plant cover to mitigate soil losses and can be established more easily following soybeans than corn for grain in the Upper Mississippi River Basin. The objective of this study was to evaluate winter rye seeding methods and their potential to minimize the effects of high rainfall rates on surface runoff, sediment and nutrient transport from agricultural landscapes by providing cover during the fall and spring dormant periods following soybean harvest. Regardless of seeding method, addition of winter rye following soybeans reduced surface runoff compared with winter fallow. With reduced runoff, nutrient and sediment losses were also reduced with the presence of winter rye when compared with winter fallow. Aerial reduced NO_3-N, NH_4-N, TP, and sediment by 81, 72, 86, and 78% in fall compared to fallow, respectively and had greater reductions in spring with 100% in all water quality parameters. Airflow reduced NO_3-N, NH_4-N, TP, and sediment by 96, 53, 99, and 91% in fall compared to fallow, respectively and had reductions in spring of 96, 100, 98, and 97%, respectively. Broadcast reduced NO_3-N, NH_4-N, TP, and sediment by 64, 53, 83, and 67% in fall compared to fallow, respectively and in spring had reductions of 97, 99, 98, and 98%, respectively. Soybean residue after harvest did provide enough ground cover to minimize surface runoff in fall for fallow treatments. After rapid decomposition of soybean residue, spring surface runoff was 95% greater than fall runoff in fallow, which is a concern for water quality and a reason to seed winter rye for protection from soil erosion during spring rainfall events. Establishing uniform stands of winter rye can be challenging depending on seeding method, date of planting, seeding rate, and environmental conditions that support winter rye germination and growth. Selecting the proper seeding method and rate can be costly to farmers that want to use this practice to provide environmental benefits. Broadcast has double the seeding rate of aerial and did not provide more environmental benefits with a higher seeding rate. This is a concern for farmers who do not need to be spending more money for establishing a cover crop when they can receive equal environmental benefits using a lower seeding rate.

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Tables and Figures

Table 1. Rye Dry Matter and Ground Cover

	Dry Matter		Ground Cover	
	Fall	Spring	Fall	Spring
Treatment	kg ha^{-1}		%	
Aerial	570c	3348b	87b	74b
Airflow	750b	1316c	97a	78ab
Broadcast	1295a	4798a	96a	83a
Fallow	0d	0d	93a	49c
LSD (0.05)	67	86	5	8
P value	0.30	0.03	0.15	0.04

† Differences were observed for winter rye biomass and ground cover for both fall and spring.

Table 2. Total surface runoff from simulated rainfall events

	Fall	**Spring**
Treatment	mm	mm
Aerial	0.11a	0.00b
Airflow	0.02a	0.47b
Broadcast	0.19a	0.31b
Fallow	0.51a	10.56a
LSD (0.05)	1.38	4.37
P value	0.35	0.03

† No differences were observed for fall surface runoff. Differences were found in spring runoff.

Table 3. Nitrate-N and Ammonium-N Losses in Runoff

	NO_3-N		NH_4-N	
	Fall	Spring*	Fall	Spring*
Treatment	mg		mg	
Aerial	5.54b	0.00b	0.09a	0.00b
Airflow	1.15b	24.25b	0.15a	0.00b
Broadcast	10.78b	16.70b	0.15a	0.09b
Fallow	29.77a	607.94a	0.32a	26.44a
LSD (0.05)	11.03	29.26	0.98	5.59
P value	0.40	0.01	0.38	0.01

† Nitrate-N and NH_4-N had statistical significance between treatments in spring and not in fall. Across fall and spring there was no statistical significance.

Table 4. Phosphorus Losses in Runoff†

	TP		PP		TDP		DIP		DOP	
	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring
Treatment					-------- mg --------					
Aerial	0.33a	0.00b	0.24a	0.00b	0.09a	0.00b	0.00a	0.00a	0.09a	0.00b
Airflow	0.02a	2.00b	0.01a	1.20b	0.01a	0.80b	0.00a	0.05a	0.01a	0.75b
Broadcast	0.41a	1.35b	0.32a	1.04b	0.09a	0.31b	0.01a	0.01a	0.08a	0.30b
Fallow	2.43a	87.94a	1.85a	64.43a	0.58a	23.51a	0.01a	0.51a	0.57a	23.00a
LSD (0.05)	3.31	13.61	2.87	11.03	1.63	7.97	0.28	1.47	1.65	7.84
P value	0.41	0.05	0.41	0.04	0.43	0.10	0.62	0.32	0.45	0.11

† No difference found for all phosphorus losses in fall or spring.

Table 5. Sediment Loss in Surface Runoff

Treatment	TSS		Total N		Total C	
	Fall	Spring*	Fall	Spring*	Fall	Spring*
			kg ha^{-1}			
Aerial	7.05b	0.00b	0.05a	0.00a	0.42a	0.00b
Airflow	2.98b	3.21b	0.02a	0.02a	0.15a	0.21b
Broadcast	10.66b	1.94b	0.07a	0.01a	0.61a	0.11b
Fallow	32.64a	115.77a	0.20a	0.36a	1.77a	4.38a
LSD (0.05)	10.71	17.55	0.89	0.79	2.65	2.87
P value	0.32	0.10	0.39	0.03	0.41	0.04

† TSS, TN, and TC had statistical significance between treatments in spring and not in fall. Across fall and spring there was no statistical significance between treatments.

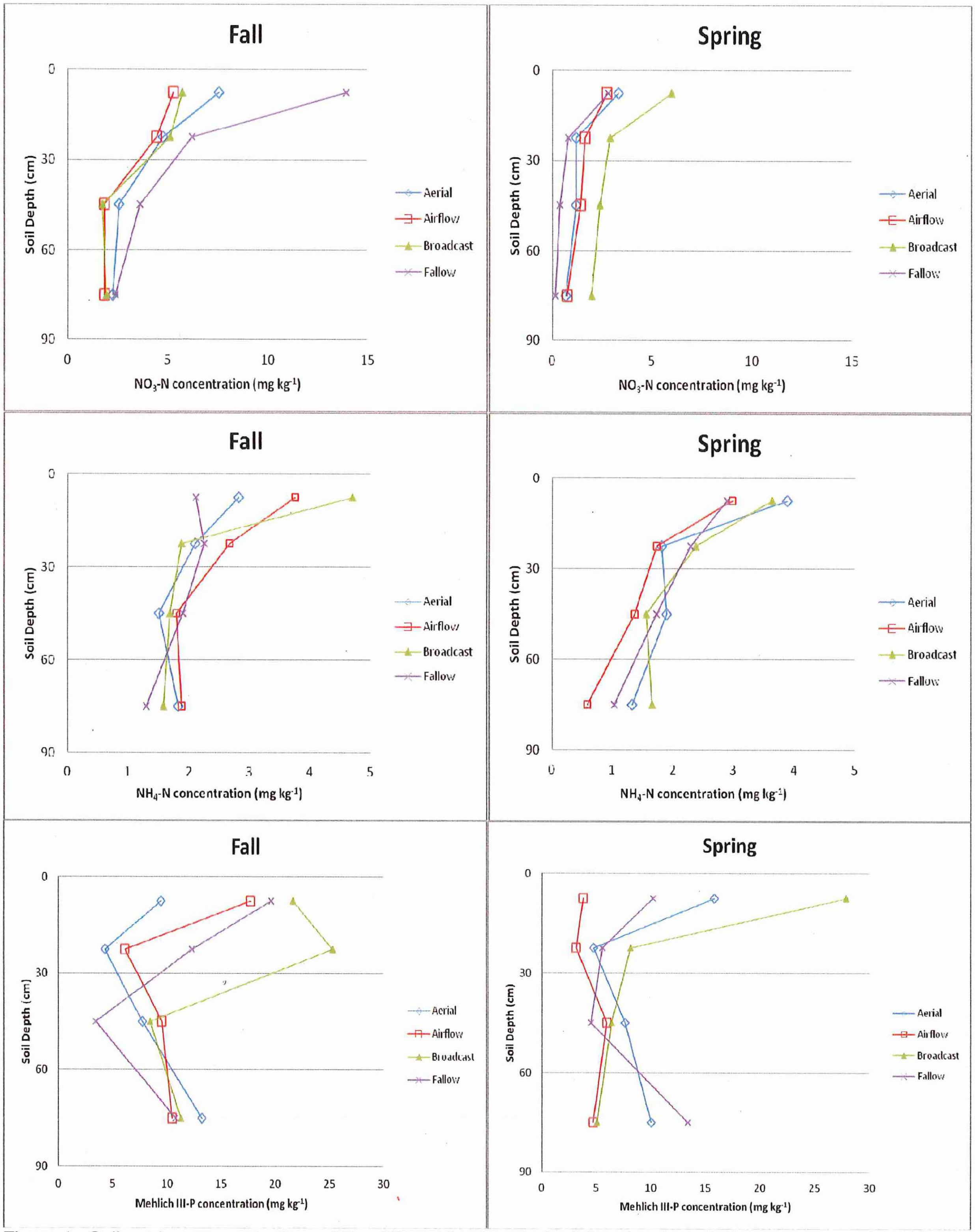

Figure 1. Soil nutrient concentrations of the different treatments for fall and spring. Soil cores were analyzed for NO_3-N, NH_4-N, and Mehlich III-P. Concentrations are reflected in the figure at the average point between sample increments. No differences were observed in fall or spring for soil concentrations of NO_3-N, NH_4-N, and Mehlich III-P.

ANOVA output: Sources of variation for fall data with confidence interval of 0.05.

Source of Effect	Total Runoff	Biomass	Ground Cover	Water NO_3-N
Treatment	NS	NS	NS	NS
Replication	NS	.	NS	NS
R	NS	NS	NS	NS
R x B	NS	NS	NS	NS
B x GC	NS	NS	NS	NS
Source of Effect	**Water NH_4-N**	**Water DIP**	**Water TP**	**Water PP**
Treatment	NS	NS	NS	NS
Replication	NS	NS	NS	NS
R	NS	NS	NS	NS
R x B	NS	NS	NS	NS
B x GC	NS	NS	NS	NS
Source of Effect	**Water TDP**	**Water DOP**	**TSS**	**Sediment TN**
Treatment	NS	NS	NS	NS
Replication	NS	NS	NS	NS
R	NS	NS	NS	NS
R x B	NS	NS	NS	NS
B x GC	NS	NS	NS	NS
Source of Effect	**Sediment TC**	**Soil NO3-N**	**Soil NH4-N**	**Soil Mehlich III-P**
Treatment	NS	NS	NS	NS
Replication	NS	**	*	NS
R	NS	NS	NS	NS
R x B	NS	NS	NS	NS
B x GC	NS	NS	NS	NS

ANOVA output: Sources of variation for spring data with confidence interval of 0.05.

Source of Effect	Total Runoff	Biomass	Ground Cover	Water NO_3-N
Treatment	*	.	*	*
Replication	NS	NS	NS	NS
R	**	NS	NS	*
R x B	*	NS	NS	.
B x GC	**	NS	NS	.
Source of Effect	**Water NH_4-N**	**Water DIP**	**Water TP**	**Water PP**
Treatment	*	NS	.	.
Replication	NS	NS	NS	NS
R	*	NS	NS	NS
R x B	.	NS	NS	NS
B x GC	.	NS	NS	NS
Source of Effect	**Water TDP**	**Water DOP**	**TSS**	**Sediment TN**
Treatment	NS	NS	.	*
Replication	NS	NS	NS	NS
R	NS	NS	**	**
R x B	NS	NS	.	.
B x GC	NS	NS	NS	NS
Source of Effect	**Sediment TC**	**Soil NO3-N**	**Soil NH4-N**	**Soil Mehlich III-P**
Treatment	.	***	.	NS
Replication	NS	***	***	NS
R	**	NS	NS	NS
R x B	.	NS	NS	NS
B x GC	NS	NS	NS	NS

Effects of Winter Rye on Surface Runoff under a Simulated Rainfall Event

Adam P. Herges, Erik S. Krueger, John M. Baker, Paul M. Porter, and Gary Feyeriesen

Abstract

Higher intensities and frequencies of rainfall events in the Upper Midwest, a predicted and observed manifestation of climate change, have the potential to cause significant damage to agricultural landscapes through soil erosion and transport of nutrients to waterways. The objective of this study was to evaluate the potential of a winter rye (*Secale cereale* L.) cover crop to minimize these effects by providing cover during the fall and spring dormant periods. A simulated rainfall event of 6.34 cm hr^{-1} for 60 minutes was applied to standing winter rye, harvested winter rye, and fallow treatments with four replications in spring 2010 and spring 2011 on a farm near Lewiston, MN. Fallow treatments produced the highest volume of surface runoff, nutrient and sediment loads compared to winter rye treatments. Total surface runoff from fallow was 11.36 mm and 15.55 mm for 2010 and 2011, respectively; compared to 0.06 mm, 5.13 mm, 0.03 mm, and 12.62 mm for standing rye and harvested rye treatments for 2010 and 2011, respectively. Nutrient and sediment loads follow similar trends to total surface runoff for each year. In 2010 and 2011, NO3-N losses were reduced by 99% and 68% for standing rye and 99% and 19% for harvested rye compared to fallow, respectively. NH4-N losses were reduced by 96% and 80% in 2010 and 2011 for standing rye and 96% and 52% for harvested rye compared to fallow. Dissolved phosphorus losses were reduced by 99% and 76% in 2010 and 2011 for standing rye compared to fallow. Dissolved phosphorus losses were reduced by 98% in 2010 for harvested rye compared to fallow but increased by 1% in 2011. Sediment load

was reduced by 99% and 92% in 2010 and 2011 for standing rye and 99% and 68% for harvested rye compared to fallow. We conclude that winter rye planted in fall will help to prevent surface runoff, soil erosion, and offsite nutrient transport relative to fallow in the fall and spring in the Upper Mississippi Basin.

Introduction

Climate change has been a major focus within the scientific community in recent decades. Increases in atmospheric carbon dioxide and other greenhouse gases have resulted in rising mean global surface temperatures, which have been coupled with an increase in mean atmospheric water vapor (Frei et al, 1998). This has coincided with a higher frequency and intensity of storm events throughout the contiguous U.S. A century ago, the most extreme storms contributed only 1% of total annual rainfall. Now extreme storms contribute 20% of total rainfall in the continental U.S. while total precipitation has only increased by 7% over the past century (Rosenzweig et al, 2000). Heavy and intense rainfall can be devastating to cropland because of induced soil erosion, nutrient loss, and flooding. The rainfall erosion index component of the Universal soil-loss equation tries to quantify the effects of rainfall events on soil loss. Rainfall erosion potential is greatly affected by rainfall intensity and less by amount of rainfall produced (Wischmeier, 1959). Since extreme storm events are occurring more frequently and with higher intensity, there is a need to provide some mitigation management tools to prevent excessive losses of sediment and nutrients from cropland.

In addition to soil quality declines associated with loss of topsoil, offsite nutrient transport also threatens surface water quality. Nutrients are lost in surface runoff in both dissolved and particulate form. Nitrogen fractions lost in surface runoff include

NH_4^+ and NO_3^- (Ruiz Diaz, D.A. et al, 2010; and Pauer and Auer, 2000). Excessive nitrate concentrations in coastal waters lead to algal blooms that cause hypoxia, damaging coastal ecosystems (David et al., 2010 and Rabalais et al., 2001). Phosphorus (P) is a major contributing factor to eutrophication of fresh waters. In agricultural landscapes, manure and chemical fertilizers are major contributors to phosphorus buildup in the soil (Hart et al., 2004). Once phosphorus reaches excessive levels in the soil, the excess P can be a source for non-point pollution when water erosion occurs (Hart et al., 2004 and Sims et al., 1998). P lost in surface runoff can be quantified and reported as total dissolved phosphorus, total phosphorus, PO_4^-, and particulate phosphorus (He, Z.L. et al, 2006). Sediment, when deposited in rivers and lakes through surface runoff can change the dynamics of water flow and ecosystems within those freshwater areas. Once sediment settles in rivers or lakes in large amounts, navigation can be affected, necessitating costly removal. Thus, a key component of climate change mitigation will involve actions to avoid these negative consequences of intense precipitation. Winter cover crops provide one potential tool.

Due to its cold tolerance, winter rye is an appropriate cover crop following corn (*Zea mays* L.) silage in the Upper Midwest (Krueger et al., 2012). Winter rye can also increase nitrogen use efficiency. The mechanism is twofold: winter rye helps to reduce soil erosion thus keeping the organic matter in the top soil, and also scavenges nitrate that would otherwise be lost through the system through leaching (Hively, 2009). A meta-analysis found a 70% average reduction in nitrate leaching when cover crops were used (Tonitto, 2006). Staver and Brinsfield found that winter rye reduced nitrogen loads by 80% in subsurface groundwater and in deeper aquifers under corn rotations

(1998). In another study, winter rye cover crops reduced nitrate concentrations in Canadian groundwater by 70% (Ball Coelho, 2005). However, the uptake of nitrogen by winter rye is dependent upon both early establishment of winter rye in the fall and robust spring biomass accumulation (Hively, 2009 and Feyereisen, 2006).

We hypothesized that the use of a winter rye cover crop planted after corn silage harvest can reduce non-point source pollution through surface runoff compared to conventional corn silage management. The objective of this study was to evaluate the potential of a winter rye cover crop to minimize the effects of high rainfall rates on surface runoff and sediment and nutrient transport from agricultural landscapes by providing cover during the fall and spring dormant periods. Since many farmers prefer to harvest winter rye for forage, we evaluated both standing and harvested rye.

Materials and Methods

Location Description, Date, and winter rye

The study was conducted on a farm located near Lewiston, MN (43.969^0 N, 91.776^0 W) in 2010 and 2011. Each year, simulations occurred on different adjacent fields on a Seaton silt loam (Fine-silty, mixed, superactive, mesic Typic Hapludalfs) with a 3% slope. This study consisted of three treatments with four replications in a completely randomized design (fig. 1). The treatment plots were situated on the upland portion of the field where there was a straight downward slope of 3 % across an area that would fit all of the 12 randomized treatments. Treatments were winter fallow after corn silage, standing winter rye, and harvested winter rye (winter rye was cut at 10.16 cm above ground using a scythe and removed from the field). Winter rye (cv. "Rymin") was seeded over the entire experimental area on 28 September 2009 and 15 October

2010 at a rate of 101 kg ha^{-1} following corn silage using a grain drill with 17.78 cm row spacing. Fallow treatments were prepared by chemical termination of rye using glyphosate (at a rate of 1 kg acid equivalent ha^{-1}) soon after rye germination on 15 October 2009 and 20 October 2010. For 2011 rainfall simulations, fallow treatments required an additional application of glyphosate on 30 March. All winter rye treatments were terminated using glyphosate after rainfall simulations in mid-May prior to corn silage planting.

Treatment plots were 4.8 m wide by 7.6 m long, with the longer side running down the slope. Galvanized steel sheets (1.52 m long by 0.152 m wide) were pounded 0.076 m into the ground to create treatment borders. A galvanized steel catchment (1.52 m long by 0.3048 m wide) was used to capture surface runoff. The rainfall simulations were conducted in the center of the treatment, leaving 0.9 m on each side of the treatments for access to the rainfall simulator. A Norton Ladder type Purdue Rainfall Simulator constructed by Advanced Design and Machine (Clarks Hill, Indiana) was used for the study. This was a pressurized nozzle type simulator with an oscillating boom. Because time constraints prevented completion of all simulations in one day, two simulations for each treatment were preformed per day (18 and 19 May 2010, 18 and 19 May 2011). City of Lewiston treated water was hauled in tanks and used to perform the surface runoff experiment. Water was pumped from the reservoir to the simulator using a Honda 5000 generator (Honda Power Equipment, Alpharetta, GA) and septic water pump (Goulds Pumps, Seneca Falls, NY). From the pump, water was transferred to a Polyvinyl chloride (PVC) manifold that then transferred the water to the three inlets on top of the rainfall simulator. The three inlets allowed the water to flow through six floodjet 3/8K SS45 nozzles (Spraying Systems Co. Wheaton, IL) that evenly dispersed the simulated rainfall to the different treatments.

Calibration of Rainfall Simulator

The Rainfall Simulator was calibrated on 19 May 2010 and 19 May 2011 after rainfall simulations were completed. A control setting was chosen for field simulations that approximately represented a 5 cm hr^{-1} storm event, corresponding to a rain event with a 10 year return frequency for Rochester, MN. For these calibrations, 40 uniform jars were arranged between and under nozzles within each plot. Rain intensity was determined from the volume of water collected in each jar and the duration of the event. Average rainfall rate using the jar method was 6.34 cm hr^{-1} for both calibrations. Ten rain gauges were used in each plot during rainfall simulations for comparison to the calibration used at the field. Average rain gauge measurement for 2010 was 6.09 cm and 5.95 cm for 2011.

Winter Rye Biomass Determination

Winter rye biomass was collected on 17 May 2010 and 17 May 2011 prior to rainfall simulations. Harvested rye treatments were established by cutting the rye to a height of 10 cm above ground and removing the clipped biomass. Biomass yield was determined by harvesting an area of 0.53 m^3 twice in each treatment. Samples were dried at 65^0C for 72 h prior to weighing. A subsample was ground, passed through a 1 mm sieve, and analyzed for total N (TKN), neutral detergent fiber and phosphorus by wet analysis by Stearns DHIA Laboratories, Sauk Centre, MN.

Water Samples

Water samples were collected in 1 L polypropylene bottles (Teledyne ISCO Inc., Lincoln, NE) every 10 minutes after initial surface runoff occurred in each simulated treatment experiment. Between samples, a bucket was used to collect all water to determine total surface runoff volume from the treatment. Water samples were immediately placed on ice in a cooler and subsequently filtered using a 0.2 micron filter (VWR International, Chicago, IL) with a non-surgical syringe (120 mL was filtered from each bottle). Filtered samples were analyzed for NO_3-N, NH_4-N, and dissolved reactive Phosphorus using a Quikchem 8500 Lachat Ion analyzer (Hach Company, Loveland, CO). Total dissolved phosphorus was determined for filtered samples (University of Minnesota Soil Testing Laboratory) using RFA method with Alpkem RFA 300 (RFA, 1986 and Astoria-Pacific, Clackamas, OR). Unfiltered samples were analyzed for Total Suspended Solids (TSS), Sediment Carbon, Sediment Nitrogen, and Total Phosphorus (TP). TSS was determined with ESS Method 340.2 (Environmental Protection Agency, US). TP analysis was performed by the University of Minnesota Soil Testing Labortory using RFA method with Alpkem RFA 300 (RFA, 1986 and Astoria-Pacific, Clackamas, OR). Sediment carbon and sediment nitrogen were determined using Elementar Vario EL combustion analyzer (Elementar Americas, Inc., Mt. Laurel, NJ).

Soil Samples

On 18 and 19 May 2010, soil samples were collected from the simulation treatments to a depth of 90 cm using a rotary hammer equipped with a 23 mm diameter probe. One core was collected at the upslope, mid slope, and downslope positions of each plot for a total of 3 cores per plot. Cores were subsampled by depth in the following increments: 0-15, 15-30, 30-60 and 60-90 cm, and composited by depth for each treatment. Soil samples were sub-sampled (approximately 200 grams per sample) for physical analysis and were dried at 105^{0}C to determine gravimetric water content and bulk density. Antecedent soil moisture for depth of 0-15 cm was 0.25, 0.28, and 0.25 for standing rye, harvested rye, and fallow, respectively for 2010. For 2011, antecedent soil moisture was 0.22, 0.24, and 0.24 for standing rye, harvested rye, and fallow, respectively. There was no statistical different between treatments and years for antecedent soil moisture. The bulk of the soil sample was dried at 37^{0}C, ground through <0.5 mm sieve, and analyzed for soil NO_3-N, NH_4-N, and Mehlich III P using a Quikchem 8500 Lachat Ion analyzer (Hach Company, Loveland, CO). Additional soil sampling to a depth of 0 – 15 cm was used to calculate antecedent soil moisture conditions at the time of rainfall simulations (Table 1). On 17 May 2011, soil samples were collected adjacent to each simulation treatments to a depth of 90 cm using a Giddings probe mounted on a truck (5.08 cm diameter). The same sampling protocol and analysis were followed as in 2010.

Ground Cover

Photographs for ground cover determination were collected on 17 May 2010 and 17 May 2011. At the time of simulations, three digital photographs were taken in each treatment using a camera mounted on a stand facing downward at a height of 1.2 m. The photographs were analyzed using USDA Sample-Point Measurement Software 1.48 (Booth, 2006). This software allows for an overlay of a 100-point grid to be placed over each photograph. Ground cover was determined by visual observation at each point on the 100-point grid overlay.

Results and Discussion

Rye Biomass, Ground Cover, Soil Composition

Standing rye and harvested rye had a 77.5 % and 73% increase in ground cover compared to fallow treatments in 2010, respectively. In 2011 standing rye and harvested rye treatments were 71.2% and 57.3% greater in ground cover than fallow, respectively (Table 1). Differences between treatments were observed in both 2010 and 2011 for ground cover and winter rye biomass. Rye biomass in the standing rye treatments was greater in 2010 than 2011 because planting occurred earlier in fall 2009 than in fall 2010. The harvested rye ground cover measurements were higher than a similar Minnesota study where after harvesting winter rye there was "at least 30% ground cover" before corn planting in the spring (Krueger et al., 2012). Not surprisingly, there is a positive correlation between winter rye biomass and ground cover percentages (Table 1). Rye biomass and ground cover aid in the prevention of soil erosion in agricultural landscapes. Both standing biomass and ground cover act as buffers to the impact of rain drops that hit the soil surface and can also impede surface water that moves laterally over land surfaces. Surface water that moves laterally over soil surfaces can accumulate and form concentrated flows or channels that sometimes can cause gullies (Reicosky and Forcella, 1998).

In 2010, soil NO_3-N concentrations were reduced by 64% and 61% after standing rye and harvested rye compared to fallow treatments (Fig. 1). Winter rye did not impact soil NH4-N or mehlich-III phosphate for either 2010 or 2011. This suggests that the winter rye effectively scavenged excess soil NO3-N during the spring. However, in 2011 there was little difference in NO_3-N among treatments, possibly resulting from later rye planting and incomplete rye termination in 2010. Reduction in NO_3-N by winter rye varies across soil types and rotations. On a research station in western Minnesota, winter rye reduced soil nitrate by 43 to 47% on silt loam soil following corn (Krueger et al. 2011). In Nebraska, winter rye reduced NO3-N by 18 to 33% following soybean on a silty clay loam soil (Kessavalou and Walters, 1999). Concerns of available soil N following termination of winter rye is a main factor affecting subsequent corn crop. Additional nitrogen fertilizing such as side-dressing nitrogen is a potential solution to providing adequate soil N in early development of subsequent crop (Kuo and Jellum, 2002).

Total Water Volume

The standing rye and harvested rye treatments for both years produced less surface runoff when compared to fallow treatments. Differences in runoff were significant for both years (Table 2). The reduction in runoff volume with rye compared with fallow was greater in 2010, primarily due to greater ground cover and total winter rye biomass than in spring 2011 (Table 2). In 2010, runoff was reduced by 99% for both standing rye and harvested rye compared to fallow. In 2011, runoff was reduced by 67% and 19% for standing rye and harvested rye, respectively, compared to fallow (Table 2). The difference in total volume of surface runoff between years was likely more attributable to differences in biomass and ground cover than to differences in antecedent rainfall. Rainfall was similar each year for the six week period before rainfall simulations, with precipitation totaling 15.2 and 14.5 cm in 2010 and 2011, respectively. Rye biomass and ground cover were lower in 2010 than 2011. These results are consistent with previous reports of increasing runoff and erosion associated with decreases in ground cover and canopy cover (Nearing et al., 2005).

NO_3-N, NH_4-N, and P loss in Surface Runoff

In both years, NO_3-N and NH_4-N losses from fallow treatments were substantially greater than from standing rye and harvested rye treatments (Table 4). NO_3-N was reduced by 99% for both standing rye and harvested rye compared to fallow in 2010. In 2011, NO_3-N was reduced by 68% and 19% for standing rye and harvested rye, respectively, compared to fallow (Table 3). Differences were found in both years for NO_3-N between treatments with standing rye having a higher reduction of NO_3-N than harvested rye when compared to fallow. NH_4-N was reduced in both years by winter rye treatments compared to fallow which had the highest loss of NH_4-N. In 2010, NH_4-N was reduced by 97% and 96% for standing rye and harvested rye, respectively, compared to fallow. In 2011, reductions in NH_4-N were 80% and 50% for standing rye and harvested rye, respectively, compared to fallow (Table 3). Similar to NO_3-N losses, standing rye provided the greatest reduction for both years in NH_4-N than harvested rye. The 2011 simulations had higher nutrient losses than 2010 because there was more runoff in every treatment compared to 2010. Concentrations of NO_3-N in runoff for all treatments ranged from 1.05 mg L^{-1} to 7.58 mg L^{-1} in fall. In spring, NO_3-N concentrations ranged from 5.10 mg L^{-1} to 5.65 mg L^{-1}. These concentrations are below the EPA water quality standard of 10 mg L^{-1} in drinking water (EPA 2012). This standard of 10 mg L^{-1} in drinking water was established to prevent human infant deaths caused by blue-baby syndrome. Blue-baby syndrome is an environmental-caused health disorder where the blood lacks the ability to carry enough oxygen to vital tissues and organs (Knobeloch et al., 2000).

Phosphorus losses followed similar pattern as NO_3-N and NH_4-N losses, with standing rye having the lowest phosphorus loss, followed by harvested rye and fallow having the highest losses of phosphorus. In 2010, total phosphorus (TP) and total dissolved phosphorus (TDP) was reduced by 99% in both standing rye and harvested rye compared to fallow. In 2011, TP was reduced by 77% and 27% for standing rye and harvested rye, respectively, compared to fallow (Table 4). TDP was reduced by 67% in standing rye compared to fallow in 2011. Harvested rye had higher TDP and dissolved inorganic phosphorus (DIP or dissolved reactive phosphorus or Ortho-P) than fallow in 2011, suggesting that there was P loss from the winter rye tissue on the surface (Hart et al., 2004) (Table 4). Concentrations of TP in runoff for all treatments ranged from 0 mg L^{-1} to 1.22 mg L^{-1} in 2010. In 2011 TP concentrations ranged from 0.20 mg L^{-1} to 7.06 mg L^{-1}. Phosphorus is the limiting nutrient for organisms in freshwater ecosystems, when in excess can cause eutrophication. Eutrophication accelerates when 0.025 mg L^{-1} is added to lakes and rivers (EPA). The maximum concentration of phosphorus in rivers is 0.1 mg L^{-1} and in lakes is 0.05 mg L^{-1} (EPA). The phosphorus in the runoff from the rainfall simulations is higher than the maximum recommendation for waterways; however, these concentrations came from the upland area of a field and were not directly running off into rivers or lakes. Phosphorus losses decrease with increased distance between field and waterways. Phosphorus losses can also decrease with additional buffer strips that would prevent sediment bound P or particulate phosphorus from reaching rivers or lakes (Dougherty et al, 2004).

Sediment Loss

Sediment loads in winter rye treatments was greater in 2011 than 2010 due to the higher runoff totals in all treatments, however, fallow had greater sediment loss in 2010 than 2011. Sediment loss from fallow treatments in both years was greater than standing rye and harvested rye treatments. In 2010, sediment loss was reduced by 99% in both standing rye and harvested rye compared to fallow. In 2011, sediment was reduced by 92% and 68% in standing rye and harvested rye, respectively, compared to fallow (Table 5). Total nitrogen (N) and Total carbon (C) show the same trend as sediment across the treatments, where fallow treatments had higher sediment, total N, and total C loads compared to winter rye treatments. As expected, greater surface runoff produced higher loads of sediment (Table 5).

Statistical Analysis

Data in the study were subjected to a two-way ANOVA (Rweb version 2.20.1., R core Team, 2009) and statistical significance was evaluated at the $p< 0.05$. In 2010, statistical differences were observed in runoff, winter rye biomass, ground cover, NO_3-N, NH_4-N, dissolved inorganic phosphorus, total phosphorus, total dissolved phosphorus, dissolved organic phosphorus, total suspended solids, sediment total nitrogen, sediment total carbon, and soil NO_3-N. Runoff had significant effect on NO_3-N, NH_4-N, and dissolved inorganic phosphorus for 2010. In 2011, statistical differences were found in runoff, winter rye biomass, ground cover, NO_3-N, NH_4-N, dissolved inorganic phosphorus, total dissolved phosphorus, total suspended solids, sediment total nitrogen, and sediment total carbon. Runoff had significant effect on NO_3-N. Biomass and runoff interaction also had an effect on NO_3-N. All other measurements not mentioned did not have any statistical differences. Least significant difference (LSD) testing was used to observe differences between treatments. LSD test confidence interval of 0.05 was used throughout the analysis.

Conclusions

Winter rye, both standing and clipped, reduced runoff in both years. In 2010, runoff was reduced by 99% for both standing rye and harvested rye compared to fallow. In 2011, runoff was reduced by 67% and 19% for standing rye and harvested rye, respectively, compared to fallow. As a consequence, nutrient and sediment loads were also reduced compared to the fallow treatments. With increasing precipitation projected for the future, providing some plant cover or residue cover will be a key component in preserving soil quality and soil health of our agricultural lands. We conclude that a winter rye cover crop on the landscape during the dormant seasons can aid in reducing runoff into rivers, lakes, or streams. Of course many other factors affect the transport of water across an agricultural field, e.g. – soil hydraulic conductivity, water holding capacity, topography, and tillage practices.

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Tables and Figures

Table 1. Dry Matter and Ground Cover for 2010 and 2011

	Dry Matter		Ground Cover	
	2010	2011	2010	2011
Treatment	(Kg/ha)		%	
Standing Rye	5872a	4096a	95.8a	85.5a
Harvested Rye	1434b	1205b	91.3b	71.6b
Fallow	0c	0c	18.3c	14.3c
LSD (0.05)	44.39	51.68	2.71	3.21
P value	<0.0000	0.001	<0.0000	<0.0000

Differences were observed in both 2010 and 2011 for winter rye biomass and ground cover.

Table 2. Total Surface Runoff for 2010 and 2011

	Runoff	
	2010	2011
Treatment	- - - - - - - - mm - - - - - - -	
Standing Rye	0.06b	5.13c
Harvested Rye	0.03b	12.62b
Fallow	11.36a	15.55a
LSD (0.05)	1.56	2.52
P value	<0.0000	0.0006

Differences were observed in both 2010 and 2011 for total surface runoff.

Table 3. Nitrate-N and Ammonium-N Losses in Runoff for 2010 and 2011

	NO_3-N		NH_4-N	
	2010	2011	2010	2011
Treatment	mg		mg	
Standing Rye	1.91b	228.59c	0.76b	12.45c
Harvested Rye	1.06b	574.89b	1.03b	30.87b
Fallow	514.02a	710.01a	23.81a	62.32a
LSD (0.05)	9.89	16.74	2.84	6.23
P value	<0.0000	0.0004	<0.0000	0.0037

Differences were observed in both 2010 and 2011 for NO_3-N and NH_4-N.

Table 4. Phosphorus Losses in Runoff for 2010 and 2011

	TP		TDP		DIP		DOP	
	2010	2011	2010	2011	2010	2011	2010	2011
Treatment	mg		mg		mg		mg	
Standing Rye	0.07b	23.53c	0.21b	31.14b	0.12b	17.55b	0.09b	13.59b
Harvested Rye	0.16b	76.66b	0.196b	96.25a	0.12b	72.42a	0.08b	28.83a
Fallow	43.23a	104.36a	53.61a	94.44a	49.09a	71.26a	4.52a	23.19a
LSD (0.05)	5.62	11.06	4.188	6.56	4.29	5.23	1.89	4.93
P value	0.001	0.103	<0.0000	0.0005	<0.0000	<0.0000	0.0019	0.2852

Differences were observed in 2010 for total phosphorus, total dissolved phosphorus, dissolved inorganic phosphorus, and dissolved organic phosphorus. In 2011, differences were observed in total dissolved phosphorus, and dissolved inorganic phosphorus. No differences were found in total phosphorus and dissolved organic phosphorus.

Table 5. Sediment loss in surface runoff for 2010 and 2011

	TSS		Total N Loss		Total C loss	
	2010	2011	2010	2011	2010	2011
Treatment			------- kg ha^{-1} ------			
Standing Rye	3.97b	51.60c	0.05b	1.23c	0.34b	10.88c
Harvested Rye	1.25b	220.15b	0.004b	5.43b	0.03b	44.08b
Fallow	1359.16a	683.85a	37.07a	16.77a	312.64a	142.52a
LSD (0.05)	23.30	13.38	4.28	2.08	12	5.86
P value	<0.0000	<0.0000	0.0002	<0.0000	0.0001	<0.0000

Differences were observed in both 2010 and 2011 for total suspended solids, sediment total nitrogen, and sediment total carbon.

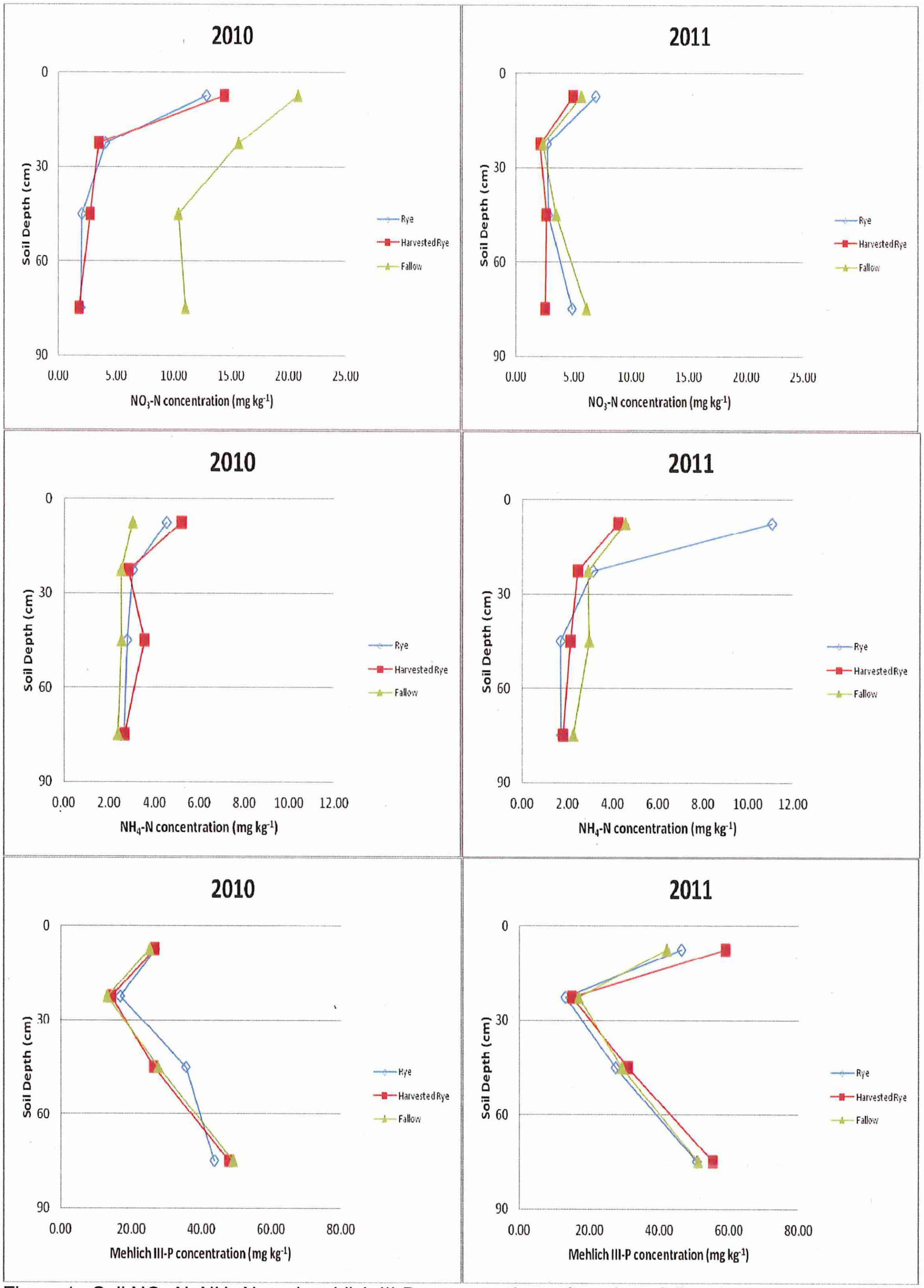


Figure 1. Soil NO_3-N, NH_4-N, and mehlich III-P concentrations after winter fallow, harvest rye, and standing rye for 2010 and 2011 near Lewiston Minnesota. Concentrations are reflected in the figure at the average point between sample increments. Differences were observed in soil NO_3-N for 2010 but not for 2011. No differences were observed in soil NH_4-N and mehlich III-P for either 2010 or 2011.

ANOVA output: Sources of variation for 2010 data with confidence interval of 0.05.

Source of Effect	Total Runoff	Biomass	Ground Cover	Water NO_3-N	Water NH_4-N
Treatment	***	***	***	***	***
Replication	NS	NS	NS	NS	NS
R		NS	NS	***	***
R X B	NS	NS	NS	NS	NS

Source of Effect	Water DIP	Water TP	Water TDP	Water DOP	TSS
Treatment	***	***	***	***	***
Replication	NS	NS	NS	NS	NS
R	***	NS	NS	NS	NS
R X B	NS	NS	NS	NS	NS

Source of Effect	Sediment TN	Sediment TC	Soil NO_3-N	Soil NH_4-N	Soil Mehlich III-P
Treatment	**	***	***	.	NS
Replication	NS	NS	***	*	***
R	NS	NS	NS	NS	NS
R X B	NS	NS	NS	NS	NS

ANOVA output: Sources of variation for 2011 data with confidence interval of 0.05.

Source of Effect	Total Runoff	Biomass	Ground Cover	Water NO_3-N	Water NH_4-N
Treatment	**	**	***	**	**
Replication	NS	NS	NS	NS	NS
R	**	NS	NS	***	NS
R X B	NS	NS	NS	***	NS
Source of Effect	**Water DIP**	**Water TP**	**Water TDP**	**Water DOP**	**TSS**
Treatment	***	.	***	NS	***
Replication	*	NS	NS	NS	NS
R	NS	NS	NS	NS	NS
R X B	.	NS	NS	NS	NS
Source of Effect	**Sediment TN**	**Sediment TC**	**Soil NO_3-N**	**Soil NH_4-N**	**Soil Mehlich III-P**
Treatment	***	***	NS	NS	NS
Replication	NS	NS	*	.	***
R	NS	NS	NS	NS	NS
R X B	NS	NS	NS	NS	NS

Effect of Removed Corn Stover on Surface Runoff in a Paired Watershed

Adam P. Herges, Erik S. Krueger, John M. Baker, Paul M. Porter, and Gary Feyeriesen

Abstract

Removal of corn (*Zea mays L.*) stover for 2nd generation biofuel production, animal bedding, or feed can have detrimental impacts on water quality. H-flumes with ISCO portable samplers and bubbler flow meters were used to monitor surface water runoff from a no-till corn grain-soybean rotation (control) and in a no-till corn grain-soybean rotation with removal of corn stover (treatment) from 2010 to 2012 in a paired watershed design. Baseline comparisons in the first year showed that the control watershed (because of larger size) had more surface runoff than the treatment watershed, but both had similar soil characteristics. Experimental year data (2011) showed that removal of corn stover increased surface runoff by 30% compared to no-till conventional practices. Water quality parameters in surface runoff (NO_3-N, NH_4-N, phosphorus and sediment) were not evaluated in 2011 due to sampler malfunction during runoff events (major event for 2011 was spring snowmelt). Indications from 2010 surface runoff sample collections showed that nutrient and sediment would have increased in 2011 because of increased volume of surface runoff. Removal of corn stover will have implications in maintaining reduced soil erosion risks associated with no-till conventional practices and will negatively impact water quality.

Introduction

Corn stover is a viable biofuel feedstock for 2nd generation (cellulosic) biofuel production that could reduce fossil fuel consumption and CO_2 emissions (Blanco-

Canqui et al., 2006). Harvesting corn stover technologies are well advanced and as cellulosic biofuel demand increases, demand for corn stover is also expected to increase. This may have adverse effects on soil quality and health with increased risk of soil erosion on corn-based agricultural land. Corn residues left after harvest are vital to environmental protection of water resources for most of the US Corn Belt. These residues if removed for biofuel production could increase soil erosion and offsite transport of nutrients into rivers, streams, and lakes. Removal of corn residue at excessive rates can influence changes at the soil surface particularly crusting and surface sealing (Blanco-Canqui et al., 2006). Crust layers are thin compared to other soil layers but are dense and have low permeability which affects soil infiltration and increase surface runoff (USDA-NRCS, 1996). Corn residue also minimizes raindrop impact that causes dispersion of surface aggregates. Several studies evaluated different rates of corn stover removal and their impact on maintaining residue requirements to reduce soil erosion risks. Thomas et al. found that removal of corn stover at rates of 38, 52.5, and 70% all statistically increase annual soil erosion (2011). However, removal of corn stover to maintain residue requirements to reduce soil erosion risks should be site specific in the US Corn Belt (Lindstrom et al. 1979).

There are 2.4 million cattle in Minnesota and have a unique effect on corn-based cropping systems because they consume both corn grain and stover (NASS, 2012). Baling of corn stover after grain harvest reduces crop residue remaining and can have adverse effects on soil quality and health. The objective of this study initially was to evaluate removal of corn stover with addition of winter rye to minimize soil erosion risks associated with removing corn residue on the soil surface. Aerially seeded winter rye into standing corn grain in September of 2010 was unsuccessful. In order to maintain field sites for an experiment, the new objective of the study was to evaluate the impact of removing corn stover on water quality in a paired watershed design. Two adjacent watersheds equipped with edge-of-field surface runoff monitoring equipment were used to compare conventional soil residue management practices and removal of corn stover.

Materials and Methods

Location Description and Date

The study was conducted on a farm located near Plainview, MN (44.187^0 N, 92.183^0 W) in 2009 to 2012. Two adjacent watersheds on Downs-Hersey Complex with 2 to 12% slope (Fine-silty, mixed, superactive, mesic Mollic Hapludalfs) were chosen for edge-of-field surface runoff monitoring. This study consisted of two treatments in a paired watershed experimental design. The treatments were baled corn stover and fallow following two years corn silage and one year soybean rotation. First year was a baseline year and the second year the treatment (removing corn stover) was applied on 30 October 2010 following harvest of corn grain. Wing-walls were constructed using methods outlined by the United States Geological Survey and the University of Wisconsin-Madison (Stuntebeck, 2008). Construction began on 11 November 2009 and ended on 13 November 2009. Watersheds were surveyed and trenched to 61 cm depth for plywood wall installation. The wall in the control watershed was 45 m. The wall in the treatment watershed measured 45 m. After wall installation and backfilling, the wall was reinforced with 1.8 m T-posts spaced 2-5 m apart. Each watershed had sufficient elevation change on the downstream side of the flumes to prevent ponding which drained into an adjacent pasture. An electric fence was installed to prevent the cattle in the pasture from damaging the equipment in both watersheds. Platforms for the ISCO shelter and rebar support for the flumes were also installed in both watersheds. One H-flumes, 0.91 m in height (Plasti-Fab Inc., Tualatin, OR) coupled with ISCO 3700 portable sampler and 4230 bubbler flow meter (Teledyne ISCO Inc., Lincoln, NE) were used at each watershed in accordance with USGS recommendations (Stuntebeck, 2008). Equipment enclosures, flumes, ISCO portable samplers, and bubbler flow meters were installed in January 2010 and flow monitoring was initiated on 5 February 2010.

Corn Stover and Yield Measurements

Corn grain was collected on 5 October 2010. Determination of corn grain yield was completed by hand harvesting corn cobs from corn plants in a 3 m length of 76 cm row at 14 locations in each watershed. A mechanical sheller was used to thresh the grain from the cobs. Subsamples for each location were dried for 3 days at 70°C. Kernels were weighed and yield was determined.

Corn stover was hand harvested in an area of 0.09 m^2 from 10 locations in the treatment watershed on 26 October 2010. Corn stover was weighed. Subsamples for each location were dried for 3 days at 70°C to determine moisture content at time of sampling. Dry mass was then determined. Field removal of corn stover occurred on 30 October 2010.

The treatment watershed was initially to be winter rye with removal of corn stover. Problems arose with the aerial seeding of winter rye in fall 2010. Aerial seeding of winter rye occurred on 2 September 2010 at a rate of 112 kg ha^{-1}. Winter rye seed was observed on the soil surface four days after the aerial application. However, there was no observed winter rye germination in the treatment watershed a week after the initial observation. We suspect that predation, 23 September 2010 storm and pilot error were key factors in the establishment of winter rye in the treatment watershed. With an unsuccessful winter rye seeding, this location resulted in a stover management experiment studying the effect of corn stover residue ground cover on runoff quantity and quality.

Soybean plants were collected on 6 October 2011 which was three days prior to field harvest. Soybean plants were hand harvested in 3 m rows (76 cm row spacing) at seven locations in each watershed. A mechanical sheller was used to thresh the beans from the pods. Subsamples for each location were dried for three days at 70°C to determine moisture content. Beans were weighed and yield was determined.

Water Samples

The automated field sites were programmed to sample on a volume basis with one sample collected for every 29.08 m^3 of surface runoff during snowmelt or rainfall events. In spring 2010, snowmelt runoff exceeded preliminary estimates and sample volume basis was changed from 29.08 to 339.6 m^3 in order to handle peak flow rates. Three samples are composited per 1 L polypropylene bottle (Teledyne ISCO Inc., Lincoln, NE). The sample collection at 29.08 m^3 in the treatment watershed was chosen so that during a runoff event, there would be sufficient sampler capacity to capture the entire event based on a predicted average water height of 0.15 m and a flow rate of 0.017 m^3s^{-1}. Water samples were immediately placed on ice in a cooler within 24 hrs and subsequently filtered using a 0.2 µ filter (VWR International, Chicago, IL) with a non-surgical syringe (120 mL was filtered from each bottle). Filtered samples were analyzed for NO3-N, NH4-N, and dissolved reactive Phosphorus using a Quikchem 8500 Lachat Ion analyzer (Hach Company, Loveland, CO). Total dissolved phosphorus was determined for filtered samples (University of Minnesota Soil Testing Laboratory) using rapid flow analyzer (RFA) method with Alpkem RFA 300 (RFA, 1986 and Astoria-Pacific, Clackamas, OR). Unfiltered samples were analyzed for Total Suspended Solids (TSS), Sediment Carbon, Sediment Nitrogen, and Total Phosphorus (TP). TSS was determined with ESS Method 340.2 (Environmental Protection Agency, US). TP analysis was performed by the University of Minnesota Soil Testing Laboratory using RFA method with Alpkem RFA 300 (RFA, 1986 and Astoria-Pacific, Clackamas, OR). Sediment carbon and sediment nitrogen were determined using Elementar Vario EL combustion analyzer (Elementar Americas, Inc., Mt. Laurel, NJ).

Soil Samples

Soil samples were collected on 19 November 2009, 3 May 2010, 30 October 2010, 20 May 2011, and 11 October 2011. Sixteen sample locations were chosen in a grid pattern for each watershed to captured slope characteristics (summit, back slope, and foot slope) and prior to each sampling date, locations were found using research grade global positioning system (GPS) mapping equipment. Two soil cores were collected at each sample location to a depth of 90 cm using a truck mounted Giddings probe (3.8 cm diameter). Cores were subsampled by depth in the following increments: 0-15 cm, 15-30 cm, 30-60 cm, and 60-90 cm and composited at each location. Soil samples were sub-sampled for physical analysis and were dried at 105^{0}C to determine gravimetric water content and bulk density. There was no statistical difference between gravimetric water content and bulk density for the watersheds. The remaining sample was dried at 37^{0}C, ground through <0.5 mm sieve, and analyzed for soil NO_3-N, NH_4-N, and Mehlich III P using a Quikchem 8500 Lachat Ion analyzer (Hach Company, Loveland, CO). The same sampling protocol and analysis were followed for each year of study.

Ground Cover

Photographs for ground cover determination were collected on 19 November 2009, 3 May 2010, 30 October 2010, 20 May 2011, and 11 October 2011. Ten digital photographs were taken in each watershed using a camera mounted on a stand facing downward at a height of 1.2 m. The photographs were analyzed using USDA Sample-Point Measurement Software 1.48 (Booth, 2006). This software allows for an overlay of a 100 point grid to be placed over each photograph. Average ground cover is determined by visual observation at each point.

Paired Watershed Design Comparisons

The control and treatment watersheds were adjacent to one another and had the same shape with east/west aspects but differed in size. The treatment watershed was 1.2 ha and the control was 4.2 ha. Watershed boundaries and area were found using research grade global positioning system (GPS) mapping equipment. Both watersheds exhibited same flow pattern in slope characteristics but the distance from upper portion of watershed to equipment used to monitor surface runoff was different. The distance surface runoff traveled from upper boundary to the flume in the treatment watershed was 85 m. The distance in the control watershed was 190 m. The size and distance runoff traveled within the watersheds were major differences.

Management of Watersheds

Farm management of both watersheds was similar throughout the study. Both watersheds received application of anhydrous ammonia, seedbed preparation and crop planting in the spring. The control watershed contained a grass waterway and the farmer was unwilling to remove it because the potential for soil erosion would increase. As a compromise, the grass waterway was trimmed continuous to keep an average 10 cm height. Corn harvest occurred on 6 November 2009 and 29 October 2010. Soybean harvest occurred on 10 October 2011. Corn (roundup ready variety) planting occurred on 28 April 2010 and soybeans (roundup ready variety) were planted on 1 June 2011. However, the farmer did not plant soybeans in the entire control watershed as planned. After we discussed the planting of soybeans in both watersheds he decided a week prior to planting to plant corn and alfalfa in about 50% of the control watershed with soybeans taking up the rest of the field without prior consulting. His response was economics with corn prices outweighing soybean prices. The treatment watershed was planted entirely with soybeans. The change in cropping rotation shows the difficulty of on-farm research.

Authenticity of Data

Measuring real-time surface runoff for accuracy has some challenges. During all runoff events, if the flume was not level, readings of flow rate were then incorrect. To deal with this issue, leveling of the flume was done at each visit to the field sites and the flumes were never unbalanced. Freezing of sampling line, ice buildup in the flume, and malfunction of sampler were the three main challenges to this study when surface runoff was observed. Determination of runoff start and end times were confirmed based on flow rates, time of runoff, and air temperatures at time of runoff for fall and spring runoff events. Manual manipulation of data then occurred during times of incorrect runoff measurements (Stuntebeck, 2008). Majority of the incorrect runoff flows were when ice buildup occurred in the flume during the night. Sampler malfunction occurred mostly during spring snowmelt events. Freezing night temperatures would cause the ice buildup in the flume and provided incorrect flow measurements. These incorrect flow measurements would trigger the sampler to take a water sample.

Some of the snowmelt that may have occurred during times when a technician could not be there had no collection of runoff samples because ice buildup in the flume caused the sampler to use up all available collection bottles. These occurrences were not frequent but based on overall total volume of runoff from each watershed; more bottles could have been collected. The control watershed had 48 bottles collected and the treatment watershed had eight bottles. Based on total runoff from both watersheds, 84 and 39 bottles should have been collected from control and treatment watersheds, respectively. The missing collection samples for the control watershed occurred in the spring of 2011 when there was 31805 m^3 of runoff which should have triggered runoff samples into 31 bottles. In addition, 17 bottles should have been collected in summer 2011 and spring snowmelt of 2012. There were 31 bottles not collected in the treatment watershed and they were missing from spring snowmelt 2011 and spring snowmelt 2012. There was 57% and 21% sample-volume coverage for control and treatment watersheds, respectively. Discovery and Pioneer farms in Wisconsin that are operated by United States Geological Survey (USGS) had 90% annual sample-volume coverage during a 6 year period from 12 edge-of-field sites (Stuntebeck, 2008).

Results and Discussion

Ground Cover, Crop Yield, Stover Removal, and Soil Composition

Ground cover percentages were similar during baseline year of fall 2009 to spring 2010. As assumed, ground cover percentages were different for experimental year in fall 2010 to spring 2011 because removal of corn stover occurred (Table 3). Fall 2011 showed ground cover were similar between watersheds because soybean residue remained. Field removal of corn stover occurred on 30 October 2010. Average dry mass of stover removed was 0.35 kg ha^{-1}. Removal of stover did have an effect on surface runoff. Total surface runoff increased in 2011 compared to 2010 (Figure 5). Comparisons of water quality parameters between 2010 and 2011 could not be completed because treatment watershed had no sample collections in spring 2011 snowmelt. The amount of runoff volume should have covered a total of 13 bottles.

Table 3. Ground Cover			
	Year	**Control**	**Treatment**
		%	%
Fall	2009	98	98
Spring	2010	92	82
Fall	2010	90	35
Spring	2011	87	33
Fall	2011	56	52

Corn grain yields and soybean yields were not affected by removal of corn stover (Table 4). Long term impacts of corn stover removal may exist but the results after one year do not. Implications of long term removal may include increase risk of soil erosion and disruption in soil organic carbon dynamics that would influence future crop yields (Blanco-Canqui, 2010).

Table 4. Crop Yield			
Crop	**Year**	**Control**	**Treatment**
		metric tons ha^{-1}	
Corn Grain	2010	9.5	11.9
Soybean	2011	3.4	3.6

Soil NO_3-N concentrations were similar between watersheds throughout the study (Figure 1). This was an expected result since removing corn stover in the fall doesn't have direct impact on soil nitrate.

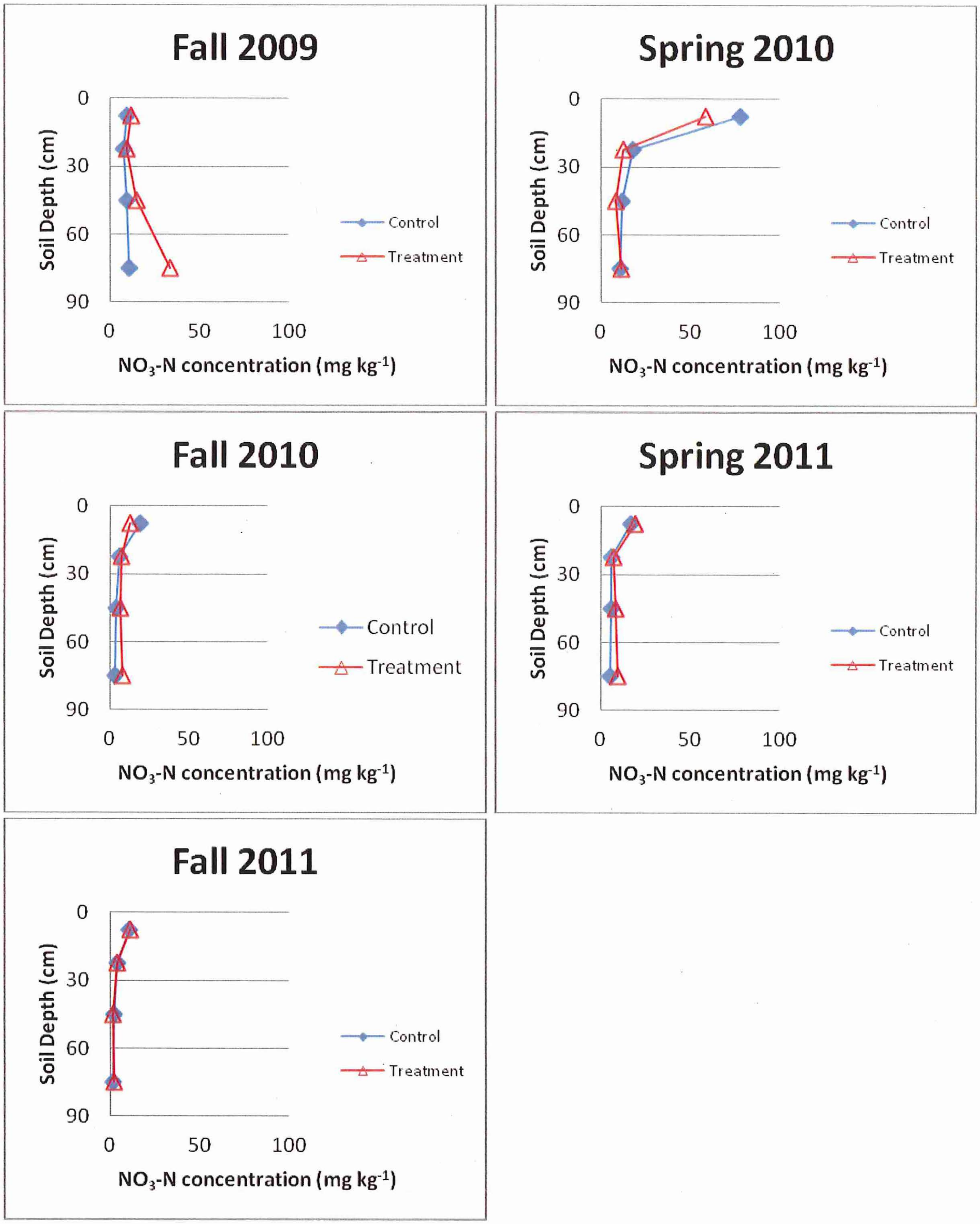


Figure 1. Soil NO_3-N concentrations for fall and spring. Concentrations are reflected in the figure at the average point between sample increments.

Ammonium concentrations in the soil fluctuate frequently during the year because it is subject to many transformations in the soil system. Nitrogen transformation of ammonium includes nitrification, immobilization, and volatilization. These transformations or fluctuations of ammonium are evident in the soil of the control and treatment watersheds (Figure 2). Anhydrous ammonia was applied in spring 2010 prior to soil sampling. Concentrations of ammonium increased between fall 2009 and spring 2010 because of this application of fertilizer (Figure 2). Anhydrous ammonia was not applied in fall 2010 or spring 2011 prior to soybean planting.

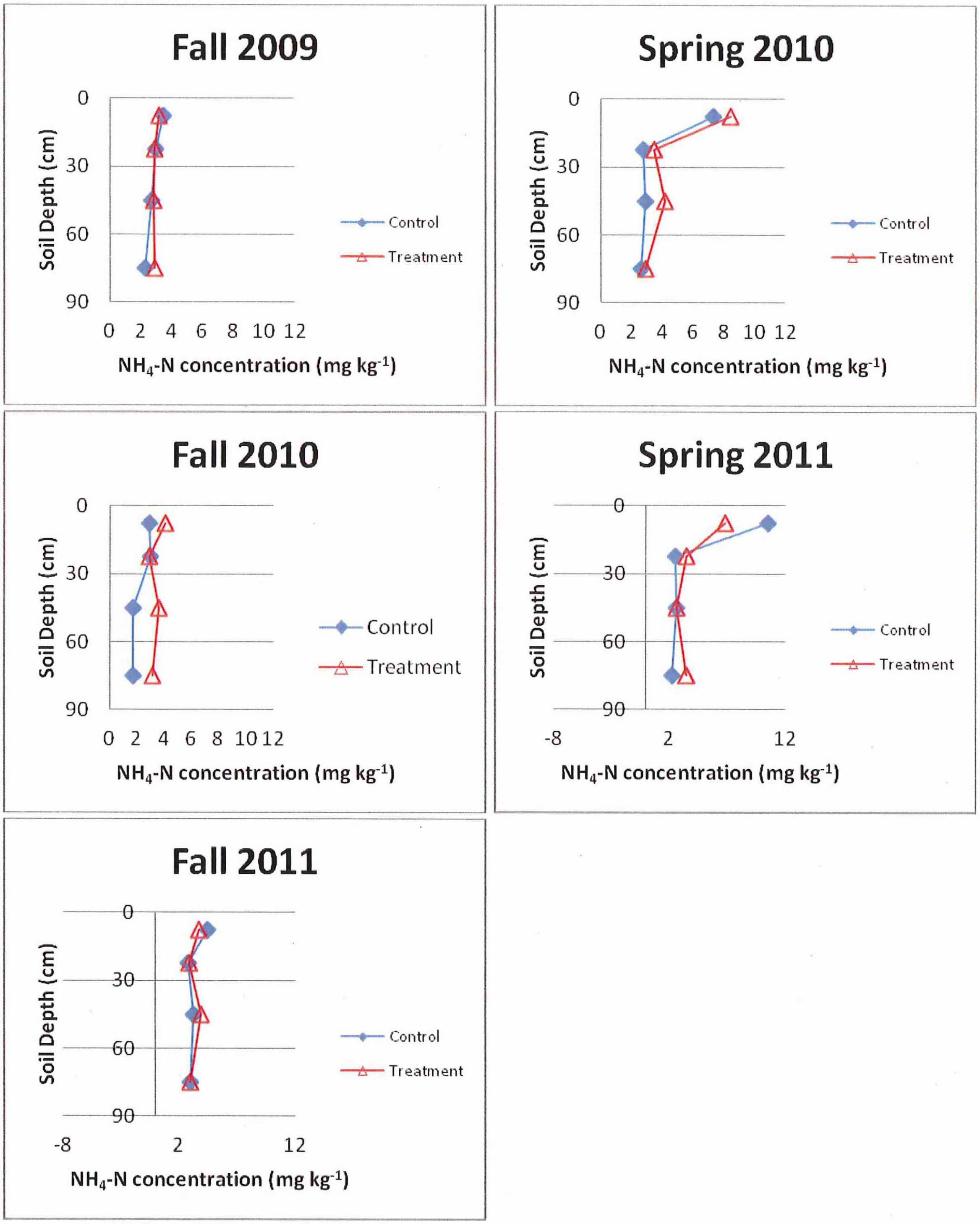


Figure 2. Soil NH_4-N concentrations for fall and spring. Concentrations are reflected in the figure at the average point between sample increments.

Soil Mehlich III-P concentrations were similar between fall and spring from 2009 to 2011 (Figure 3). This was an expected result since removing corn stover should not have a direct impact on bio-available soil phosphorus.

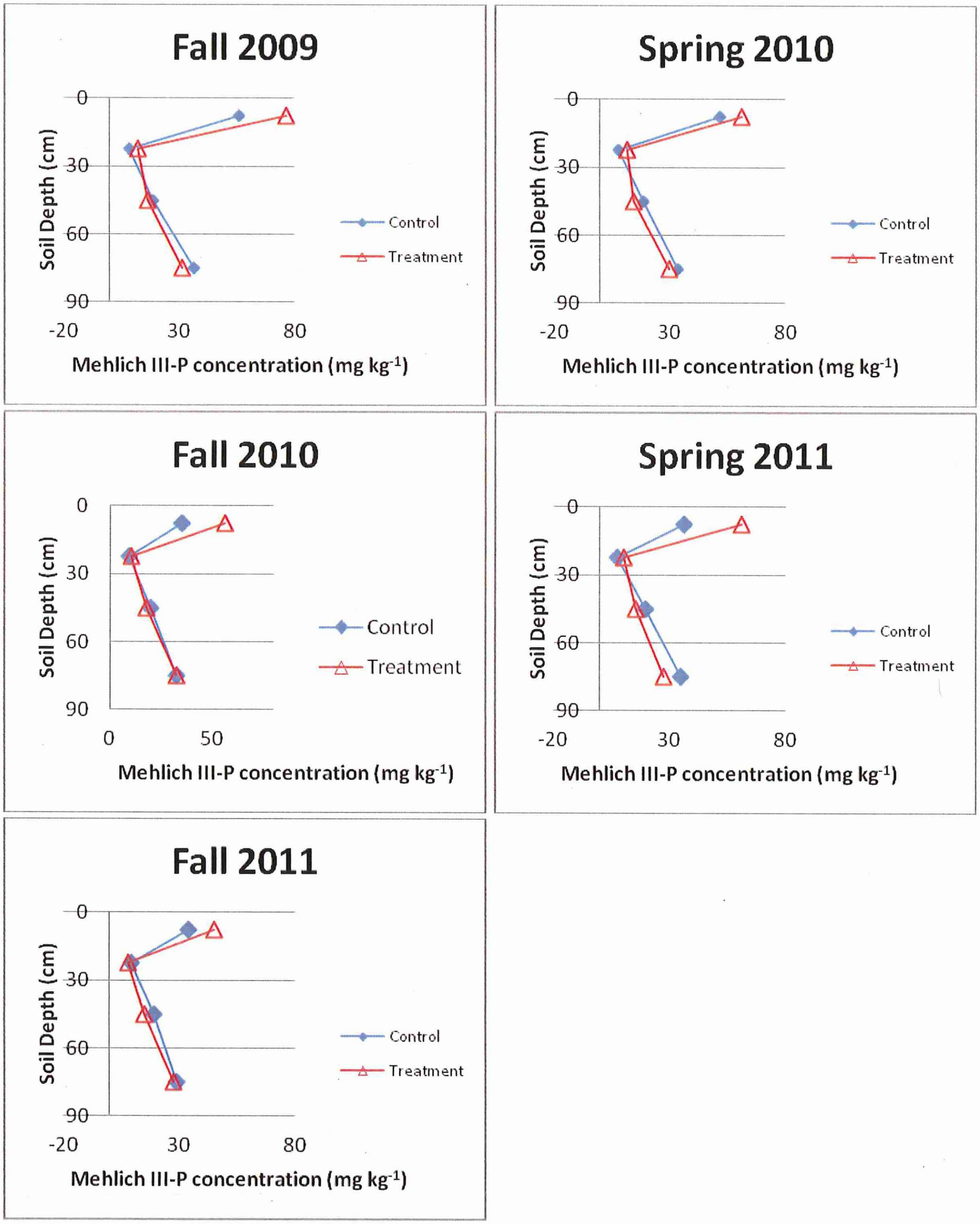


Figure 3. Soil Mehlich III-P concentrations for fall and spring. Concentrations are reflected in the figure at the average point between sample increments.

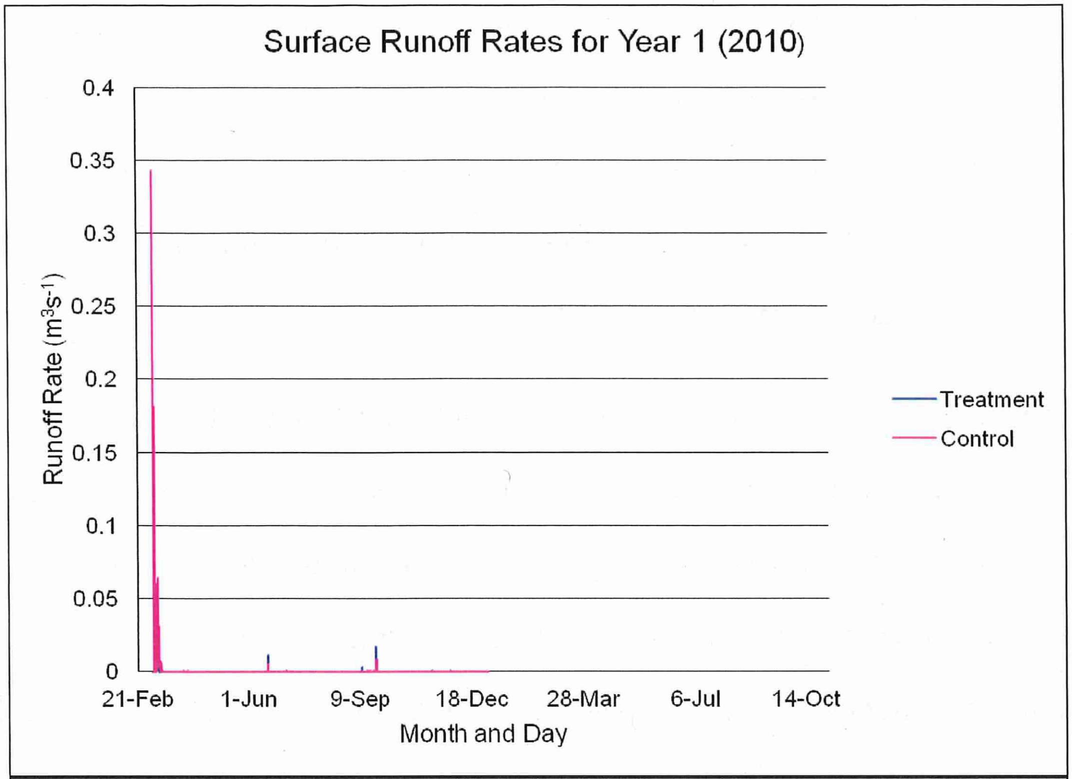
Total Water Volume

Differences in total surface runoff were observed in 10 out of 25 months. These 10 months included the 4 major surface runoff events that had sample collections (see runoff losses below). In 2010, the control had 70% more surface runoff than the treatment. In 2011, the control had 43% more surface runoff than the treatment. With the removal of the corn stover, surface runoff increased by 30%.

Major differences in surface runoff were observed in snowmelt events of 2010, 2011, and 2012. In snowmelt event of 2010, both the control and treatment watersheds, runoff began 6 March 2010 and ended 14 March 2010 (Figure 4). Surface runoff rate in the control watershed exceeded preliminary estimates and the ISCO sampler was reset to a reduced sample collection rate, one sample / 339.6 m^3 s^{-1} for the peak of the spring snow melt. The sample collection interval in the treatment watershed was one sample for 29.06 m^3 of surface runoff. The control watershed had a greater volume of runoff than the treatment watershed (Figure 5). The control watershed had a maximum rate of surface runoff of 0.343 m^3 s^{-1}. This flow rate corresponds to a head of 0.616 m. The treatment watershed had a maximum flow rate of 0.007 m^3 s^{-1} which corresponds to a head of 0.098 m (Figure 4).

Summer rainfall events in 2010 produced little or no runoff from either the control or treatment watersheds. The lack of runoff from these watersheds may have been due to high corn stover residue still present on the soil surface. The cooperator uses a no-till system which is a best management practice for water quality.

Fall 2010 rainfall events also produced little to no runoff from either the control or treatment watersheds. The major storm event on 23 September 2010 had a total rainfall of 19.05 cm. However, this rainfall event produced little to no runoff in both watersheds. Total runoff in the control was 106 m^3 and the treatment was 84 m^3. Again, the lack of runoff from these watersheds was probably due to high corn stover residue still present on the soil surface.



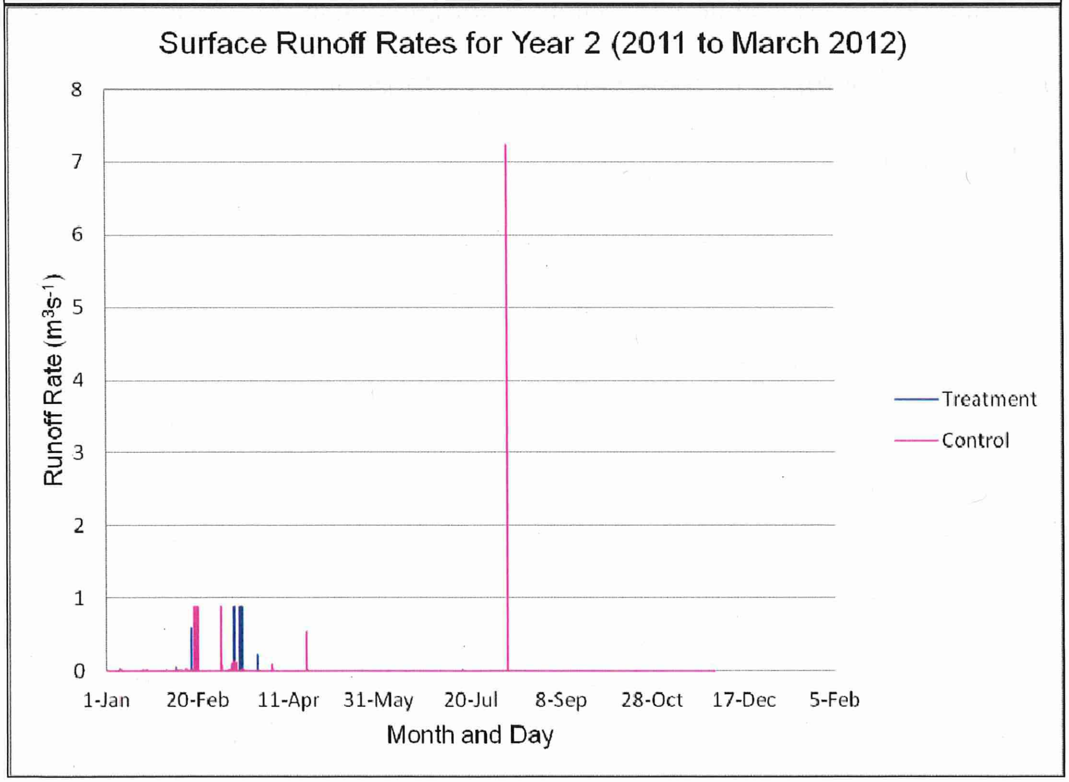
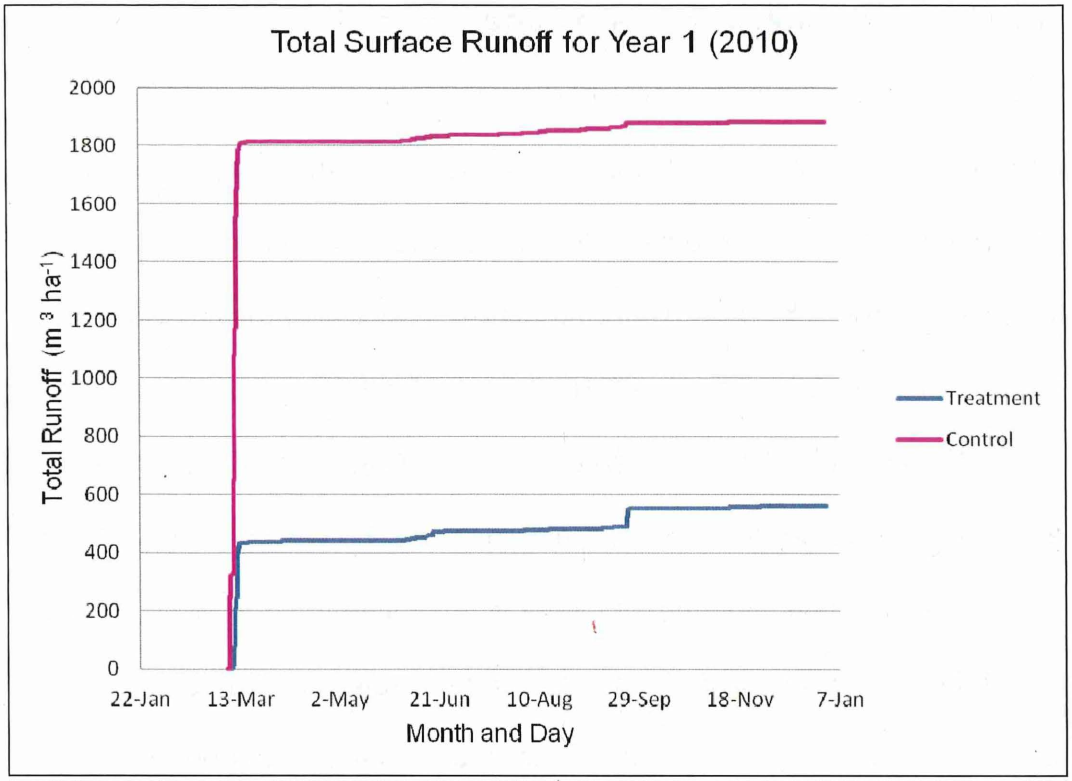


Figure 4. Rates of flow for both watersheds in 2010 and 2011.

Spring 2011 snowmelt produced a greater surface runoff than spring of 2010. The control watershed had 1814 m^3 ha^{-1} of runoff in 2010 and 7573 m^3 ha^{-1} in 2011. The treatment had 439 m^3 ha^{-1} in 2010 and 944 m^3 ha^{-1} in 2011. There were three snowmelt periods on 16 February, 11 March, and 20 March (Figure 4). The greatest snowmelt runoff occurred on 11 March 2011.

The summer and fall 2011 rainfall events did not produce sufficient amount of rainfall for runoff to occur. The winter of 2011 to 2012 had mild winter conditions that produced below normal snow and above normal temperatures. As a result this winter provided little to no snowmelt from the control and treatment watersheds. Runoff flow rates from both watersheds had low flow starting on 12 March 2012, but the snowmelt did not produce enough runoff flow to initiate a sample collection. Both watersheds had less than 15 m^3 ha^{-1} of runoff in snowmelt of 2012. Most of the snowmelt infiltrated the soils in both watersheds.



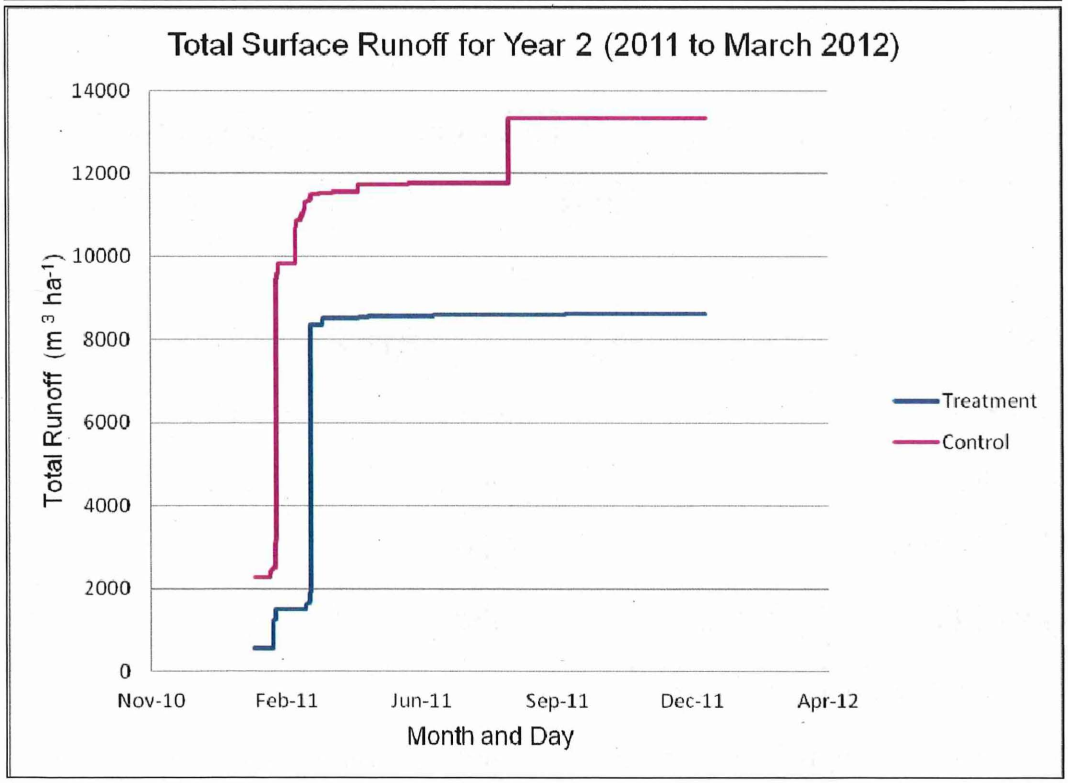


Figure 5. Total volume of runoff (m^3 ha^{-1}) for both watersheds in 2010 and 2011.

NO_3-N, NH_4-N, and Phosphorus loss in Surface Runoff

Only 2 out of the 4 runoff events had sample collection in both watersheds. Comparison can only be made in those two events (Table 4). Sampler malfunction occurred during the other two events. Both watersheds had similar NO_3-N and NH_4-N loads in snowmelt event of 2010. This was expected since removing corn stover happened in fall 2010. A September 2010 storm had sampling occur in both watersheds. The control watershed had 87% more NO_3-N and 86% more NH_4-N loads than the treatment watershed, however the loads were the lowest observed in the study (Table 4). Runoffs between watersheds were comparable to each other. Control had 25 m^3 ha^{-1} and the treatment was 70 m^3 ha^{-1} for the September 23rd storm. Concentrations in the samples were also lower than other events (Figure 6).

Table 4. NO_3-N and NH_4-N Loads in Surface Runoff from Specific Events

	Control		Treatment	
Event	**NO_3-N**	**NH_4-N**	**NO_3-N**	**NH_4-N**
	- - - - - - - - - kg ha^{-1} - - - - - - - - -			
Snowmelt 2010	1.18	0.29	1.03	0.05
Summer 2010	-*	-*	0.14	0.004
Sept 22nd, 23rd 2010	0.14	0.60	0.018	0.085
Snowmelt 2011	4.07	3.59	-*	-*

* missing data is due to sampler malfunction during events

None of the samples collected from the watersheds exceeded the EPA water quality standard of 10 mg L^{-1} in drinking water. This standard of 10 mg L in drinking water was established to prevent human infant deaths caused by blue-baby syndrome.

Blue-baby syndrome is an environmental-caused health disorder where the blood lacks the ability to carry enough oxygen to vital tissues and organs (Knobeloch et al., 2000). The highest observed NO_3-N concentration was 8.3 mg L^{-1} and was in the treatment during the 2010 snowmelt (Figure 6). The lowest observed NO_3-N concentration was 0.04 mg L^{-1} in the 2011 snowmelt in the control watershed. The highest NH_4-N concentration was 6.85 mg L^{-1} and occurred during the September storm in the control watershed (Figure 7). The lowest NH_4-N concentration was 0.0001 mg L^{-1} during the snowmelt event of 2010 in the treatment watershed (Figure 7). Even with lower concentrations, the control watershed had more surface runoff thus more NO_3-N and NH_4-N lost in surface water (Table 4).

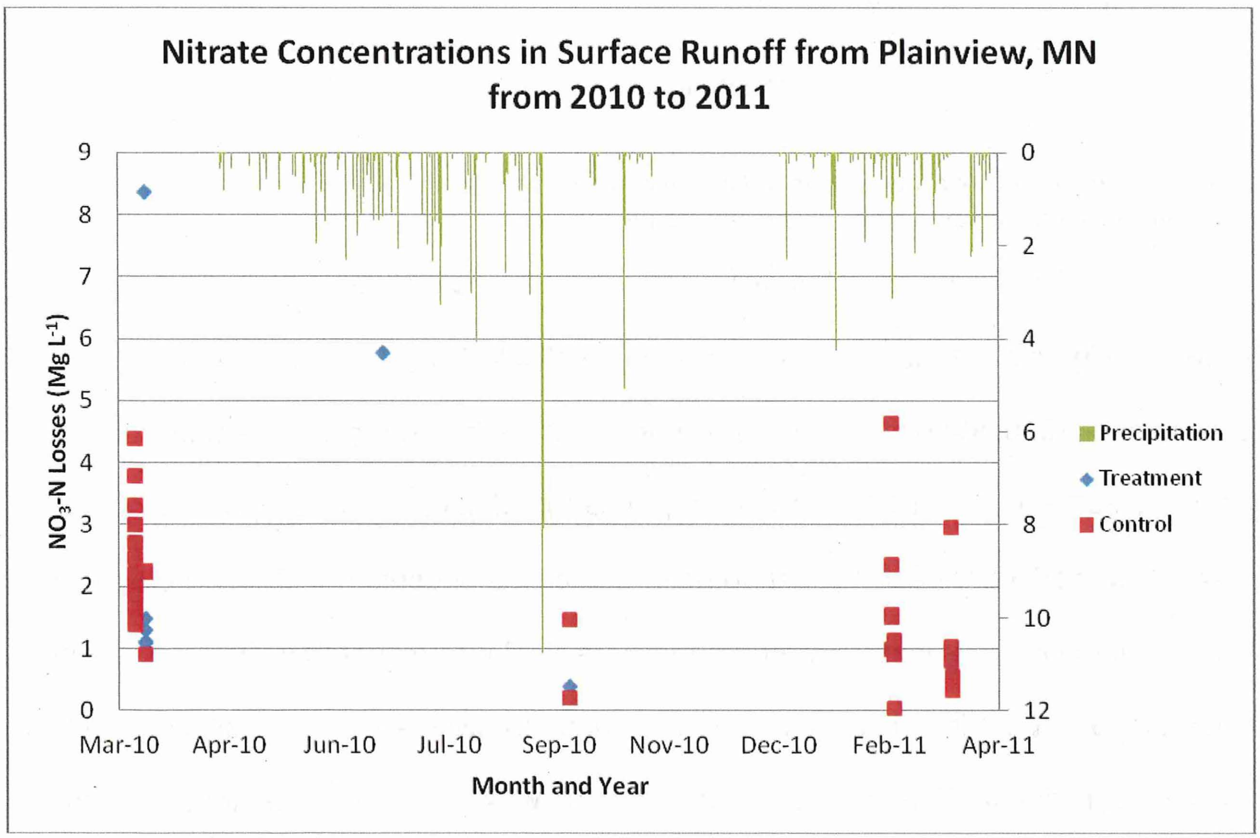


Figure 6. Nitrate concentrations for control and treatment watersheds. Squares and diamonds are concentrations from samples taken during surface runoff events.

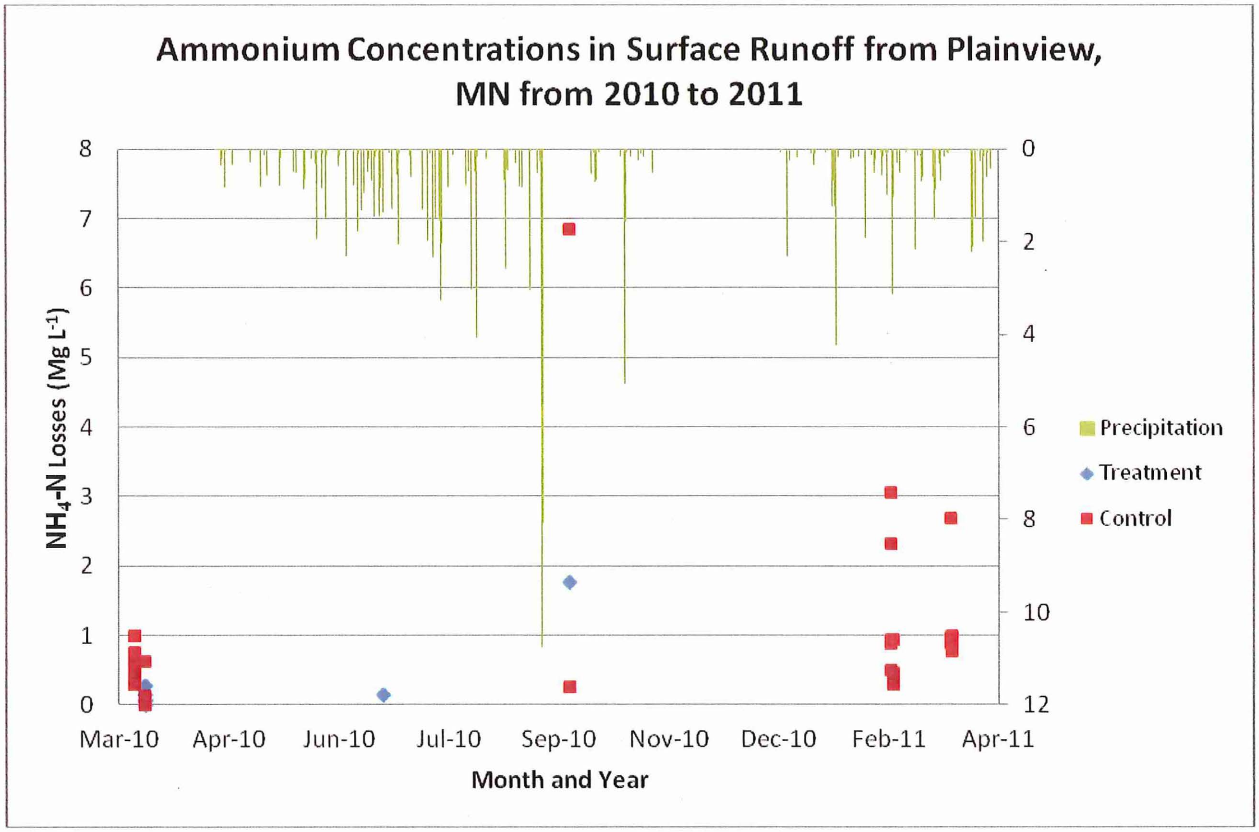


Figure 7. Ammonium concentrations for control and treatment watersheds. Squares and diamonds are concentrations from samples taken during surface runoff events.

The control watershed had more total phosphorus (TP) loads than the treatment watershed in both events where samples were collected (Table 5). During the snowmelt of 2010, the control had 42% more TP than the treatment. Total dissolved phosphorus (TDP) was the same in both (Table 5). Majority of phosphorus in the control was sediment-bound phosphorus or particulate phosphorus (PP). The opposite was observed in the treatment watershed where TDP was higher than PP. Interesting is the amount of sediment was higher in the treatment watershed than the control during this event (Table 6). This implies that phosphorus was at higher concentrations in the water than in the sediment.

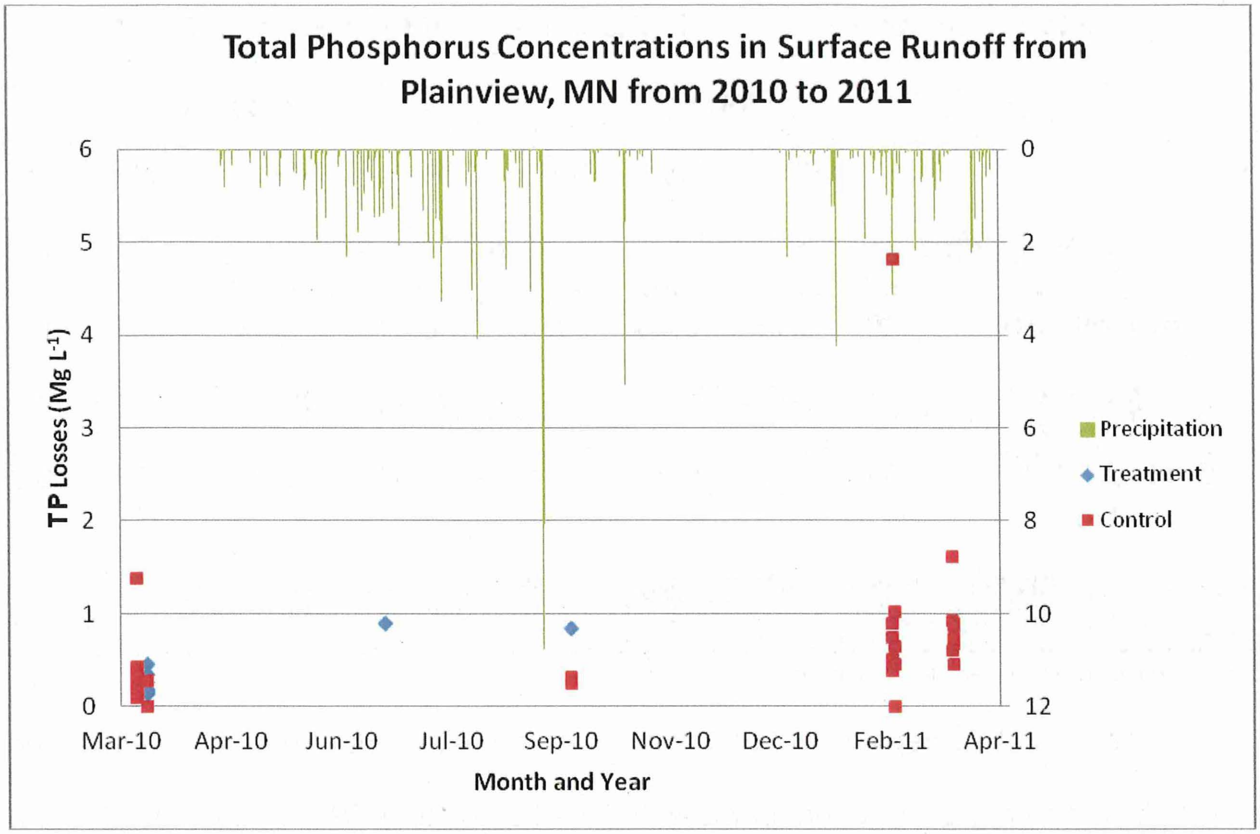


Figure 8. Total phosphorus concentrations for control and treatment watersheds. Squares and diamonds are concentrations from samples taken during surface runoff events.

Highest concentrations of TP were observed in the control watershed during the spring 2011 snowmelt event. This concentration was 4.8 mg L^{-1}. The lowest TP concentrations were observed in the 2010 snowmelt event in both watersheds. These concentrations ranged from 0 to 0.2 mg L^{-1} (Figure 8). Phosphate concentrations were higher during summer 2010 and spring 2011. Highest concentration of phosphate occurred on 1 July 2010 in the treatment watershed at 1.71 mg L^{-1}. In the control watershed during the spring 2011 snowmelt, highest phosphate concentration was 1.22 mg L^{-1}. Phosphate or dissolved inorganic phosphorus (DIP) is readily available to plants as a phosphorus source. It is also readily available to algae in rivers, lakes, and streams, where if in excess can cause eutrophication. A majority of the phosphorus concentrations measured (99%) in the surface runoff in both watersheds exceeded

Table 5. Phosphorus Loads in Surface Runoff from Specific Events

	Control				Treatment			
Event	**TP**	**PP**	**TDP**	**DIP**	**TP**	**PP**	**TDP**	**DIP**
	- - - - - - - - - - - - - kg ha^{-1} - - - - - - - - - - - - -							
Snowmelt 2010	0.19	0.11	0.08	0.07	0.11	0.03	0.08	0.09
Summer 2010	-----	-----	-----	-----*	0.022	0.002	0.02	0.04
Sept 22nd, 23rd 2010	0.05	0.01	0.04	0.1	0.04	0.01	0.03	0.03
Snowmelt 2011	2.83	0.93	1.90	1.85	-----	-----	-----	-----*

* missing data is due to sampler malfunction during events

The 22 and 23 September 2010 storm was another event where both watersheds had collected samples. The control watershed had 20% more TP in surface runoff than the treatment (Table 5). PP and TDP were also similar between watersheds for this event.

0.025 mg L^{-1}, the level that causes accelerated eutrophication in lakes (Figure 9). Max recommended DIP concentrations for streams and rivers are 0.1 mg L^{-1}. Only 92% of samples were over the max recommended concentrations for streams and rivers. This edge-of-field monitoring was not near any body of water. Majority of the phosphorus in the runoff would probably never reach a waterway at these concentrations, because the distance is too great. Also the runoff from these watersheds runs into pasture land which also has a lagoon catchment.

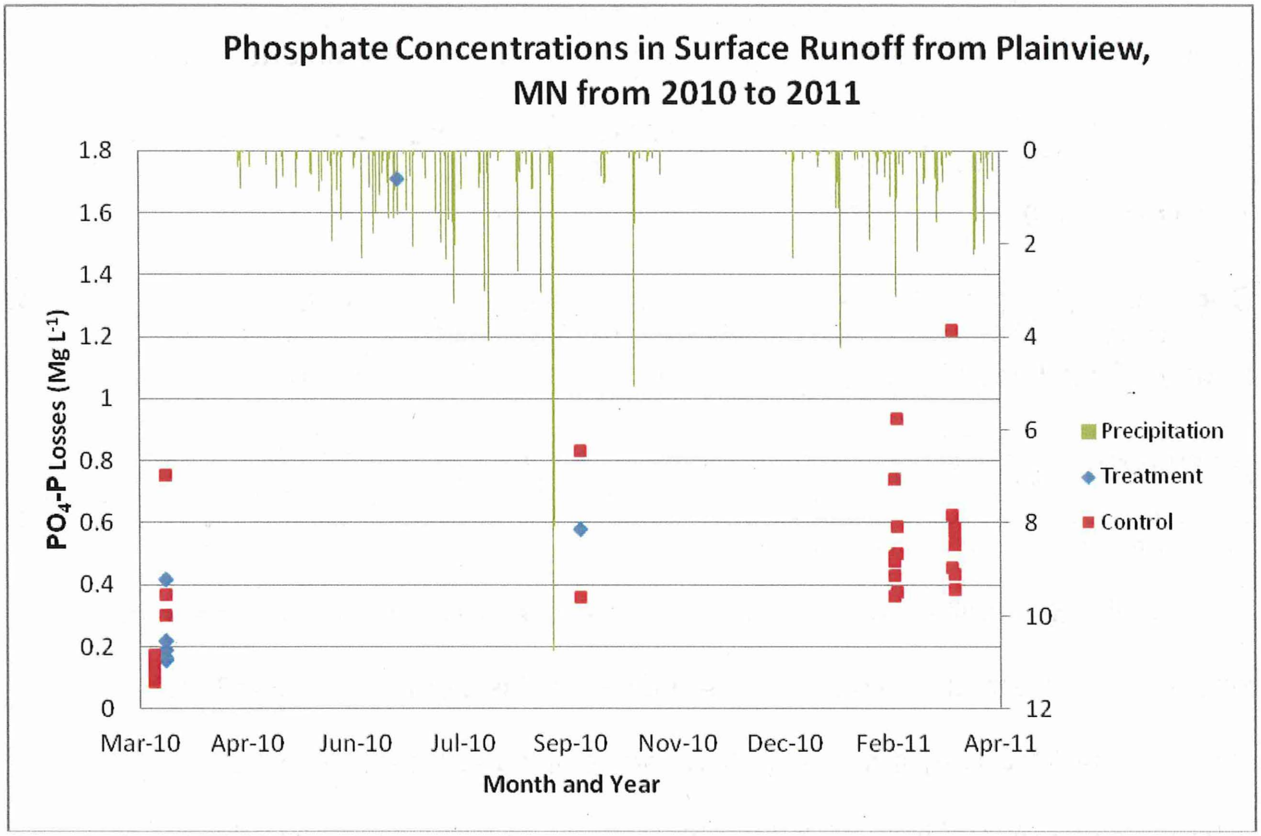


Figure 9. Dissolved Inorganic Phosphorus or Phosphate concentrations for control and treatment watersheds. Squares and diamonds are concentrations from samples taken during surface runoff events.

Sediment Loss

Unlike nitrogen and phosphorus loads, sediment was observed higher in 1 of the 2 events for the control watershed. Snowmelt event of 2010 had 14% higher sediment loads in the treatment than the control. This was a result of higher total suspended solid (TSS) concentrations in the samples collected than but amount of runoff. Highest TSS concentration was 23765 mg L^{-1} and was collected in the treatment watershed. Control watershed had TSS concentrations ranging from 5565 to 12765 mg L^{-1} (Figure 10). C/N ratios were 8 for both watersheds for the snowmelt event of 2010.

Table 6. Sediment Loads in Surface Runoff

	Control			Treatment		
Event	**Sediment**	**N**	**C**	**Sediment**	**N**	**C**
	- - - - - - - - - - - - - kg ha^{-1} - - - - - - - - - - - - -					
Snowmelt 2010	3588	7	57	4164	9	74
Summer 2010	-----*	-----*	-----*	629	2	20
Sept 22nd, 23rd 2010	10580	71	623	3140	15	136
Snowmelt 2011	874	4	39	-----*	-----*	-----*

* missing data is due to sampler malfunction during events

In the September 2010 storm the control watershed had 70% more sediment load than the treatment (Table 6). The runoff from this storm had higher TSS concentrations than any other event that had samples collected. The TSS concentrations ranged from 61963 to 65536 mg L^{-1} in both watersheds (Figure 10). From what was sampled in the watersheds, 3.6 metric tons ha^{-1} of soil was lost from the control watershed and 6.6 metric tons ha^{-1} was lost from the treatment watershed in surface runoff from 2010 to 2011. Soil erosion is a major environmental concern. Soil is being lost 10 to 40 times faster than it is being replenished (Pimentel, 2006).

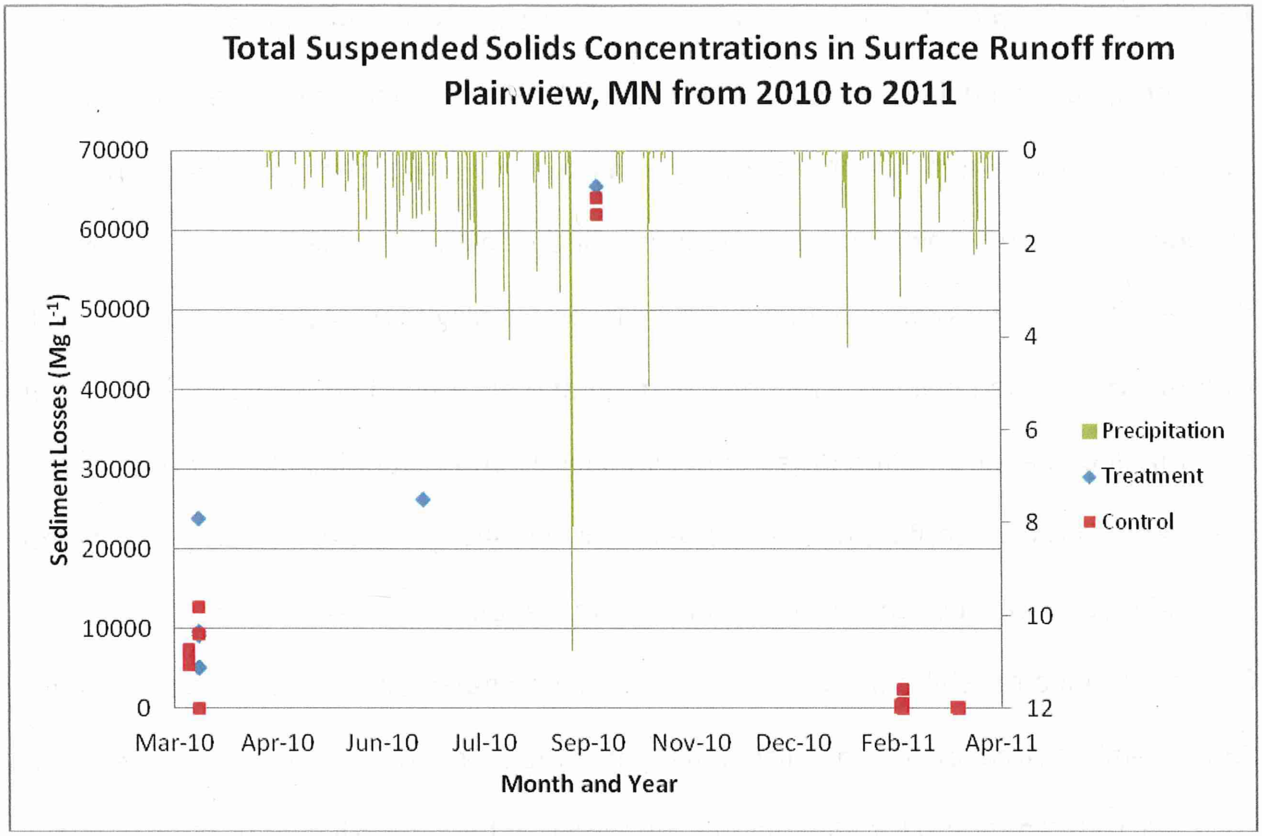


Figure 10. Sediment concentrations for control and treatment watersheds. Triangles and squares are concentrations from samples taken during surface runoff events.

Conclusion

Removal of corn stover in the fall has potential to increase soil erosion. Surface runoff increased by 30% in the treatment watershed after stover was removed. The long term impacts of baling or removing corn stover could be detrimental to soil quality and health. Sediments and nutrients lost in surface runoff were not calculated because sample collection did not occur in 2011 in the treatment watershed. Any indications of sediment loss and nutrient loss from this watershed would have been greater in 2011 than 2010 because surface runoff was greater. Both watersheds exhibited same shape and slope, but differed in field size and distance that surface runoff traveled from upper portion to monitoring equipment. Evaluating surface runoff in a paired watershed in an on-farm research setting presents constraints relative to University Experiment Station lands. Flexibility must be shared between the researchers and farmer involved because economic losses must be avoided. This issue arose in the last year of the study when soybeans were planted. Prior to planting soybeans, it was agreed upon that both watersheds would be planted into soybeans. One week prior to planting the cooperator decided that corn for grain would provide more profitability than soybeans. The control watershed was then planted 50% corn for grain and alfalfa and 50% soybeans. Another major fault of the study is the duration of evaluating surface runoff in these two systems. Two years does not capture climatic variations in weather from year to year, suggesting that more years of study are necessary to control variation in weather from year to year. One major accomplishment was that we were able to have equipment in place when the 23 September storm occurred which caused the largest flooding event since 18 August 2007. A 100-year storm for this region is 15.24 cm of total rainfall over a 24-hour period.

Acknowledgements

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Effects of Winter Rye following Corn Silage on Surface Runoff in Paired Watershed

Adam P. Herges, Erik S. Krueger, John M. Baker, Paul M. Porter, and Gary Feyeriesen

Abstract

Soil conservation is paramount in a world where monoculture cropping systems are main-stream and higher frequency and intensity of storm events are increasing. The objective of this study was to evaluate the potential of a winter rye (*Secale cereale* L.) cover crop to minimize soil erosion and transportation of nutrients to waterways by providing cover during the fall and spring dormant periods in a paired watershed design. H-flumes with ISCO portable samplers and bubbler flow meters were used to monitor surface water runoff from a corn silage-winter rye-soybean rotation (treatment watershed) to a conventional corn silage-soybean rotation (control watershed) from 2010 to 2012. Treatment watershed had 60% more total runoff than control where majority of runoff was in spring snowmelt events. Even though winter rye scavenged 30% of nitrate during dormant periods, treatment watershed had higher NO_3-N and NH_4-N loads than control watershed in 2 out of the 3 events where samples were collected. This was also true in phosphorus and sediment transport. Differences in field management in fall seasons accounted for the differences in surface runoff of snowmelt events. We conclude that winter rye should still be considered a best management practice and that consideration of more years of study should be observed.

Introduction

With climate change, world population growth and food production demands continue to rise, sustaining or improving soil health is vital to the survival of agriculture for future generations. Soil conservation is paramount with continuation of monoculture cropping systems that use chemical inputs to maintain yields and lack biological inputs. Addition of a cover crop during fallow periods in monocultures may provide environmental benefits that are lacking in monoculture cropping systems. However, finding an appropriate cover crop for successful preservation of soil resources for your region can be challenging. Winter rye is a highly suitable cover crop for the Upper Mississippi River Basin following corn silage harvest. Corn silage offers early establishment of winter rye to prevent soil erosion from a cropping system that generate minimal crop residue on the soil surface. Additional benefits that winter rye cover crop can offer is retention of nitrogen in the soil, suppression of weeds, and additional forage for ruminants. Winter rye is particularly well at reducing nitrate leaching during dormant periods of crop production. A meta-analysis found a 70% average reduction in nitrate leaching when cover crops were used (Tonitto, 2006). Staver and Brinsfield found that winter rye reduced nitrogen loads by 80% in subsurface groundwater and in deeper aquifers under corn rotations (1998).

In 2010 and 2011, corn silage was harvested on 141,639 hectares which is about 2% of total land farmed in Minnesota (USDA NASS, 2011 and USDA NASS, 2012). The lack of crop residue in corn silage cropping systems is a concern because with reduced crop residue inputs, soil will typically lose organic matter and soil quality declines. There has also been an increase in higher frequency and intensity of storm events across the contiguous U.S. A century ago, the most extreme storms contributed only 1% of total annual rainfall. Now extreme storms contribute 20% of total rainfall in the continental U.S. while total precipitation has only increased by 7% over the past century (Rosenzweig et al, 2000). This is alarming to soil conservation measures that have been in effect since the Great Depression. Continual research and implementation of sustainable management practices is important to sustaining soil quality and health in the agricultural landscape.

This study's main focus is on implementing a management practice of incorporating winter rye cover crop into a corn silage-soybean cropping rotation and evaluating surface runoff in a paired watershed design. We hypothesized that the use of a winter rye cover crop planted after corn silage harvest can reduce non-point source pollution through surface runoff compared to conventional corn silage management. The objective of this study was to evaluate the potential of a winter rye cover crop to minimize surface runoff and sediment and nutrient transport from agricultural landscapes by providing cover during the fall and spring dormant periods. Since many farmers prefer to harvest winter rye for forage, we evaluated the potential addition of winter rye as feed for dairy cows.

Materials and Methods

Location Description and Date

The study was conducted on a farm located near Lewiston, MN (43.969^0 N, 91.776^0 W) in 2009 to 2012. Two adjacent watersheds on Seaton silt loam with 0 to 6% slope (Fine-silty, mixed, superactive, mesic Typic Hapludalfs) were chosen for edge-of-field surface runoff monitoring. This study consisted of two treatments in a paired watershed experimental design. The treatments were drilled winter rye and fallow following two years corn silage and one year soybean rotation. Winter rye (cv. "Rymin") was seeded in treatment watershed on 23 September 2009 and 15 October 2010 at a rate of 101 kg ha^{-1} following corn silage using a grain drill with 17.78 cm row spacing. Winter rye was chemically terminated using glyphosate in mid-May prior to subsequent crop planting. Wing-walls were constructed using methods outlined by the United States Geological Survey and the University of Wisconsin-Madison (Stuntebeck, 2008). Construction began in mid October and ended on 29 October 2009. Watersheds were surveyed and trenched to 61 cm depth for plywood wall installation. The wall in the control watershed (no rye) is 76 m. The wall in the treatment watershed measures 60 m. After wall installation and backfilling, the wall was reinforced with 1.8 m T-posts spaced 2-5 m apart. Each watershed has a culvert in the bordering drainage ditches. The flume placement will allow the outflow of water to go directly toward the culvert to minimize ponding downstream of the flume. Platforms for the ISCO shelter and rebar support for the flumes were also installed in both watersheds. One H-flumes, 0.91 m in height (Plasti-Fab Inc., Tualatin, OR) coupled with ISCO 3700 portable sampler and 4230 bubbler flow meter (Teledyne ISCO Inc., Lincoln, NE) were used at each watershed in accordance with USGS recommendations (Stuntebeck, 2008). Equipment enclosures, flumes, ISCO portable samplers, and bubbler flow meters were installed in January 2010 and flow monitoring was initiated on 3 February 2010.

Winter Rye

Winter rye biomass was collected on 19 November 2009, 17 May 2010, 30 November 2010, and 19 May 2011. Biomass yield was determined by harvesting an area of 0.18 m^3 three times at seven GPS referenced locations within the watershed. Samples were dried at 650C for 72 h prior to weighing. A subsample was ground, passed through a 1 mm sieve, and analyzed for total N (TKN), neutral detergent fiber and phosphorus by wet analysis by Stearns DHIA Laboratories, Sauk Centre, MN.

Yield Measurements

Corn plants were collected on 7 September 2010. Determination of corn biomass was completed by hand harvesting corn plants in a 3 m length of 76 cm row at 14 locations in each watershed. Each sample was weighed on site and subsampled for moisture content. Subsamples for each location were dried for 3 days at 70°C. Dry matter was determined based on weight and moisture content.

Soybean plants were collected on 6 October 2011 which was 4 days prior to field harvest. Soybean plants were hand harvested in 3 m rows (76 cm row spacing) at 7 locations in each watershed. A mechanical sheller was used to thresh the beans from the pods. Subsamples for each location were dried for 3 days at 70°C to determine moisture content. Beans were weighed and yield was determined.

Water Samples

The automated field sites were programmed to sample on a volume basis with one sample collected for every 29.08 m^3 of surface runoff during snowmelt or rainfall events. Three samples are composited per 1 L polypropylene bottle (Teledyne ISCO Inc., Lincoln, NE). The sample collection at 29.08 m^3 was chosen so that during a runoff event, there would be sufficient sampler capacity to capture the entire event based on a predicted average water height of 0.15 m and a flow rate of 0.017 m^3s^{-1}. Water samples were immediately placed on ice in a cooler within 24 hrs and subsequently filtered using a 0.2 micron filter (VWR International, Chicago, IL) with a non-surgical syringe (120 mL was filtered from each bottle). Filtered samples were analyzed for NO_3-N, NH_4-N, and dissolved reactive Phosphorus using a Quikchem 8500 Lachat Ion analyzer (Hach Company, Loveland, CO). Total dissolved phosphorus was determined for filtered samples (University of Minnesota Soil Testing Laboratory) using rapid flow analyzer (RFA) method with Alpkem RFA 300 (RFA, 1986 and Astoria-Pacific, Clackamas, OR). Unfiltered samples were analyzed for Total Suspended Solids (TSS), Sediment Carbon, Sediment Nitrogen, and Total Phosphorus (TP). TSS was determined with ESS Method 340.2 (Environmental Protection Agency, US). TP analysis was performed by the University of Minnesota Soil Testing Laboratory using RFA method with Alpkem RFA 300 (RFA, 1986 and Astoria-Pacific, Clackamas, OR). Sediment carbon and sediment nitrogen were determined using Elementar Vario EL combustion analyzer (Elementar Americas, Inc., Mt. Laurel, NJ).

Soil Samples

Soil samples were collected on 09 October 2009, 24 May 2010, 5 October 2010, 19 May 2011, and 10 October 2011. Sixteen sample locations were chosen in a grid pattern for each watershed to captured slope characteristics (summit, back slope, and foot slope) and prior to each sampling date, locations were found using research grade global positioning system (GPS) mapping equipment. Two soil cores were collected at each sample location to a depth of 90 cm using a truck mounted Giddings probe (3.8 cm diameter). Cores were subsampled by depth in the following increments: 0-15 cm, 15-30 cm, 30-60 cm, and 60-90 cm and composited at each location. Soil samples were sub-sampled for physical analysis and were dried at 105^{0}C to determine gravimetric water content and bulk density. There was no difference between gravimetric water content or bulk density for the watersheds. The remaining sample was dried at $37^{0}C$, ground through <0.5 mm sieve, and analyzed for soil NO_3-N, NH_4-N, and Mehlich III P using a Quikchem 8500 Lachat Ion analyzer (Hach Company, Loveland, CO). The same sampling protocol and analysis were followed for each year of study.

Ground Cover Determination

Photographs for ground cover determination were collected on 20 November 2009, 20 May 2010, 30 November 2010, 18 May 2011, and 10 October 2011. Ten digital photographs were taken in each watershed using a camera mounted on a stand facing downward at a height of 1.2 m. The photographs were analyzed using USDA Sample-Point Measurement Software 1.48 (Booth, 2006). This software allows for an overlay of a 100-point grid to be placed over each photograph. Ground cover is determined by visual observation at each point.

Paired Watershed Design Comparisons

The control and treatment watersheds were adjacent to one another and had the same shape but differed in size. The treatment watershed was 1.2 ha and the control was 3 ha. Watershed boundaries and area were found using research grade global positioning system (GPS) mapping equipment. Both watersheds exhibited same flow pattern in slope characteristics but the distance from upper portion of watershed to equipment used to monitor surface runoff was different. The distance surface runoff traveled from upper boundary to the flume in the treatment watershed was 110 m. The distance in the control watershed was 180 m. In addition, the treatment watershed faced north and south, whereas the control watershed faced east and west. This was an important feature of the watersheds and how they behaved during snowmelt events with respects to solar radiation. The differences in the two watersheds were not desirable, however locating two exact watersheds that are adjacent to one another is nearly impossible. This was our best case scenario for this study.

Management of Watersheds

Both watersheds were slightly managed differently throughout the study. Winter rye was planted in the treatment watershed in 2009 and 2010 and did not allow for fall tillage or manure injection to take place. In the control watershed, fall chisel-disc tillage and manure injection occurred prior to freezing of soil in the fall of both years. Contour planting in the spring was observed in both watersheds. In spring 2010, winter rye harvest delayed corn planting which resulted in the farmer using a short season corn silage plant compared to normal corn silage planting in the control watershed. However, corn silage in the treatment watershed was able to catch up in maturity to the corn silage in the control watershed. Similarities between the watersheds included contour planting of corn silage and soybean crops. Differences in management were fall tillage and manure injection in control compared to only winter planting in the treatment watershed.

Authenticity of Data

Measuring real-time surface runoff for accuracy has some challenges. During all runoff events, if the flume was not level, readings of flow rate were then incorrect. To deal with this issue, leveling of the flume was done at each visit to the field sites and the flumes were never unbalanced. Freezing of sampling line, ice buildup in the flume, and malfunction of sampler were the three main challenges to this study when surface runoff was observed. Determination of runoff start and end times were confirmed based on flow rates, time of runoff, and air temperatures at time of runoff for fall and spring runoff events. Manual manipulation of data then occurred during times of incorrect runoff measurements (Stuntebeck, 2008). Majority of the incorrect runoff flows were when ice buildup occurred in the flume during the night. Sampler malfunction occurred mostly during spring snowmelt events. Freezing night temperatures would cause the ice buildup in the flume and provided incorrect flow measurements. These incorrect flow measurements would trigger the sampler to take a water sample.

Some of the snowmelt that may have occurred during times when a technician could not be there had no collection of runoff samples because ice buildup in the flume caused the sampler to use up all available collection bottles. These occurrences were not frequent but based on overall total volume of runoff from each watershed; more bottles could have been collected. The control watershed had 24 bottles collected and the treatment watershed had 62 bottles. Based on total runoff from both watersheds, 32 and 79 bottles should have been collected from control and treatment watersheds, respectively. The missing collection samples for the control watershed occurred in the spring of 2010 when there was 282 m^3 ha^{-1} of runoff which should have triggered runoff samples into nine bottles. Seventeen bottles were not collected in the treatment watershed and they were missing from summer 2010 and spring 2011 events. There was 75% and 79% sample-volume coverage for control and treatment watersheds, respectively. Discovery and Pioneer farms in Wisconsin that are operated by United States Geological Survey (USGS) had 90% annual sample-volume coverage during a 6 year period from 12 edge-of-field sites (Stuntebeck, 2008).

Results and Discussion

Winter Rye, Yield, Ground Cover, and Soil Composition

Winter rye biomass was 15% greater in spring 2010 than 2011 because of earlier planting in fall. Fall growth in 2009 was 82% greater than fall 2011 (Table 1). Establishing winter rye following corn silage earlier in the fall will potentially provide more biomass in the spring if environmental conditions are favorable. Winter rye had 3% TKN and 0.39% phosphorus. Nitrogen accumulation for winter rye in fall 2009 and spring 2010 was 25 kg ha^{-1} and 190 kg ha^{-1}, respectively. Nitrogen accumulation for winter rye in fall 2010 and spring 2011 was 4 kg ha^{-1} and 162 kg ha^{-1}, respectively (Table 1). Neutral detergent fiber was 43% which is compared to pure alfalfa of 40%. Winter rye could be used in a mixed grass-legume stands, where the forage at feeding should contain 46 to 48% NDF.

Table 1. Winter Rye Biomass Yield

Season	Year	Biomass (kg ha^{-1})
Fall	2009	845
Spring	2010	6342
Fall	2010	148
Spring	2011	5385

Optimal growth of winter rye is crucial if harvesting for animal feed or to prevent soil erosion. In 2010, spring growth of winter rye yielded 6.34 metric tons ha^{-1} which was used as rye-silage for dairy herd. Rye can have effects on subsequent crop yield because of water and nutrient usage and termination of winter rye in the spring can delay crop planting. This was observed in 2010 corn silage yields. A 30% reduction in corn silage yield occurred in the treatment watershed compared to the control (Table 2).

Wet field conditions did not allow for winter rye to be harvested which led to delay corn silage planting. The delay of corn silage between watersheds was a month. A short season corn silage variety was then used in the treatment watershed so yield loss was less extreme. Even with addition of rye biomass with corn silage yields, there was still a 10% reduction in yield (Table 2). Soybean yield for 2011 was 3.3 metric tons $ha^{-1}$and 3.3 metric tons ha^{-1} in control and treatment, respectively.

Table 2. 2010 Biomass yields

Watershed	Corn Silage	Rye Biomass	Yield Loss	With Rye Yield Loss
	metric tons ha^{-1}	metric tons ha^{-1}	%	%
Control	32.48	-	-	-
Treatment	22.88	6.34	30	10

Ground cover varied between watersheds and between years. Residue cover decreased in the control watershed from fall to spring where as residue cover increased in the treatment watershed (Table 3). This was due to residue decomposition in the control and presence of winter rye growth in the treatment from fall to spring. Ground cover in the control during the fall was either slightly above or below the 30% conservation standard by NRCS. This is considered adequate cover to reduce soil erosion. However, in the spring of both years, ground cover in the control watershed was less than ideal to prevent soil erosion. In fall of 2011, ground cover was similar between watersheds after soybean harvest because no planting of winter rye occurred in the treatment watershed that fall.

Table 3. Ground Cover

	Year	Control	Treatment
		%	%
Fall	2009	25	64.8
Spring	2010	2.9	100
Fall	2010	43.9	56.8
Spring	2011	11.3	90.2
Fall	2011	19.5	21.2

In spring 2010, winter rye reduced soil NO_3-N concentrations by 30% compared to the control watershed suggesting that the rye effectively scavenged excess soil NO_3-N during the spring. In 2011, winter rye had less of an effect on soil NO_3-N concentrations (no statistical difference) because the control watershed had manure injected at a rate of 93,500 L ha^{-1} immediately following corn silage harvest which compromised our results. Fall 2011 soil NO_3-N concentrations were similar between watersheds following soybean harvest with no addition of winter rye.

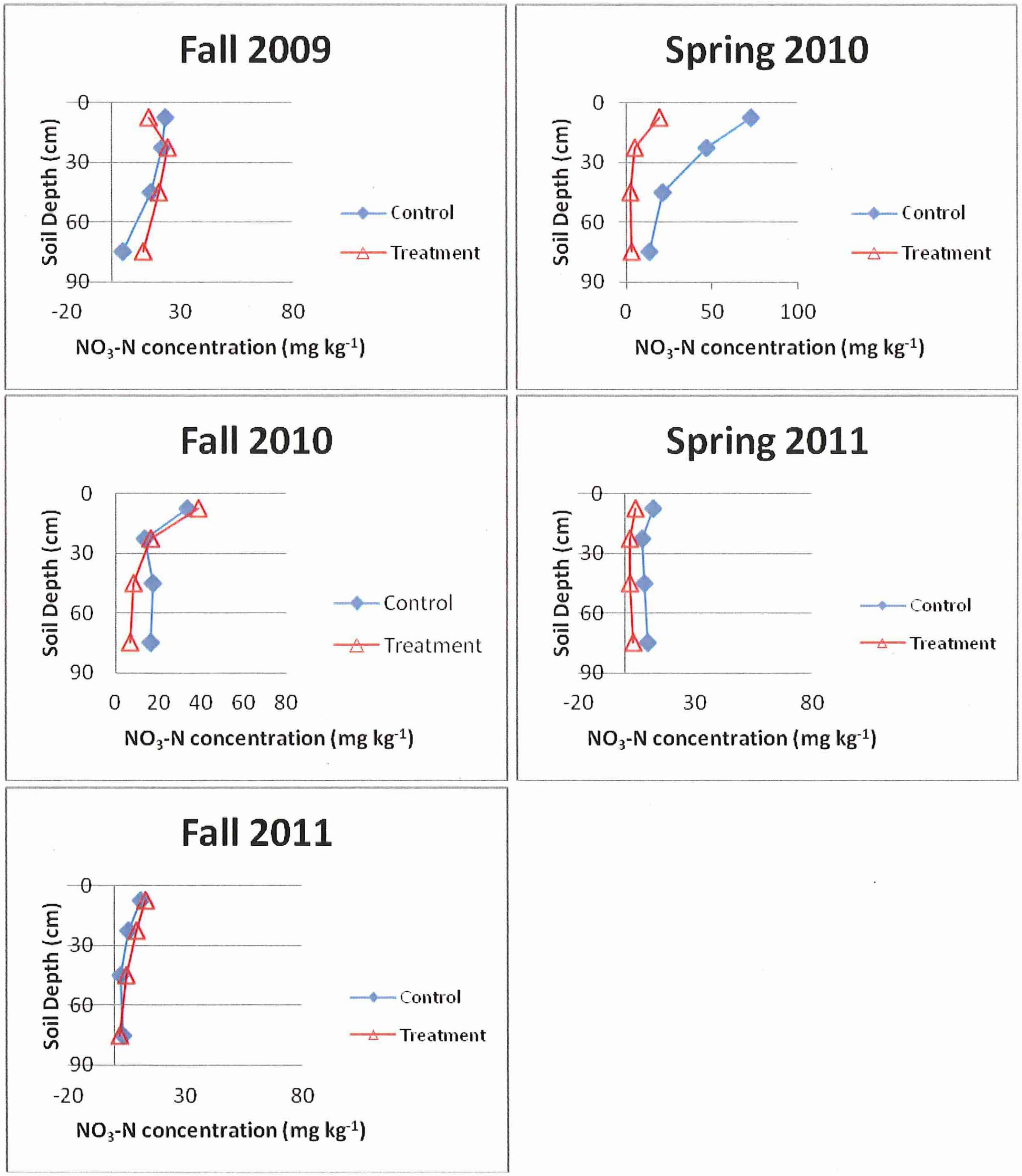


Figure 1. Soil NO_3-N concentrations for fall and spring. Concentrations are reflected in the figure at the average point between sample increments.

Ammonium concentrations in the soil fluctuate frequently during the year because it is subject to many changes in the soil system. Nitrogen transformation of ammonium includes nitrification, immobilization, and volatilization. These transformations or fluctuations of ammonium are evident in the soil of the control and treatment watersheds (Figure 2). There was no difference between NH_4-N concentrations from year to year. The addition of manure in the control watershed in both years caused frequent transformations of ammonium throughout the year.

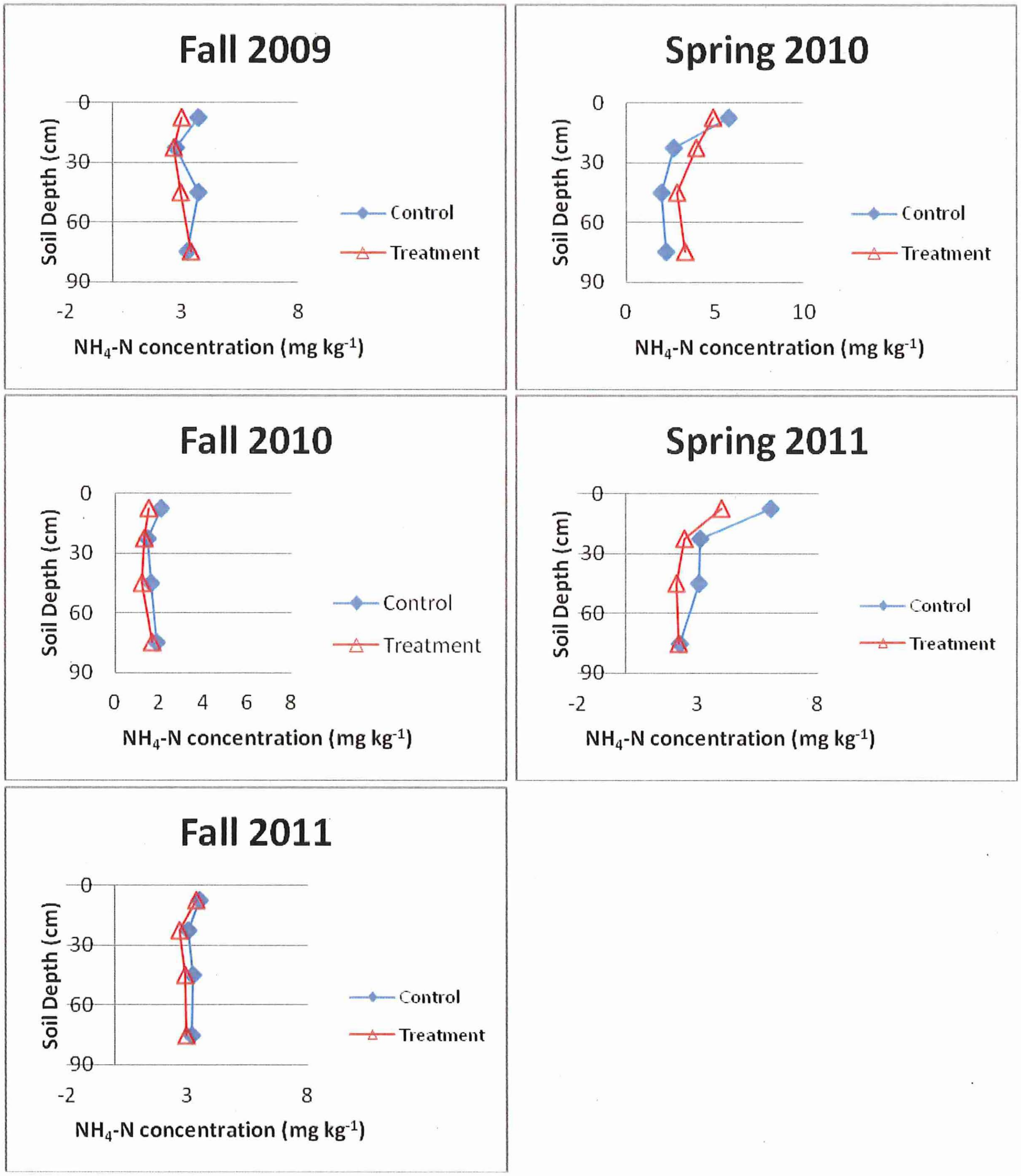


Figure 2. Soil NH_4-N concentrations for fall and spring. Concentrations are reflected in the figure at the average point between sample increments.

Soil Mehlich III-P concentrations varied slightly between fall and spring from 2009 to 2011. Phosphorus concentrations did not vary in the treatment watershed from fall to spring when winter rye was present suggesting that winter rye did not uptake P. In the control watershed P concentrations increased from fall to spring because of fall manure application (Figure 3).

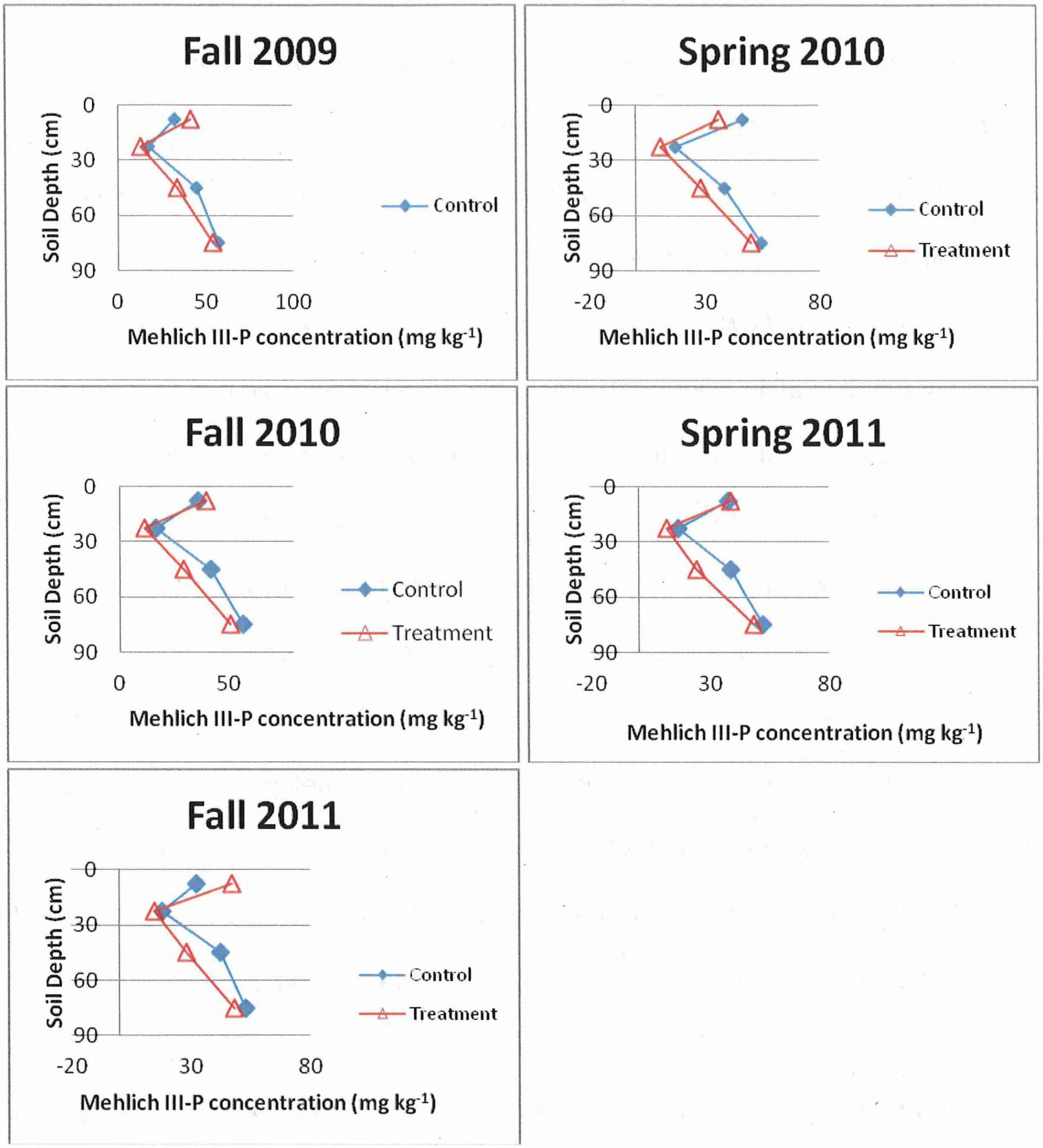
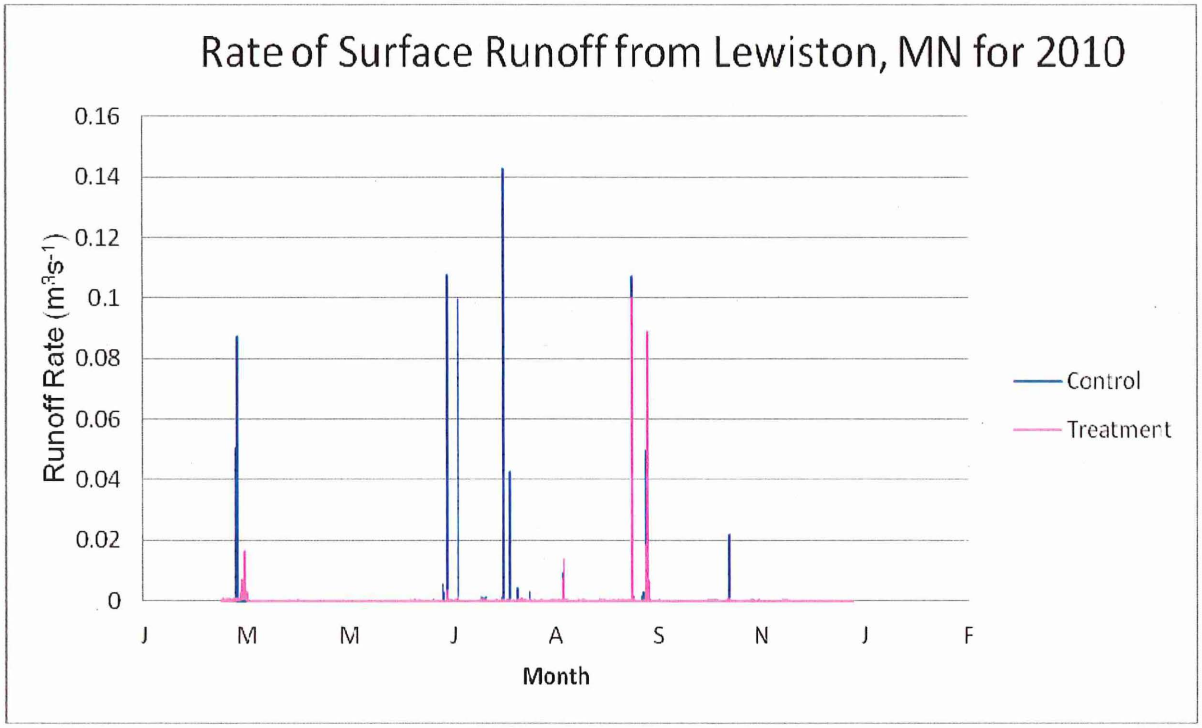


Figure 3. Soil Mehlich III-P concentrations for fall and spring. Concentrations are reflected in the figure at the average point between sample increments.

Total Water Volume

Differences in total surface runoff were observed in 9 out of 26 months. These 9 months included the 5 major surface runoff events that had sample collections (see runoff losses below). The treatment watershed had 60% more runoff than the control watershed. Majority of the difference in annual runoff occurred during spring snowmelt events of 2010 and 2011, as well as the 23 September 2010 rainfall event. Higher rates of flow were observed in both watersheds in 2010 than 2011. The control watershed had more frequent rates of flow in 2010, whereas the treatment watershed had more frequent flow of runoff in 2011 (Figure 4). The higher rates of flow did not correlate to higher total volumes of runoff. The treatment watershed had a higher total runoff because runoff was occurring for longer periods of time than the control watershed. Evidence of this was the spring 2010 snowmelt where the treatment watershed runoff began on 3 March 2010 and ended on 14 March 2010 and runoff on the control watershed began 7 March 2010 and ended on 8 March 2010. Total volume of runoff from each watershed was similar at the beginning of the snowmelt period, but both the duration of runoff and the total volume of runoff from the treatment watershed were greater. Spring 2011 snowmelt produced a greater surface runoff than spring 2010. There were three snowmelt periods on 16 February, 11 March, and 20 March in 2011 (Figure 4).

The snowmelt events produced 75% more runoff in the treatment watershed than the control. This was due to snow catchment with the winter rye and the north-south facing aspects of the watershed. Snow cover insulates soils from freezing and allows for better infiltration of snowmelt in the spring (Schimel et al., 1996). Less snow cover causes a deeper penetration of frost in the soil profile, thus limiting water infiltration in the spring when snowmelt occurs (Shanley and Chalmers, 1999). We had both of these processes occurring in the two watersheds. First, the treatment watershed held more snow in both years and resulted in more snowmelt runoff. Secondly, the north-south aspect of the treatment watershed allowed for the snow to melt during the winter months when temperatures were at 0^{0}C or higher and then refreeze during the night when temperatures dropped. This fluctuation of slight melting and then refreezing caused an ice layer of 7.62 cm in the treatment watershed for both years which allowed for more water to runoff and not infiltrate the soil when snowmelt occurred. Furrows created by tillage in the control impeded runoff and promoted infiltration, which may have limited the total volume of runoff from the control watershed. There were no such furrows in the treatment watershed as primary and secondary tillage, in addition to rye seeding, resulted in a smooth soil surface. Contouring ripping or tillage in the fall allows for better infiltration of northern latitude soils (Pikul et al., 1996). These major management differences in the watersheds provided the differences in snowmelt runoff for the two years.



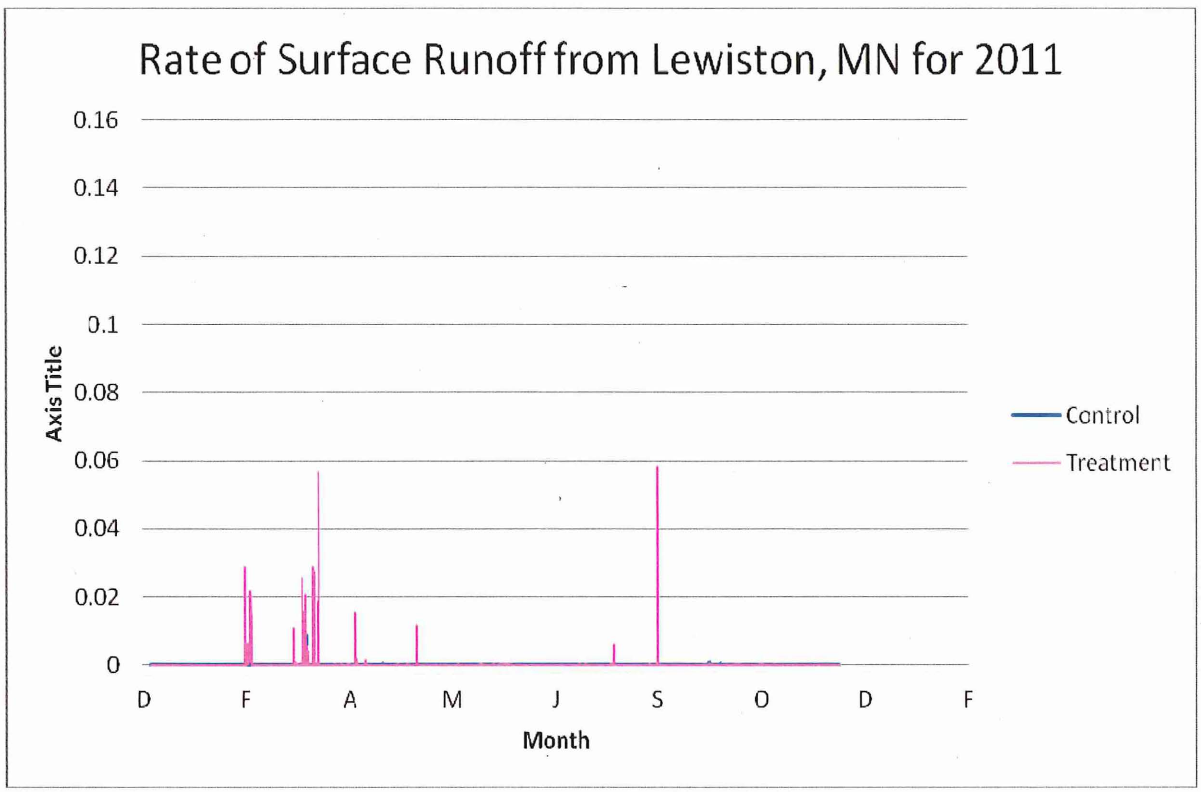
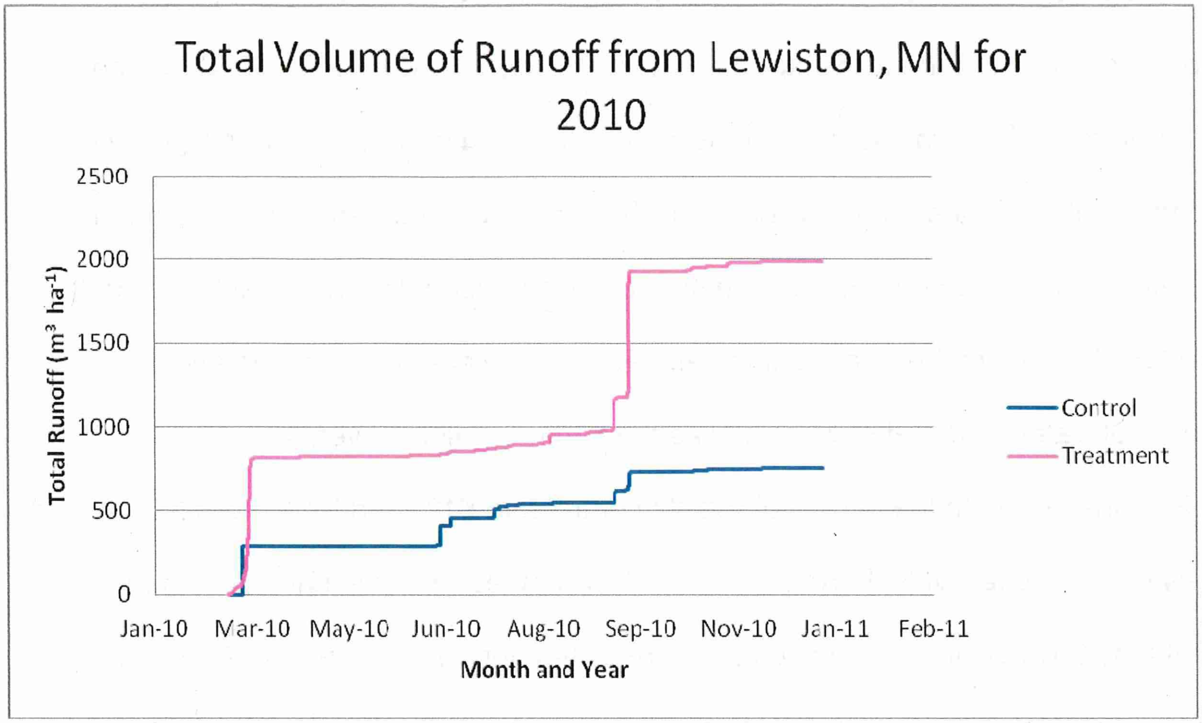


Figure 4. Rates of flow for both watershed in 2010 and 2011.

Summer runoff events of 2010 occurred more frequently in the control watershed than the treatment watershed (Figure 5). Both watersheds had summer runoff events on 17 June 2010 and 23 June 2010 with rainfall rates of 3.86 cm and 3.2 cm respectively. However, the control watershed had greater maximum rates of runoff compared to the treatment watershed. The control watershed maximum rates of runoff were 0.108 m^3 s^{-1} on 6/17/10 and 0.099 m^3 s^{-1} on 23 June 2010, corresponding to a head of 0.36 m and 0.34 m, respectively (Fig. 4). The treatment watershed maximum rates of runoff were 0.003 m^3 s^{-1} and 0.0012 m^3 s^{-1}, respectively (Fig. 4). Their corresponding head heights of water were 0.06 m and 0.04 m, respectively. These summer events accumulated 262 m^3 ha^{-1} of runoff in the control compared to 133 m^3 ha^{-1} in the treatment watershed.

Both watersheds had fall runoff events on 15 September 2010 and 23 September 2010 with rainfall rates of 8.1 cm and 18 cm, respectively. However, the control watershed had a greater maximum rate of runoff on 15 September 2010 compared to the treatment watershed. The control watershed maximum rate of runoff was 0.107 m^3 s^{-1} and the treatment watershed maximum rate of runoff was 0.09 m^3 s^{-1} corresponding to a head height of 0.36 m and 0.34 m, respectively (Fig. 4). In contrast to the 15 September 2010 rainfall event the maximum runoff rates were higher in the treatment watershed than the control watershed on 23 September 2010. The runoff rates at peak flow were 0.08 m^3 s^{-1} (head height of 0.32 m) and 0.05 m^3 s^{-1} (head height of 0.25 m), respectively (Fig. 4). In this event the control watershed had 110 m^3 ha^{-1} of runoff and the treatment watershed had 751 m^3 ha^{-1} (Figure 5). The 23 September 2010 rainfall event was massive and the runoff caused a blow out on the wall of the control watershed. The maximum rate of runoff for the control watershed is misleading because runoff escaped underneath the wall (blowout issue) during this runoff period. It is unknown when the blow out occurred during the storm event and what volume of runoff escaped.



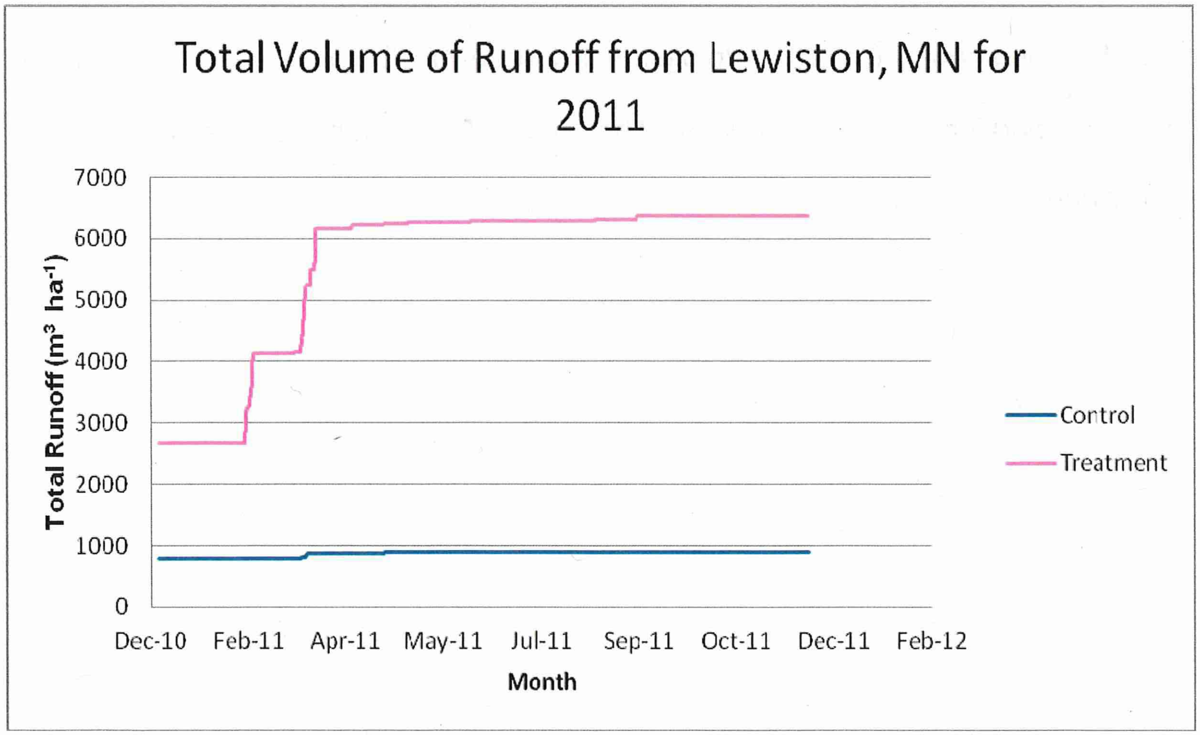


Figure 5. Total volume of runoff ($m^3\ ha^{-1}$) for both watersheds in 2010 and 2011.

NO_3-N, NH_4-N, and Phosphorus loss in Surface Runoff

The treatment watershed had more NO_3-N and NH_4-N loads than control watershed in 2 out of the 3 events where samples were collected (Table 4). In the 22-23rd September 2010 rainfall event treatment watershed had 63% more NO_3-N load than the control. In the same event, the NH_4-N load from the treatment watershed was 28% greater than the control. Snowmelt of 2011 produced 87% more NO_3-N and 89% more NH_4-N loads in the treatment watershed than the control. The one event where the control watershed had more load was the summer rainfall events on 17 June 2010 and 23 June 2010. In these rainfall events control had 61% and 99% more NO_3-N and NH_4-N loads, respectively than the treatment watershed. For the snowmelt of 2010 and the 18 May 2011 rainfall events comparisons could not be made because the sampler malfunctioned for the control watershed. This was due to the sampler distributer being jammed. For the snowmelt of 2011, this jamming issue was because water froze on the distributer causing it not to work properly. The 18 May 2011 event had the same issue, but ice buildup did not occur.

Table 4. NO_3-N and NH_4-N Loads in Surface Runoff from Specific Events

	Control		Treatment	
Event	**NO_3-N**	**NH_4-N**	**NO_3-N**	**NH_4-N**
	------------ kg ha^{-1} ------------			
Snowmelt 2010	-*	-*	1.0	0.09
Summer 2010 Rain Showers	0.23	2.03	0.09	0.002
Sept 22nd , 23rd 2010	0.27	0.15	0.73	0.21
Snowmelt 2011	0.36	0.15	2.7	1.4
May 18th 2011	-*	-*	0.01	0.01

* missing data is due to sampler malfunction during events

None of the samples collected from the watersheds were over 10 ppm. These concentrations are below the EPA water quality standard of 10 mg L^{-1} in drinking water. This standard of 10 mg L in drinking water was established to prevent human infant deaths caused by blue-baby syndrome. Blue-baby syndrome is an environmental-caused health disorder where the blood lacks the ability to carry enough oxygen to vital tissues and organs (Knobeloch et al., 2000). The control watershed had the highest concentrations of nitrate of 9.44 mg L^{-1} and 9.24 mg L^{-1} on 29 July 2010 rainfall event and in spring 2011 snowmelt, respectively (Figure 6). Ammonium concentrations were also higher in the control than the treatment watershed (Figure 7). The highest concentration of ammonium was observed on 5 May 2010 with a concentration of 11.4 mg L^{-1}. However, the treatment watershed had more surface runoff from events which resulted in higher loads than the control (Table 4).

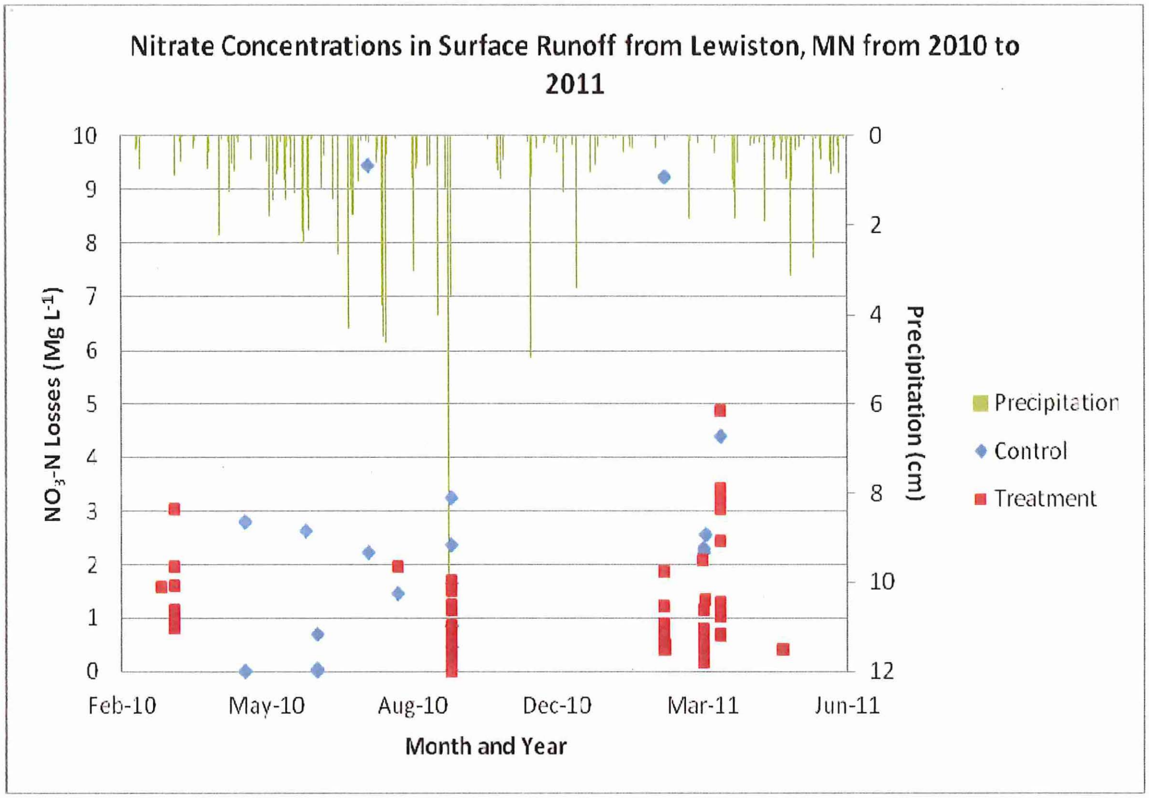


Figure 6. Nitrate concentrations for control and treatment watersheds. Squares and diamonds are concentrations from samples taken during surface runoff events.

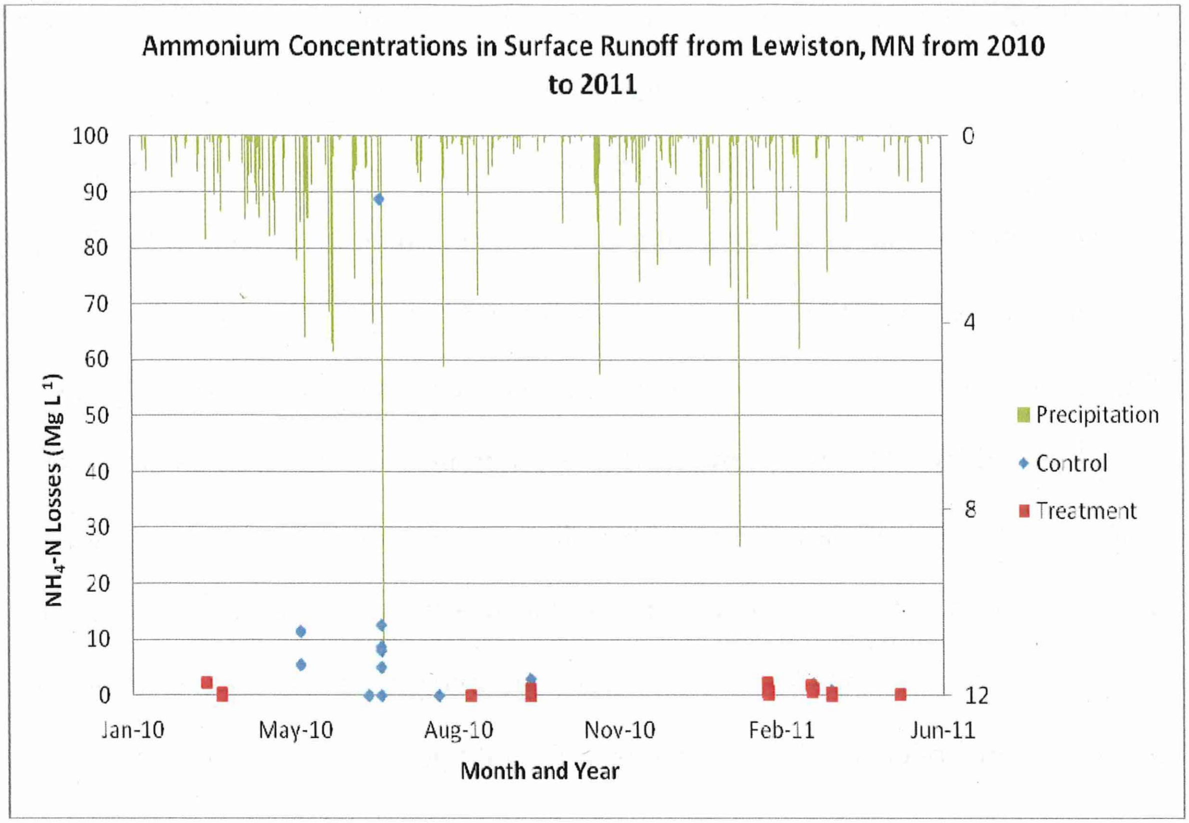


Figure 7. Ammonium concentrations for control and treatment watersheds. Squares and diamonds are concentrations from samples taken during surface runoff events.

The treatment watershed had more total phosphorus (TP) loads than control watershed in 2 out of the 3 events where samples were collected (Table 5). In the 22 September and 23 September 2010 rainfall event the treatment watershed had 87% more TP than the control watershed. Majority of the TP in that event was sediment-bound P, or particulate phosphorus (PP). In the 2011 snowmelt event, treatment watershed had 94% more TP than the control. Similar to the September rainfall event, PP was the source of the phosphorus. The summer 2010 rainfall events on 17 June and 23 June TP was 85% more in the control than the treatment watershed. The TP was mostly comprised of PP in this event as well. Total dissolved phosphorus (TDP) was higher than PP in 4 of the surface runoff events (2 in control and 2 in treatment) (Table 5.) Dissolved inorganic phosphorus (DIP) also known as phosphate was the majority in total dissolved phosphorus than dissolved organic phosphorus (DOP) in all of the samples collected. DIP is readily available to plants as a phosphorus source. It is also readily available to algae in rivers, lakes, and streams, where if in excess can cause eutrophication. Majority of the phosphorus concentrations collected (99%) from the surface runoff in both watersheds would have caused accelerated eutrophication in lakes (Figure 9). Accelerated eutrophication of lakes happens when concentrations of 0.025 mg L^{-1} are added. Max recommended DIP concentrations for streams and rivers are 0.1 mg L^{-1}. Only 88% of samples were over the max recommended concentrations for streams and rivers. This edge-of-field monitoring was not near any lakes, rivers, or streams. These concentrations in the runoff would probably never reach a waterway at these concentrations, because the distance is too great and the runoff from these watersheds empty into pasture land.

Table 5. Phosphorus Loads in Surface Runoff from Specific Events

	Control					Treatment				
	TP	PP	TDP	DIP	DOP	TP	PP	TDP	DIP	DOP
Event					kg ha^{-1}					
Snowmelt 2010	- -*					0.2	0.05	0.15	0.14	0.01
Summer 2010 Rain Showers	0.27	0.2	0.07	0.04	0.03	0.04	0.01	0.03	0.03	-
Sept 22nd, 23rd 2010	0.16	0.04	0.12	0.11	0.01	1.23	0.83	0.40	0.34	0.06
Snowmelt 2011	0.15	0.05	0.10	0.09	0.01	2.48	1.78	0.70	0.70	-
May 18th 2011	- -*					0.01	0.003	0.007	0.007	-

* missing data is due to sampler malfunction during events

The highest levels of TP were observed in the treatment watershed in the spring 2011 snowmelt event were TP was 11 mg L^{-1} (Figure 8). The highest observed TP concentration for the control watershed was 4.68 mg L^{-1} on 23 June 2010 (Figure 8). The highest concentrations of DIP or phosphate in runoff were seen in the control watershed. These higher concentrations were in 8 samples ranging from 0.75 to 1.26 mg L^{-1} (Figure 9). These concentrations were observed in the September 2010 storm and spring 2011 snowmelt. The highest concentration of DIP in the treatment was 0.64 mg L^{-1} on 15th August 2010 (Figure 9).

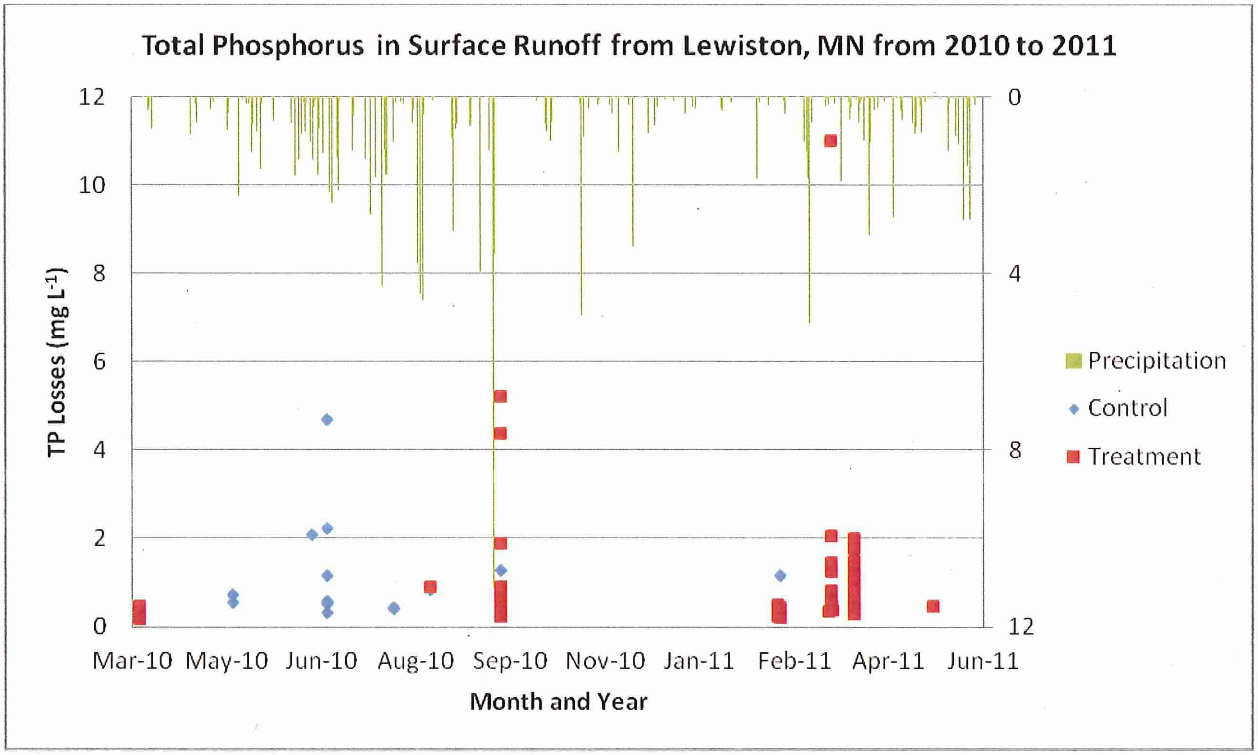


Figure 8. Total phosphorus concentrations for control and treatment watersheds. Squares and diamonds are concentrations from samples taken during surface runoff events.

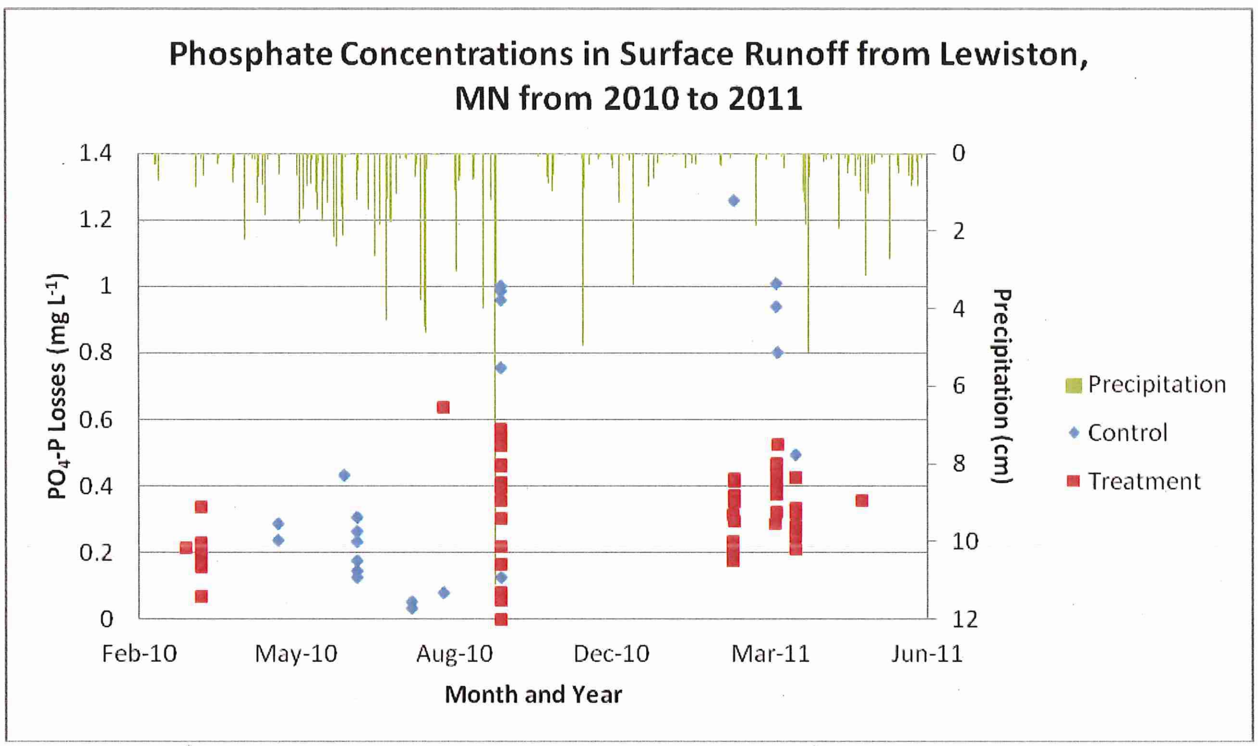


Figure 9. Dissolved Inorganic Phosphorus or Phosphate concentrations for control and treatment watersheds. Squares and diamonds are concentrations from samples taken during surface runoff events.

Sediment Loss

Similar to nitrogen and phosphorus loads, sediment loads were higher in the treatment watershed in 2 out of the 3 events where sampled were collected from both watersheds (Table 6). In the September 2010 storm, treatment had 78% more sediment than the control. In the snowmelt event of 2011, treatment watershed had 99% more sediment load than the control. The summer rainfall of 2010 produced 97% more sediment load in the control than the treatment. From what was sampled in the watersheds, 248 metric tons ha^{-1} of soil was lost from the treatment watershed and 32 metric tons ha^{-1} was lost from the control watershed in surface runoff. Soil erosion next to world population growth is a major threat to human survival for future generations. Soil is being lost 10 to 40 times faster than it is being replenished (Pimentel, 2006). The C/N ratio for the treatment watershed was 8.7 where as the control was 7.7. The highest total suspended solid (TSS) concentrations were in the treatment watershed and occurred in the spring 2011 snowmelt event. These concentrations ranged from 220040 to 396990 mg L^{-1} (Figure 10). The highest TSS concentration in the control was observed on 5th May 2010 and was 177800 mg L^{-1} (Figure 10).

Table 6. Sediment Loads in Surface Runoff

	Control			Treatment		
	Sediment	N	C	Sediment	N	C
Event	------------ kg ha^{-1} ------------					
Snowmelt 2010	-*	-*	-*	4206	14	95
Summer 2010 Rain Showers	15359	54	410	473	2	22
Sept 22nd, 23rd 2010	16099	66	538	72752	345	3032
Snowmelt 2011	343	1	11	169954	556	5221
May 18th 2011	-*	-*	-*	194	0.9	7.2

* missing data is due to sampler malfunction during events

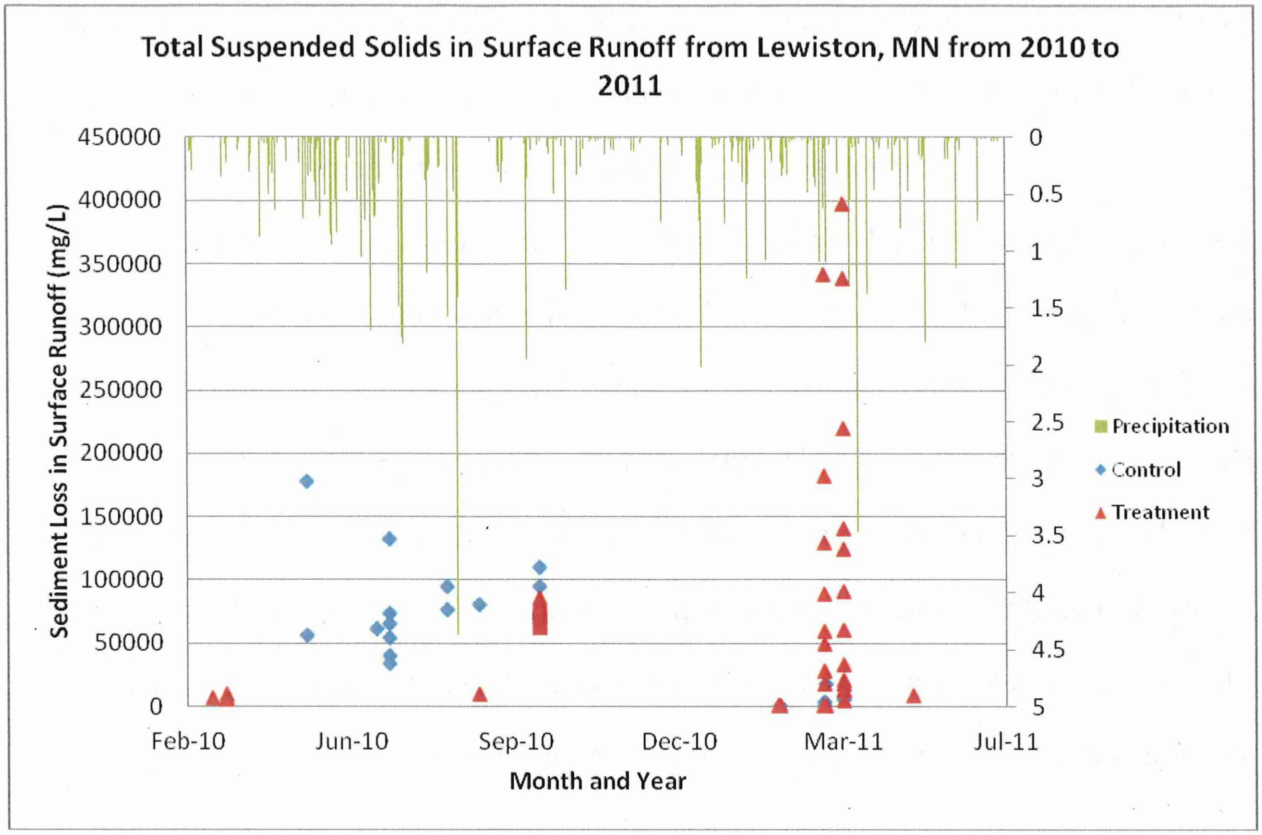


Figure 10. Sediment concentrations for control and treatment watersheds. Triangles and diamonds are concentrations from samples taken during surface runoff events.

Conclusion

The treatment (rye) watershed had 60% more surface runoff than the control (fallow) watershed from 2010 to 2012 and subsequently had more nutrient and sediment loss. Winter rye cover cropping as a best management practice is thought to reduce surface water runoff and off field transport of nutrients and sediment. While majority of studies show this result; this study did not have the same conclusions. The differences in surface runoff and loss of nutrients and sediment are most likely due to the differences in watershed characteristics and management of the fields. Both watersheds exhibited same shape and slope, but differed in field size and distance that surface runoff traveled from upper portion to monitoring equipment. Evaluating surface runoff in a paired watershed in an on-farm research setting has restrictions than one that could be conducted at a research station. Flexibility had to be shared between the researchers and farmer involved because loss of economical gains from these watersheds was not a viable option when trying to control aspects within the management of the two watersheds. Another major fault of the study is the duration of evaluating surface runoff in these two systems. Two years does not capture climatic variations in weather from year to year, suggesting that more years of study should occur to control variation in weather from year to year. One major accomplishment was that we were able to have equipment in place when the 23 September storm occurred which caused the largest flooding event since 18 August 2007. A 100-year storm for this region is 15.24 cm of total rainfall over a 24-hour period.

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Overall Conclusion

Winter rye reduced soil erosion and nutrient transport in surface runoff in the simulated rainfall studies but was less apparent in the edge-of-field Lewiston study. Winter rye, both standing and clipped, reduced runoff in both years from the Lewiston rainfall study, allowing 99% less surface runoff in 2010 and; 67% and 19% for standing rye and harvested rye in 2011, respectively, than fallow treatments. As a consequence, nutrient and sediment loads were also reduced compared to the fallow treatments. Surface runoff was also reduced in winter rye treatments from the Rosemount rainfall simulation study. Aerial, airflow and broadcast seeding methods reduced surface runoff, sediment, and nutrients compared to fallow treatments. Uniformity in winter rye stands is essential to having successful prevention of soil erosion and nutrient losses. However, increasing rate of seeding does not necessarily provide uniformity across the field. Broadcast treatments were seeded at a rate of 224 kg ha^{-1}, whereas aerial and airflow treatments were 112 kg ha^{-1}. Broadcast has double the seeding rate of aerial and did not provide more environmental benefits. This is a concern for farmers who do not need to be spending more money for establishing a cover crop when they can receive equal environmental benefits using a lower seeding rate.

At the edge-of-field experiment in Plainview, surface runoff by area increased by 30% in the treatment watershed after stover was removed. The long term impacts of baling or removing corn stover could be detrimental to improving soil quality and health. Sediments and nutrients lost in surface runoff were not calculated because sample collection did not occur in 2011 in the treatment watershed. Any indications of sediment loss and nutrient loss from this watershed would have been greater in 2011 than 2010 because surface runoff was greater. Evaluating surface runoff in a paired watershed in an on-farm research setting has restrictions than one that could be conducted at a research station. Flexibility had to be shared between the researchers and farmer involved because loss of economical gains from these watersheds was not a viable option when trying to control aspects within the management of the two watersheds. This issue arose in the last year of the study when soybeans were planted. Prior to planting soybeans, it was agreed upon that both watersheds would be planted into soybeans. One week prior to planting the cooperator decided that corn for grain would provide more profitability than soybeans. The control watershed was then planted 50% corn for grain and alfalfa and 50% soybeans. These situations can arise when conducting on-farm research.

At the edge-of-field experiment in Lewiston, the treatment (rye) watershed had 60% more surface runoff than the control (fallow) watershed from 2010 to 2012 and subsequently had more nutrient and sediment loss. Winter rye cover cropping as a best management practice is thought to reduce surface water runoff and off field transport of nutrients and sediment. While majority of studies show this result; this study did not have the same conclusions. The differences in surface runoff and loss of nutrients and sediment are most likely due to the differences in watershed characteristics and management of the fields. Both watersheds exhibited same shape and slope, but differed in field size and distance that surface runoff traveled from upper portion to monitoring equipment. Evaluating surface runoff in a paired watershed in an on-farm research setting has restrictions than one that could be conducted at a research station. Flexibility had to be shared between the researchers and farmer involved because loss of economical gains from these watersheds was not a viable option when trying to control aspects within the management of the two watersheds. Another major fault of the study is the duration of evaluating surface runoff in these two systems. Two years does not capture climatic variations in weather from year to year, suggesting that more years of study should occur to control variation in weather from year to year. One major accomplishment was that we were able to have equipment in place when the 23 September storm occurred which caused the largest flooding event since 18 August 2007. A 100-year storm for this region is 15.24 cm of total rainfall over a 24-hour period.