Quantifying cover crop and reduced tillage impacts on corn silage production and water quality

By

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Quantifying Cover Crop and Reduced Tillage Impacts on Corn Silage Production and Water Quality

Laura C. Adams

Under the supervision of Dr. Francisco J. Arriaga at the University of Wisconsin- Madison

Abstract

In Wisconsin, the dairy industry is essential to both the state's economy and community's way of life. Corn silage is the predominant feed for cows due to its high feed value. When harvesting corn silage, the entire crop is removed, often leaving soil bare which increases susceptibility to erosion and runoff. Many Wisconsin lakes and streams contain high amounts of sediment and phosphorus (P), effecting aquatic ecosystems. Reduced tillage methods and growing a cover crop after harvest increase soil coverage and are two strategies used by farmers to control erosion and nutrient losses. In addition to protecting the soil, cereal rye grown as a cover crop in dairy systems can have an added benefit of being harvested in the spring and used as additional feed. This study was conducted to determine the potential of incorporating cereal rye as a cover crop into a Wisconsin dairy system, analyzing the impacts on overall production and water quality.

In the first part of this study, a survey was created and distributed to various agricultural professionals in Wisconsin to determine if cover crops are a commonly used practice in the state, and to find the incentives or barriers surrounding cover crops. With 165 completed surveys returned (30.6% response rate), 86.1% of respondents have used or currently use cover crops in their operation. Top benefits to using cover crops were a reduction in erosion (74.1%) and an improvement in soil health (58.0%). There were various reasons given that deter farmers away from using cover crops, such as time/labor required

(52.2%) and no measurable economic return (39.1%). Many participants, both cover crop users and non-users, expressed their desire to better understand how cover crops fit into their specific operation and how their use would affect the timing of other management practices.

With cover crops being used in various operations in Wisconsin, it was clear that further research on the topic would be beneficial. High yields and maximum production is vital to a farmer, leading to the second part of this study. Three cover crop treatments (no cover crop, cover crop terminated, and cover crop harvested) and two tillage methods (conventional tillage and no-tillage) were compared to determine impacts on overall production. There were no significant differences in forage yields between treatments in 2014, most likely attributed to low cover crop biomass production due to late planting. Forage yields in 2015 were similar between treatments, with exception of the conventional tillage with no cover, which had a statistically lower yield than the other treatment combinations. We found that in 2016, the cereal rye harvested treatment yield (corn silage plus rylage) was greater than no cover crop or cover crop terminated treatment yields, regardless of tillage. Estimated milk production was also greater in cereal rye harvested plots compared to cover crop terminated plots in 2016.

The last part of this study aimed to determine the ability of cereal rye as a cover crop to reduce runoff, sediment, and various P losses. Two cover crop treatments (no cover crop and cover crop) and two tillage methods (conventional tillage and no-tillage) were compared. Rainfall simulations were performed at three different times throughout the cropping cycle (June 2016, October 2016, and April 2017). Regardless of tillage, treatments with cover crops reduced total runoff volume by 24.1%, sediment loss by 51.5%, and total P loads by 42.0% when averaged across rainfall simulation timings. Bioavailable P, which is considered to be the most influential pollutant in freshwater ecosystems, was reduced by 33.8% with cover crops when averaged across the three-month simulation timings. Tillage had no effect on any parameters analyzed. In Wisconsin, most runoff and sediment losses occur when soils are thawing between March and May. In the April rainfall simulations, treatments containing rye as a cover crop reduced runoff by 45.9%, sediment loss by 70.7%, Total P by 68.5% and Bioavailable P by 65.9%, suggesting that cover crops can play a significant role during such a vulnerable time of year.

Although this study uncovered the potential of cover crops, there is much more work that can be done in the future. Completing a full economic analysis when incorporating cover crops into an operation could allow farmers to truly see profit margins. Cover crops have a bounty of other benefits, such as improving physical soil properties. An analysis on various properties could uncover even more cover crop values. Our study site was under the different management practices for only three years. The influence of both tillage and cover crop might not be seen in such a short time. Long-term studies would be beneficial to truly understand the role of these management practices.

Chapter 1: Determining the barriers and incentives of using cover crops on Wisconsin farms.

Abstract

Cover crops are used in a variety of ways and can have a range of benefits in an agricultural system. The use of cover crops is increasing throughout the United States, yet many barriers that prevent farmers from adopting the practice. Few studies have been conducted that focus on cover crop use, and no studies have occurred in the state of Wisconsin. A short survey was created aiming to determine if farmers are incorporating cover crops into their operation, the reasons farmers use them, or why they choose not to use cover crops. The survey was distributed at various University of Wisconsin-Extension Soil, Water and Nutrient Management regional meetings at eight locations throughout the state and one field day in Arlington, WI, with 165 completed surveys returned. More than 86% of the respondents have or are currently using cover crops in their operations, with 13.9% never having used cover crops. Top benefits to using cover crops were reduction in soil erosion (74.1%), soil health improvement (58.0%), and increases in organic matter (54.0%). Non-cover crop users gave various reasons that prevent them from growing cover crops, with time/labor requirements being the most common reason (52.2%), followed by no measurable economic return (39.1%), and cost of planting and managing (30.4%). Overall, regardless if respondents used or did not use cover crops, money and timing seemed to be the largest issues surrounding cover crop adoption. Many expressed their desire to know how cover crops fit into their specific operation and how they will affect other management practices (i.e. planting and tillage timings). Results of this study can allow researchers and field

practitioners to focus on finding solutions for these specific issues, hopefully causing an increase in acres planted under cover crops.

Introduction

The use of cover crops by farmers can be traced back over hundreds of years. There is evidence from ancient farmers incorporating crops into rotation to, "replenish the soil" (Groff, 2015). Cover crops can be used for an abundance of benefits, including the reduction of soil erosion (Frye et al., 1985), controlling weeds (Teasedale, 1996), and enhancing nutrient cycling (Dabney et al., 2001). Although other soil erosion control agents (e.g. grassed water ways, contour stripping, and terracing) are also used in Wisconsin (Gould et al., 1989), cover crops have been found superior due to other benefits they provide, such as having the potential to increase following cash crop yields (Wyland et al., 1996; Sainju and Singh, 1997). Because of this, the use of cover crops has been steadily increasing over the past few decades in the United States. The 2015-2016 Cover Crop Annual Report (Sustainable Agriculture Research and Education) noted a 25% increase in hectares planted in cover crops from 2014 to 2015.

With 10.3 million acres of cover crops planted in 2012 (USDA, 2013), clearly this practice is being used. However, 915 million acres was planted on in 2012 in the U.S., indicating that cover crops are only used on 1.1% of all cropland. There are numerous facets that continue to be barriers for farmers to adopt the use of cover crops. Some of these include interference with spring field work or fall harvest, cost in labor, unavailable equipment, and reduction in cash crop yields (Young and Tucker, 1999). Analyzing a farmer's choice whether or not to use sustainable agricultural practices (SAP) can be complex. Access to information, economic feasibility, infrastructure availability, and social repercussions are all barriers of SAPs adoption (Rodriguez et al., 2009). Rodriguez et al. (2009) found that when farmers were asked what are the major obstacles or barriers that producers must overcome to adopt SAPs, economics was chosen by 56% of the participants, followed by education and information at 53%. It is advantageous to understand the hindrances behind adoption of SAPs, in order for researchers and scientists to be able to work towards finding solutions to those specific issues.

Few surveys have been completed that were specifically aimed toward cover crop use. In 1999, Young and Tucker focused on western New York vegetable growers and their use of cover crops. They found that one of the most important issues of adoption was the interference cover crops had with spring field work and/or fall harvest. They noted that cost of labor and equipment was a drawback for farmers as well. Overall, both direct and indirect costs were the biggest concerns communicated by farmers. A similar study was completed in the U.S. Corn Belt in 2007 (Singer et al.). This study estimated that only 18% of farmers in the region had ever used cover crops in their operation before. The largest reasons for farmers not to use cover crops were: do not know enough about them (43.1%), already use no-tillage practices (38.6%), and too much time involved (34.8%). Only 54% of farmers answered "yes" when asked if they had enough information to make a decision about managing and using cover crops in their operation. Many farmers expressed their desire for information about cost estimates for using cover crops.

Undoubtedly, costs and profit margins are most important to a farmer when they consider their management plans. Singer et al. (2007) found that 56% of farmers would plant cover crops if cost sharing was offered to them. In 2015, croplands in Iowa planted with cover crops increased 22% when funding through federal and state incentive programs was available. This demonstrates the potential success of conservation compliance programs.

Featherstone and Goodwin (1993) used a simultaneous-equation Tobit model to evaluate relationships between farm characteristics and investment of conservation practices. Their study, using data from 541 Kansas farms, found that a greater participation in government programs lead to farmers spending more on long-term conservation. They also determined that farms with larger total acreage have a higher probability of making conservation expenditures, which was similar to findings by Gould et al. (1989).

It is vital to narrow down the area of interest to effectively perceive the thoughts and perspectives of growers. What is true in surveys completed in certain parts of the United States may not match up with what farmers believe in other regions. Aspects such as topography, climate, soil characteristics and cropping systems can be vastly different between regions, all of which influence the way a farming operation is managed. There have not been any surveys conducted that focus solely on the state of Wisconsin. This study's objective was to extend a survey to a local range of participants to obtain results specific to the state of Wisconsin with the aim to better address farmer's needs, adoption methods, and future cover crop research.

Materials and Methods

A cover crop survey was created using themes and questions derived from the 2013-2014 Cover Crop Survey completed by the Conservation Technology Information Center (CTIC) and the Sustainable Agriculture Research and Education (SARE) program (2015). No personal identifiable information or specific operation data was requested, only the participant's county of residence was inquired. Questions, delivery and other survey protocols were reviewed by the Education and Social/Behavioral Science Institutional Review Board (IRB) and revised as needed to follow relevant federal regulations, state laws, and local University policies (http://irb.wisc.edu/).

All participants were asked to fill out the first page of the survey, which contained broad information about themselves and their land use techniques (i.e. total farmed acres, type of tillage used). They were then prompted to answer one set of questions if they answered "no" to using cover crops (total of 8 questions), or a different set of questions if they answered "yes" (total of 15 questions). The survey was constructed to be short in length and simple to answer, encouraging participation. Most of the questions were multiple choice, with the option to write in an original answer under the choice "other".

Surveys were distributed in paper form at an Agronomy and Soil Science Field day at the Arlington Research Station in Columbia Co, and at eight different Soil, Water and Nutrient Management meetings hosted by the Department of Soil Science and UW-Cooperative Extension throughout the fall of 2016. These meetings were held in different counties around the state of WI (Figure 1). The completed surveys were collected the same day as they were filled out.

Results & Discussion

Approximately 540 surveys were distributed, with 165 completed surveys returned, giving a 30.6% response rate. Of the 165 completed surveys, 142 participants (86.1%) selected "yes" to using cover crops in the past or present, with 23 participants (13.9%) selecting "no" to ever using cover crops. Out of the 72 counties in Wisconsin, 52 were represented (Figure 2). The 2016 cover crop survey completed by SARE and CTIC received 2,020 completed surveys with 81% of participants indicating that they have used cover crops on their farm.

Characteristics of Respondents

The survey was given out to a variety of agricultural professionals. Sixty-five participants (39.4%) described themselves as crop consultants, 26 participants (15.8%) listed themselves as commodity crop farmers, 26 participants (15.8%) listed themselves as both crop farmers and crop consultants, and 12 (7.3%) described themselves as livestock producers (Table 1).

It was difficult to separate crop advisors' responses from commodity/vegetable crop and livestock producers' responses while summarizing results because multiple crop consultants also classified themselves as farmers. An argument can be made that a crop advisor's "yes' response to using cover crops skewed the overall percentage of Wisconsin farmers that use cover crops. On some surveys, participants that marked both crop advisor and commodity crop grower wrote in the margin that they answered the questions based on their personal operation, rather than the ones they advise. Although fascinating and important to receive a crop consultant's point of view, the survey results would be stronger and clearer if only commodity growers, vegetable growers, and livestock producers were the target audience.

Combining all responses, 94.6% of acres were under conventional systems (i.e. used pesticide), with 4.5% being organic systems. Across commodity crop, horticultural crop, and livestock producers, the average size farm from farmer survey participants was between 150-499 acres (Table 2). However, total consulted acres for crop consultants was 2,000+ acres for 61.7% of crop consultant survey participants.

Tillage Practices

Participants indicated what type of tillage methods they use on their crop acres or the acres they consult/advise. Conventional tillage was most widely used, with 40.5% of acres under this practice (Figure 3). Rotational no-tillage (17.7%) and continuous no-tillage

(17.6%) were the next widely used, followed by vertical (13.1%) and reduced (11.0%) tillage. These responses indicate that tillage is widely used in Wisconsin.

Type and Management of Cover Crop

A total of 86.1% of the survey participants indicated using cover crops. Further, responses showed that cover crop growers have experience using numerous different species of cover crops. Participants were asked to select all cover crops they have experience using, past or present. Winter cereal grains were the most popular species used (89.4%) by participants, with 69.0% having used brassicas (Figure 4). In contrast, responses by participants of the CTIC/SARE national survey indicated radish was most popular (95%), followed by 82% using cereal rye, and 65% planting winter wheat. A significant portion of growers using cover crops have used two-species or multi-species mixes on their fields, with 64.1% responded saying, “on some fields” (Figure 5). A few (13.0%) responded that they always use two-species or multi-species mixes, while 23.2% have never used two-species or multi-species mixes. In the national survey, 57% of respondents said they used mixes on their farm in 2015.

The most common method for cover crop termination in the spring indicated by participants was the use of herbicides (82.4%) (Figure 6). The next popular methods were tillage (49.3%) and planting cover crops that winter kill (46.5%). Mowing (16.2%), grazing (9.2%), and roller crimping (6.3%) each received a few responses.

Benefits to Using Cover Crops

Cover crop users were asked to choose the top three reasons why they grow cover crops. Soil erosion reduction was selected by most participants at 74.1%, followed by soil health enrichment (58.0%) (Table 3). The next popular choices were that cover crops increase soil organic matter (54.0%) and reduce soil compaction (33.8%). Some participants chose to write in other values they saw, which consisted of: "nutrient retention," "additional feed," and "aeration." Similarly, in the SARE/CTIC national survey, 86% of respondents chose increasing soil health as the most important benefit, followed by reducing soil erosion (83%) and increasing soil organic matter (82%).

Barriers to Using Cover Crops

Of the 23 participants that have never used cover crops, 52.2% of them said that the time and/or labor required was the most common deterrent (Table 4). The next popular answer was that cover crops did not provide any measurable economic return (39.1%). Cost of planting and managing was also a frequent answer (30.4%) as well as participants writing in their own original answer. Depending on the crop production system, participants expressed that cover crops did not fit in to their rotation, writing comments such as, "cropping cycles – potatoes," and "establishing cropping patterns doesn't allow time to plant cover crop unless harvesting corn silage." Timing was a hindrance, with participants stating, "harvest too late to get cover established," and "not long enough growing season to plant a cover crop." For one participant, their reason for not growing cover crops was simply because, “my dad doesn’t want to.” Lastly, one participant wrote in that he/she did not feel as though the research was complete or conclusive pertaining to cover crops.

Unfortunately, the national survey released in 2016 did not inquire more information from participants that did not use cover crops. They did, however, ask users what the biggest challenges were when it came to cover crops. “Establishment” was listed as the top challenge (32% major challenge, 49% minor challenge), followed by time/labor required (31% major, 52% minor), which is similar to the results presented here. Respondents also listed no measurable economic return as a challenge (16% major, 44% minor) along with seeding the right species for my operation (27% major, 52% minor).

In our survey results, a reoccurring theme in the responses, both from users and non-users, was that timing was a hindrance to cover crop growth. Each operation has a unique rotation schedule which affects harvest dates, manure applications, and other management practices. Respondents expressed their desire to learn how cover crops can fit into their specific operation in terms of these timing issues. To add to these hurdles, cover crops perform differently depending on the soil type and climate, making it difficult to replicate methods used in other regions of the United States. These results emphasize the many challengers for cover crop adoption at state, regional, and national scales.

The next largest issue expressed was the cost of incorporating cover crops into existing cropping systems, with little or no measurable economic return obtained. In a study completed by Drost (1996), it was found that farmers rank financial risk as the most important factor when making decisions for their agricultural operation. Although farmers may not see tangible rewards in the first few years of growing cover crops, benefits may arise later. Cover crops have the ability to enhance soil health, positively effecting long-term productivity. Therefore, although benefits may not be seen immediately, five or ten years in the future the financial advantages may be tangible. Long term studies are needed to discover and quantify these benefits.

Financial Assistance

Depending on state and federal funding, farmers may or may not be able to receive financial assistance for using cover crops. Many of the participants (57.4%) had never received cost-share assistance before (Table 5). Of cover crop users, 7.0% responded that they will only plant cover crops when given financial assistance. These results are encouraging in that they show a large portion of farmers understand the potential benefits of cover crops by their willingness to use them even without cost-share incentives. However, financial assistance is still a significant contributor to cover crop adoption.

In the CTIC/SARE national survey, 62% strongly agreed or agreed that they would increase cover crop use in their operations if it would lower their crop insurance premiums. This suggests that government assistance could be successful in encouraging cover crop use.

Market Prices

Cover crop users were asked to indicate the impact the cash crop market prices have on their use of growing cover crops. Most participants responded that crop prices have a moderate impact (47.4%) with no impact (43.7%) following closely behind (Table 6). Only 8.9% of participants responded that market prices had a heavy impact on their decision to grow cover crops each year. These responses indicate that there are other drivers behind farm cover crop adoption, not just commodity markets.

Insurance Restriction

Farmers often buy crop insurance each growing season, which have many rules and restrictions to how they can operate their farms. Cover crop users were asked if insurance impacts the amount of acres they plant on. Most participants answered that while they use crop insurance, there was no impact due to rules and restrictions (45.0%), with 27.9% stating their insurance has a moderate impact, and 4.7% stating it has a heavy impact (Table 7). Other participants (22.5%) stated that there is no impact because they do not use crop insurance.

Future Research

All participants were asked to rate the importance of different research topics from "not important" to "extremely important". Participants thought that developing cover crops that fit their cash crop timing was most important (52.6%) (Figure 7). The next highest interest was research focused on aiding cover crop growers in developing plans that fit their specific operation, with 45.8% choosing extremely important. Participants did not think that developing cover crops that enhance cash crop disease resistance was a particularly important research focus, with only 17.3% choosing extremely important and 38.0% of participants choosing somewhat important.

Influencing Agents

There are numerous groups of contacts that provide information and advice to farmers when making decisions for their farm. Participants that indicated using cover crops were asked to rank how influential various groups are when they make decisions about cover crops in their operation. The group that had the highest influence was University or Extension agents (23.0% high influence), followed by local conservation educators (9.8%) and private crop advisors (11.9%) (Figure 8). The groups that held the least influence were cash crop seed dealers (57.6% no influence) and landlords (56.0%). This information allows us to see where a majority of farmers get their cover crop information from and if we can better communicate new and innovative ideas. These results show that one-on-one interactions with extension personnel and meetings are successful at connecting with farmers.

Future Survey Changes

Unfortunately, the survey we created did not include a question asking how many total acres of cover crops farmers plant on, only the total amount of planted crop acres. It would have been useful to examine the total amount of crop land specifically under cover crops in Wisconsin. According to the national survey, each farmer planted an average of 298 acres in cover crops in 2015.

It would also have been ideal to include a question that inquired if growers have previously used cover crops, but do not anymore, what their reason was for discontinuing. Likewise, our questions were stated as, "have you ever," rather than "currently," possibly having an impact on methods used in Wisconsin today. Perhaps, if this survey is distributed again in the future, these changes can be taken into account.

Conclusions

The survey results obtained in this study can aid in future cover crop research and communication. With more than 86% of participants using cover crops in their operation, clearly this practice is being used in Wisconsin. Barriers remain that discourage use, and this survey aimed to uncover these obstacles while also discovering the advantages farmers perceive when using cover crops. The target audience included only agricultural professionals in Wisconsin to determine issues specific to the state. Not surprisingly, it was found that participants that used cover crops enjoyed benefits such as soil erosion reduction and an increase in soil health. Responses from both cover crop users and non-users followed a similar trend that time and money were the largest obstacles when incorporating cover crops into their system. Non-cover crop users expressed their desire to learn how cover crops can fit into their specific operation, with timing being a major concern.

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Figure 1. Distribution of survey in Wisconsin by counties that held a Soil, Water and Nutrient Management meeting by the Dept. of Soil Science and UW-Cooperative Extension in the fall of 2016 (circled in red), and Columbia county (circled in green) which held the Agronomy and Soil Science Field day at the Arlington Research Station in August 2016. Surveys were distributed at each meeting and collected the same day.

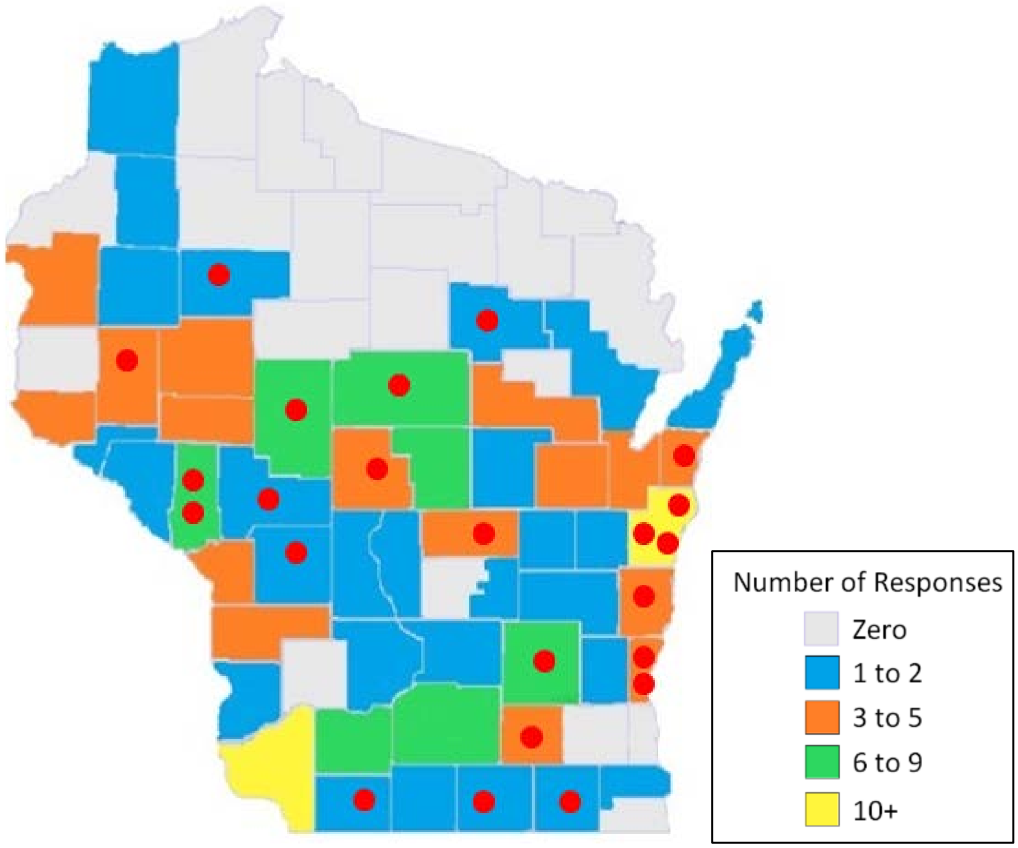

Figure 2. Number of completed survey responses received from each Wisconsin county. There were a total of 23 responses that indicated "no" to ever using cover crops. The red dots indicate the county of residence of each non-user.

Table 1. Number of respondent’s answers when asked how they would describe themselves.

How would you describe yourself?	Response (%)
Crop consultant	39.4
Commodity crop farmer	15.8
Commodity crop/horticulture farmer AND crop consultant	15.8
Commodity crop farmer AND livestock producer	7.3
Livestock producer	4.2
Commodity crop AND horticulture crop farmer	3.6
Horticultural crop farmer	1.2
Conservation agency employee	4.2
Researcher	2.4
Other	4.2

Table 2. Percentage of total acres planted on by farmers and consulted on by crop consultants.

Acres	Farmers: total acres planted/year (%)	Consultants: total acres consulted/year (%)
1-9	2.5	6.4
10-49	7.4	6.4
50-149	23.5	2.1
150-499	23.5	8.5
500-999	16	10.6
1,000-1,999	9.9	4.3
2,000+	17.3	61.7

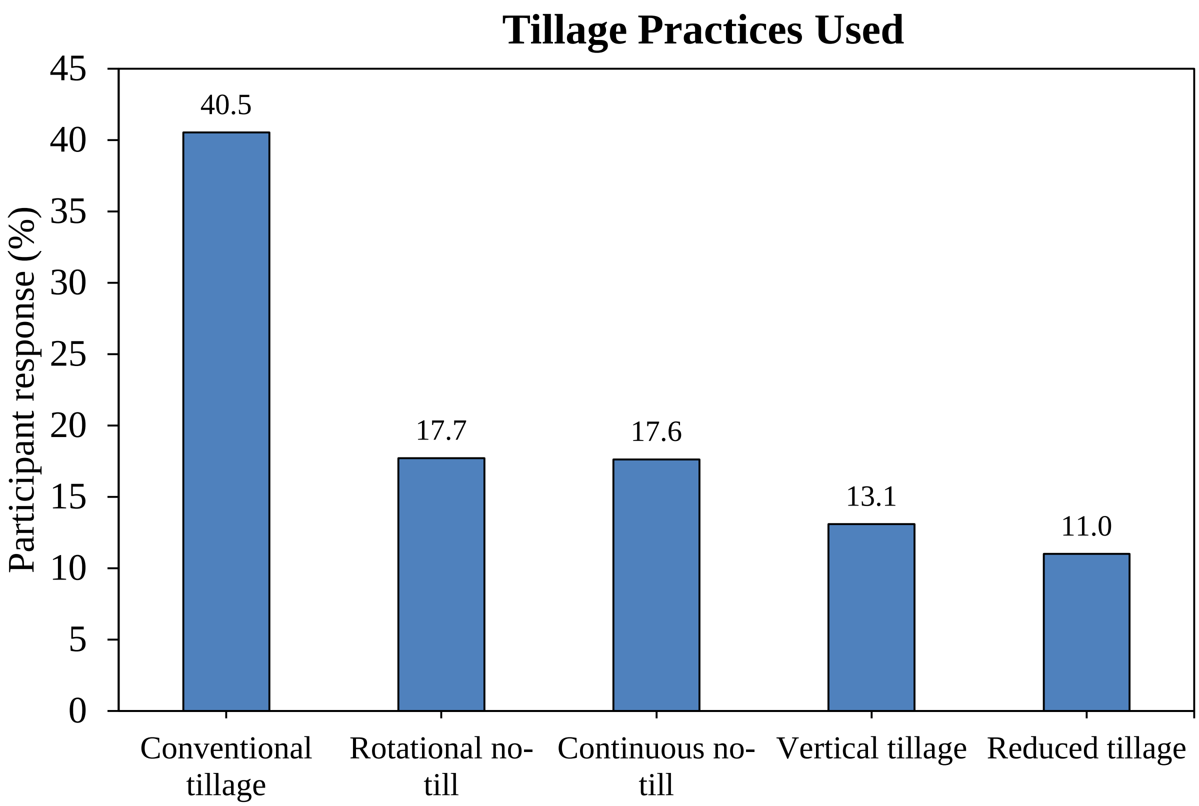

Figure 3. Tillage practices used by survey participants. Responses are from the question, "percent of total acres under the following tillage practices."

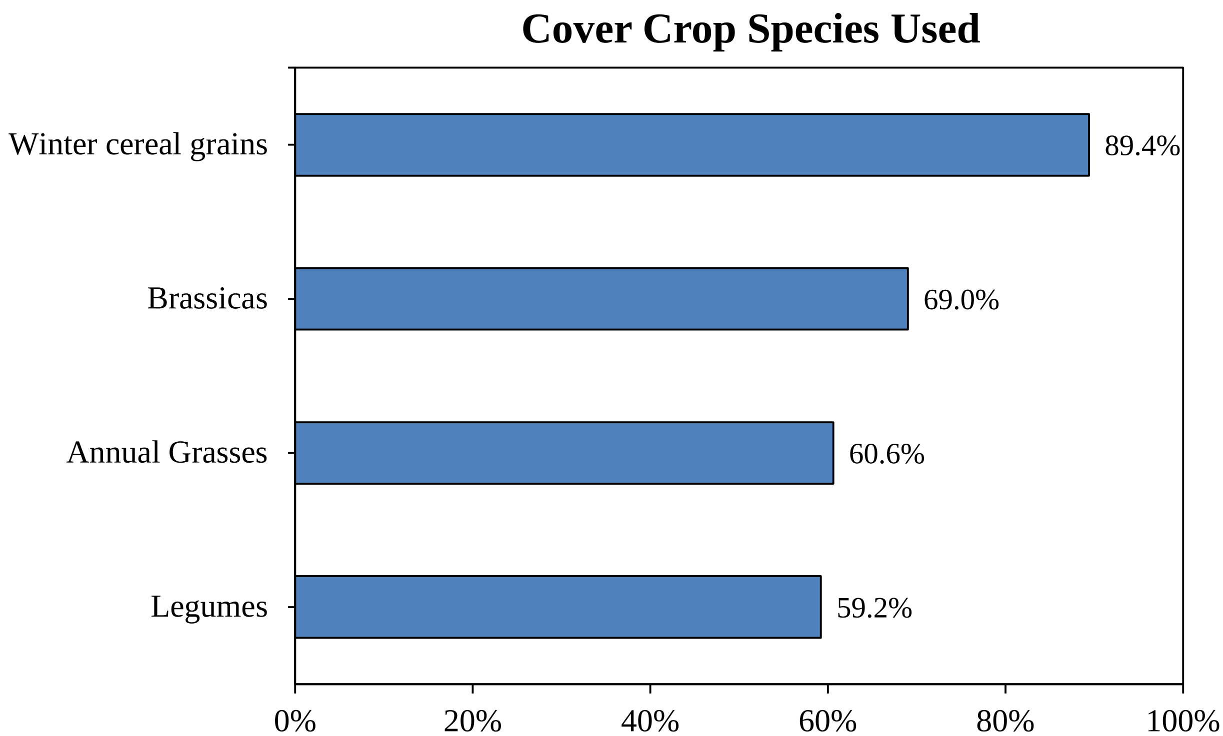

Figure 4. Percentage of cover crop species used as indicated by 152 survey responses. Participants were asked to indicate any and all species they are currently or have used in the past.

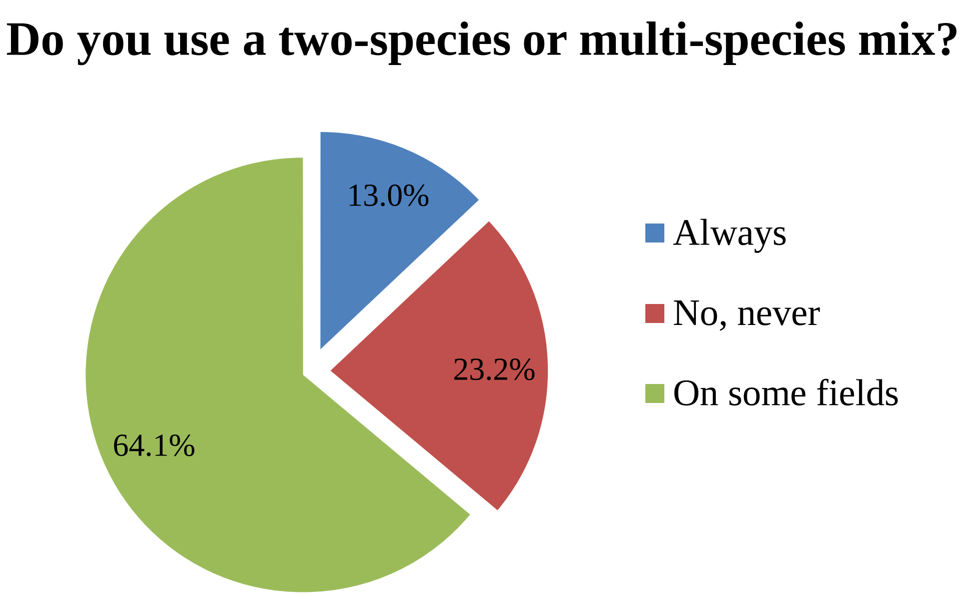

Figure 5. Percentage of participants that have used two-species or multi-species mixes when planting cover crops.

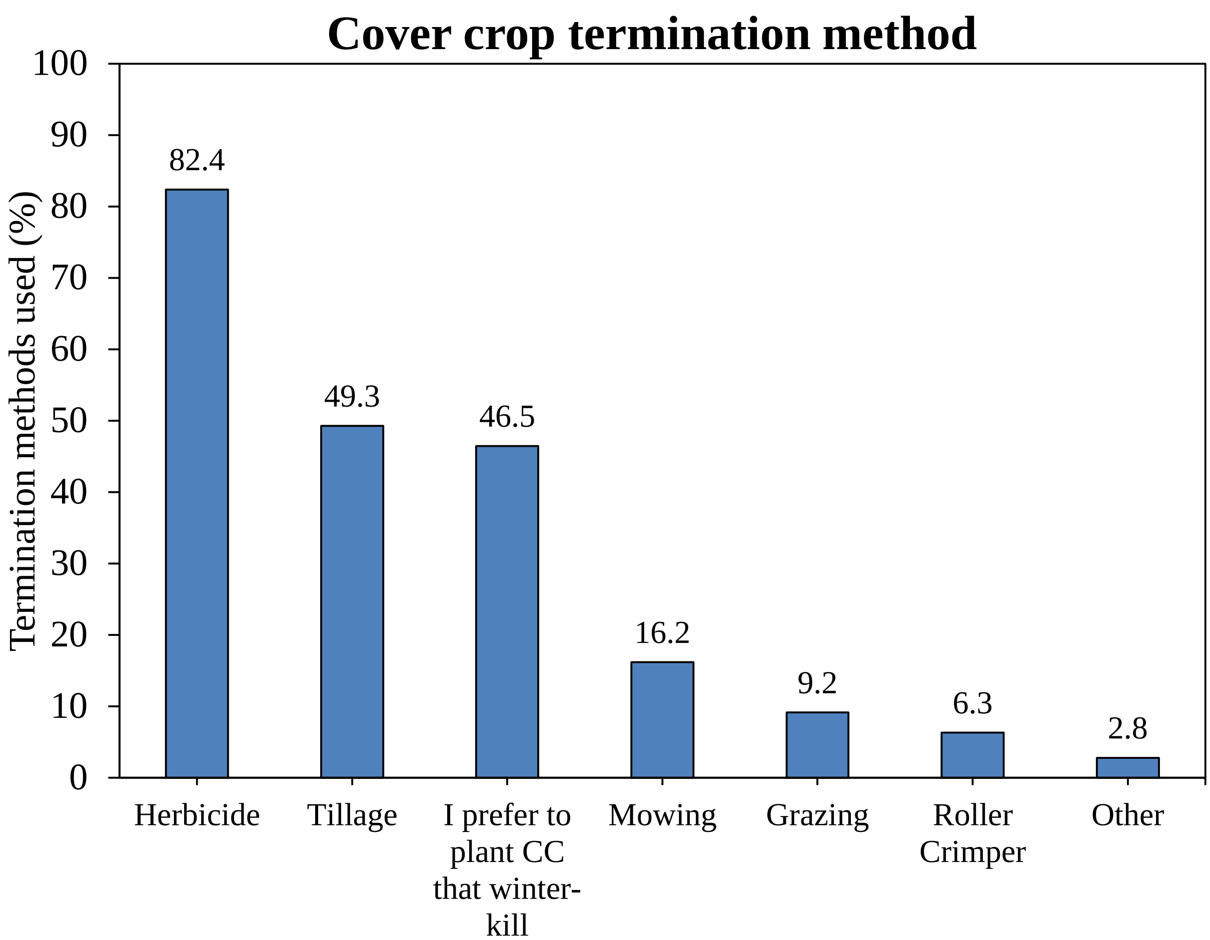

Figure 6. Methods of terminating cover crops as a percentage of total responses. Participants were asked to note any and all methods they are currently using or have used in the past.

Table 3. Benefits of using cover crops indicated by 142 respondents that have or are currently using cover crops.

Benefits of using cover crops indicated by users	Response (%)
Reduces soil erosion	74.1
Improves soil health	58.0
Increases soil organic matter	54.0
Reduces soil compaction	33.8
Provides a nitrogen source	17.3
Controls weeds	16.5
Increases yields in the following cash crop	13.7
Winter kills easily	7.9
Produces fibrous roots	4.3
Winter hardiness/survival	3.6
Provides deep tap roots	3.6
Decreases cost of producing following cash crop	2.9
Economic return (haying, grazing, etc.)	2.2
Other	2.2

Table 4. Top factors that prevent the use of cover crops indicated by respondents that have never used cover crops.

Factors that prevent the use of cover crops indicated by non-users	**Response (%)**
Time/labor required	52.2
No measurable economic return	39.1
Cost of planting and managing	30.4
Other	30.4
Cover crop seed cost	26.1
Too wet in the spring – fear of delaying planting	21.7
Difficulty establishing cover crops	21.7
Uses to much moisture	13.0
Yield reduction in the following cash crop	13.0
Becomes a weed the following year	13.0
Increases overall crop production risk	4.3
Nitrogen immobilization	4.3
Cover crop seed availability	4.3

Table 5. Participant responses when asked if they have received cost-share assistance incentive payments to plant cover crops.

	% responses
Yes, I only plant using financial assistance	7.0
Yes, I have periodically received and used financial assistance	35.7
No, I have never received financial assistance	57.4

Table 6. Impact of cash crop market prices on use of cover crops.

	% response
Heavy impact	8.9
Moderate impact	47.4
No impact	43.7

Table 7. Impact of crop insurance rules and restrictions on total acres of cover crops planted each year.

	% response
Heavy impact	4.7
Moderate impact	27.9
No impact, I do not use crop insurance	22.5
No impact, I use crop insurance	45.0

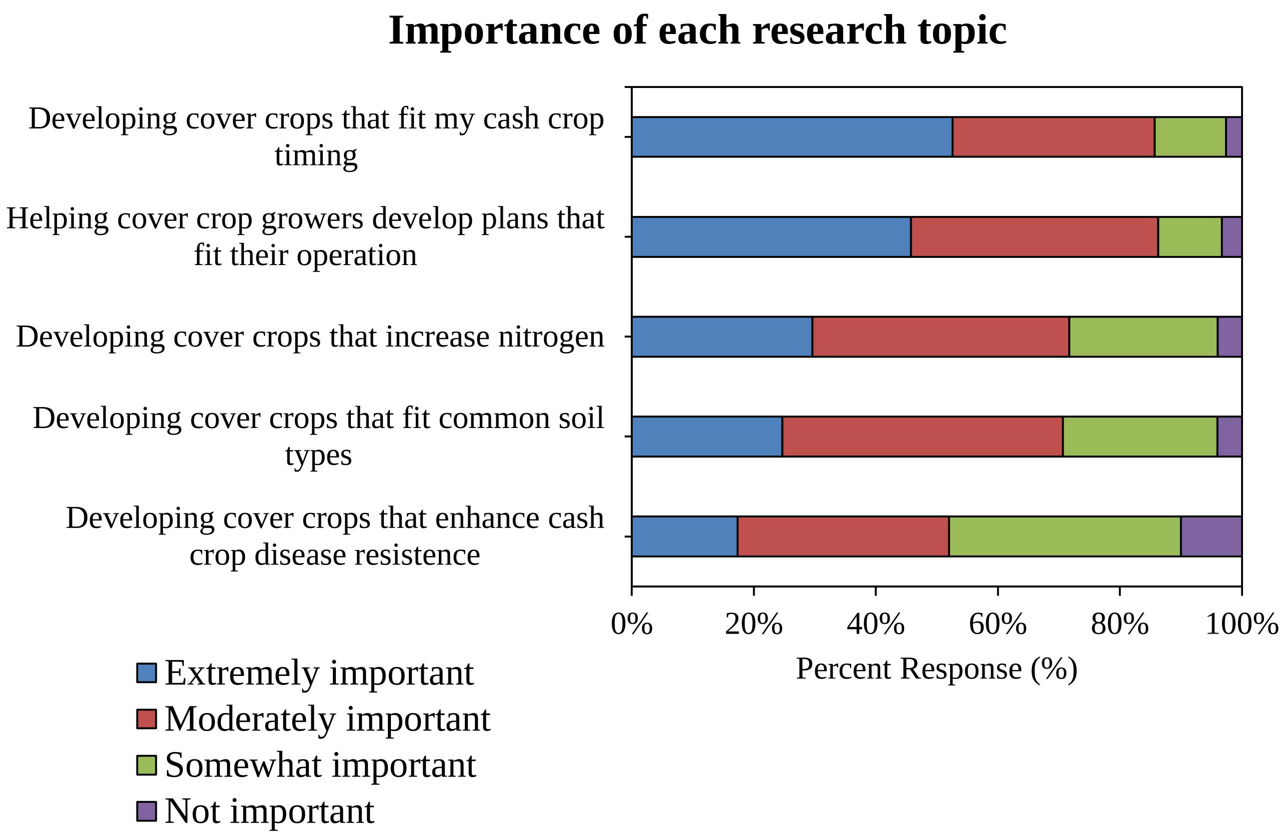

Figure 7. Percentage of all participants (regardless of cover crop use or not) that rated the importance of each research topic related to cover crops from not important to extremely important.

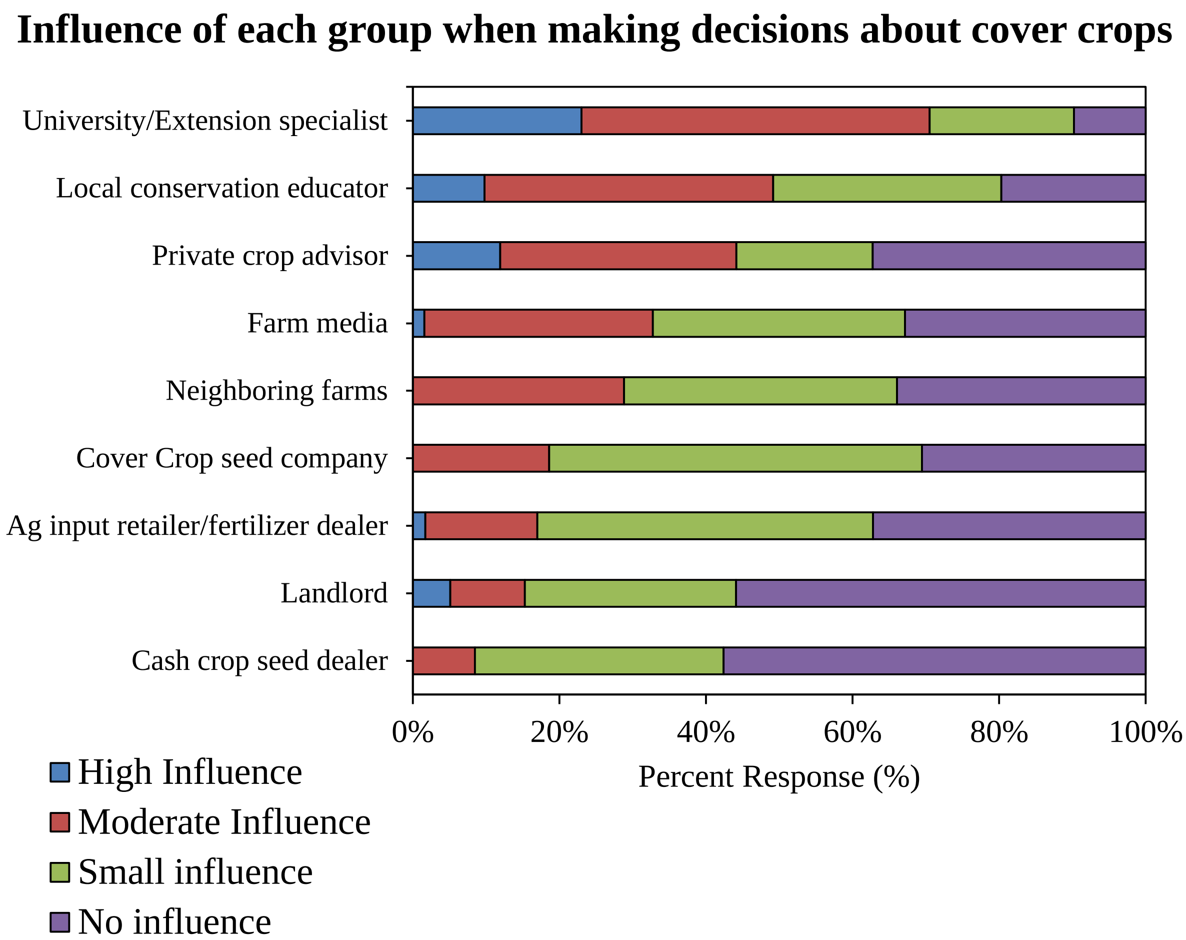

Figure 8. The influence of each group has on a farmer when making decision about cover crops.

Chapter 2: Using Conservation Tillage and Cereal Rye as a Cover Crop to Increase Total Productivity of Corn Silage

Abstract

Dairy is an integral part of Wisconsin's economy and lifestyle. With over one million dairy cows in the state, large amounts of feed must be produced, with corn (*Zea mays*) silage being the most commonly used forage. In a dairy forage rotation, growing cereal rye as a cover crop can potentially provide additional feed if harvested in the spring, while reducing erosion and increasing soil organic matter. This study examined the impact of using cereal rye (*Secale cereale*) as a cover crop, in combination with conservation tillage, on corn silage productivity in Wisconsin. Six corn silage production systems were established in 2013 using two tillage methods (conventional and no-tillage) and three cover crop treatments (no cover crop, cover crop terminated, cover crop harvested). Cereal rye was planted after corn harvest each year and harvested in late May in the required treatments. The sum of CT CCH forage yields (corn silage plus rylage) was greater than CT NCC in 2015. In 2016, CCH total forage yield was greater than NCC and CC when averaged over the two tillages. A difference in estimated milk production was seen in 2016 where CCH > CC. Overall, tillage did not have an influence on yields. These results suggest that if dairy farmers incorporate cereal rye as a cover crop into their operations, milk yields will either remain the same or increase.

Introduction

Wisconsin is the second largest milk producing state in the United States, generating 30.1 billion pounds of milk in 2016 (USDA NASS, 2017). Dairy is vital for the state and contributes largely to regional and global economies. With over 1.2 million dairy cows, a large amount of feed is required. The predominant feed in dairy forage systems is corn silage (Jordan and Fourdraine, 1993) and when harvested, little residue is left on the soil surface. Additionally, it is typical for Wisconsin farmers to use tillage practices in the fall and/or spring to control weeds and prepare the seedbed. These tillage practices reduce the amount of crop residue left on the soil surface. Bare soil increases susceptibility to erosion (McGregor et al., 1975) and soil degradation (Jokela et al., 2009), ultimately having an impact on productivity (Gebhardt et al., 1985). Long-term soil health is imperative to ensure high yields of corn silage as well as other cash crops. Conservation tillage and cover crops are two potential management practices that could help silage systems by increasing the amount of plant residue on the soil surface, which in turn should help maintain soil health and sustain high crop yields.

Soil erosion, runoff, and nutrient losses can be reduced by the use of conservation tillage (Baker and Laflen, 1983) and cover crops (Reeves, 1994). The Conservation Technology Information Center (West Lafayette, IN) defines conservation tillage as having at least 30% of the soil surface covered by plant residue. Cover crops are grown after cash crops are harvested in the fall to create ground coverage over winter (USDA, 2017). In production systems that have residues on the soil surface, there is an increase in infiltration (Cassel et al., 1995), soil structure is enhanced (Lynch and Bragg, 1985), and lost soil organic matter (SOM) can be restored (Schlesinger, 1985) compared to soils without residue cover.

There are numerous plant species that are used as cover crops depending on the desired benefits and production system. Cereal rye is a popular choice to use as a cover crop in Wisconsin. Rye is hardy enough to survive the harsh winters and continues to grow in the spring (Stoskopf, 1985), providing additional protection from erosion. Because of the increased residue coverage, rye has been shown to reduce erosion (Kaspar et al., 2001), maintain SOM (Kaspar et al., 2006), and reduce nitrate (NO_3-N) leaching (Strock et al., 2004).

Rye can be especially advantageous for dairy farmers, as late spring rye can be harvested and used as additional high quality feed (Maloney et al., 1999). However, harvesting rye may cause corn planting to be delayed, reducing yields (Krueger et al., 2011). Rye has also been shown to reduce soil moisture (Liebl et al., 1992), reduce organic carbon and nitrogen (Kuo and Jellum, 2000) and cause an allelopathic effect (Raimbault et al., 1990; Tollenaar et al., 1992) on the following corn crop, effecting yields. Despite these impacts, it was found in Ontario that the sum of rye and corn yield has the potential to exceed corn yields alone, improving overall profitability (Raimbault et al., 1990; Tollenaar et al., 1992). Further, harvested rye in the spring can provide supplemental feed during a time of year when stored feed supply is low.

This study's objective was to determine the effect of conservation tillage and cereal rye as a cover crop on corn silage yields in Wisconsin to determine if they can increase total productivity in a dairy forage system.

Materials and Methods

This study took place in Columbia County, Wisconsin from 2013-2016. The primary soil series at this location was Plano silt loam, with Saybrook and Ringwood soils found in smaller areas where the land slopes from 2 to 3%. Each plot measured 13.7 m wide by 152 m long to allow for the use of farm-sized equipment for field operations to better represent farm conditions. Tillage treatments consisted of conventional tillage (CT) and no-tillage (NT), while cover crop treatments consisted of no cover (NCC), cereal rye chemically terminated with an herbicide at least two weeks before corn planting (CC), and cereal rye harvested as forage before corn planting (CCH). The fields were in a 3-year rotation with alfalfa (*Medicago sativa*), with both phases of the rotation present each year. Conventional tillage operations consisted of a one-pass with a vertical tillage implement (True-Tandem^{tm} 330 Turbo, Case IH, Racine, WI) in the fall after manure application, and a soil finisher pass in the spring. The only soil disturbance to the no-tilled plots was caused by planting operations and dairy liquid manure injection.

Corn was seeded with a no-tillage planter (John Deere 1750, Moline, IL) in the spring at a 13,760 seeds ha^{-1} seeding rate. The corn hybrid used for the NCC and CC treatment was Dekalb DKC 57-75RIB (Monsanto Corp., St. Louis, MO) with a maturity rating of 107 days and for the CCH was Dekalb DKC 48-12RIB with a maturity rating of 98 days. The difference in maturity ratings between these two treatments was to account for the delayed planting of corn in the CCH treatment. The corn in the NCC and CC treatments was seeded typically in the first week of May, with corn in the CCH plots seeded in the last week of May, allowing cereal rye to grow longer.

Liquid dairy manure was applied to every corn silage plot by injecting 112,200 liters ha^{-1} (12,000 gal ac^{-1}) each fall. Alfalfa plots only received manure (at the same rate) in the fall of 2016 in preparation for the following spring when corn and alfalfa crops were rotated. In the required plots, cereal rye was seeded with a no-tillage grain drill (John Deere 1590, Moline, IL) every fall at a seeding rate of 100 kg ha^{-1}.

Corn silage and rye in the CCH treatment were harvested using a self-propelled forage harvester with a yield monitor. The average yield value for the entire length of each plot was used as the yield for that particular plot. Plant tissue subsamples were collected, placed in sealed plastic bags and stored frozen until they were analyzed. Corn and rye tissue samples were analyzed for moisture content and for feed quality parameters using a near infrared standard procedure by the Soil and Forage Quality Laboratory in Marshfield, WI. Quality parameters reported here include crude protein, acid detergent fibers (ADF), neutral detergent fibers (NDR), fat and ash concentrations. Milk production per ton of forage for each treatment was estimated using the Nutrient Requirements of Dairy Cattle approach using forage quality parameters (NRC, 2001). Milk production per hectare was estimated by multiplying the milk production per ton of forage times the forage yield per hectare for each individual treatment each year. Using the milk production per hectare allows for comparing treatment effects on total forage yield in combination with forage quality.

A complete factorial design (two tillage methods X three cover crop treatments), with three replications in a completely randomized block design was used for the treatment combinations. Total yields for the CCH include corn silage plus rye yield. Data were analyzed using a general linear model in JMP Pro 13 (SAS Institute Inc., Cary, NC). Statistical analysis was performed for each year individually since the objective of this work was to determine the differences among management practices taking into account each years' particular conditions individually (e.g. weather, timeliness of rye establishment, etc.), and not averaging across years. Differences were considered statistically significant when $p \leq 0.05$.

Results and Discussion

Cereal rye was planted late in fall of 2013, resulting in limited growth. Since one of the goals of this study was to follow operations similar to a working farm, rye was not harvested in the CCH treatment in the following spring of 2014 given that rye biomass was about 225 kg ha^{-1}. Yields for CCH treatments in 2014 therefore, only have corn silage represented. For 2015 and 2016 total yields and milk production, the CCH treatments are the sum of corn silage and rylage.

There were no differences in total silage yields in 2014 due to tillage or cover crop treatments (Table 1). The lack of significant effect by cover crop in 2014 can be attributed to late rye cover crop planting in fall of 2013 and thus low biomass production. Similarly, tillage treatments were only in place one year in 2014 and most likely there were no differences between tillage treatments. In 2015, there was an interaction between tillage and cover crop ($p = 0.0423$). Statistically, total forage yields were greater for CT CCH when compared to CT NCC treatments (Figure 1). However, forage yields were similar for CT CCH and all other remaining treatments. Nevertheless, CT NCC had the lowest yield values numerically. The spring of 2016 was warmer and received more precipitation than average (U.S. Climate Data), which perhaps aided in increased rye growth, and possibly contributed to a significant effect for cover crop as a factor on total forage yield ($p<0.0001$). However, when comparing the cover crop treatments, total forage yields were significantly greater for CCH compared to NCC and CC (Figure 2). Therefore, it seems that the main effect of rye as a cover crop in 2016 related to the additional rye biomass production and not as a positive effect on corn yield. This was similar to the findings of Raimbault et al. (1990), who noted a higher total biomass yield of rye plus corn compared to corn silage alone in Ontario. Unlike our study however, Raimbault et al. (1990) found that tillage had a greater influence on yields rather than cover crop management, with less corn growth in no-tillage treatments. Tollenaar et al. (1992) also found that corn silage with cereal rye produced higher above ground biomass than corn alone. However, the study by Tollenaar et al. suggested that if rye is harvested as a forage crop, this type of system might not be as economically beneficial due to the added costs of harvesting and handling of dry forage, with little total yield difference obtained.

Total forage yields are important for dairy farms, but the quality of the forage is vital in terms of the nutrition it provides for dairy cows. For this reason, this study also investigated the impact of tillage and rye as a cover crop on forage quality. There were no significant differences in any forage quality parameters for the treatments included in this study. However, cover crop influenced protein and ash content in 2015, with CCH having significantly higher crude protein than the other two treatments ($p = 0.0098$; Figure 3). Similarly, CCH had significantly higher ash content than the CC treatment ($p = 0.0325$; Figure 5). Cover crop also significantly affected fat and ash concentrations in 2016 (Table 2). Fat concentrations were reduced with CCH treatments compared to NCC treatments, but fat concentration was similar between NCC and CC, and CC and CCH ($p = 0.0282$; Figure 5). Ash concentration in corn silage was greater in CCH compared to NCC and CC treatments ($p = 0.0483$; Figure 6). Differences in corn silage quality during the 2015 and 2016 seasons because of the cover crop treatment could possibly be attributed to the shorter maturity rating corn variety used in CCH and not to the presence of rye as a cover crop.

Total milk production was not significantly affected by the tillage or cover crop treatments for any of the years, with exception of cover crop in 2016 ($p = 0.0090$; Table 3). The CCH treatment had the greatest total milk production and was significantly greater than CC, but similar to NCC (Figure 7). In general, the differences in total milk production are not consistent or large in magnitude, suggesting that overall differences in the quality and amount of forage production between the cover and tillage treatments were small.

Conclusions

When comparing total dry matter yields, cereal rye planted to provide soil cover in the fall, winter, and early spring, and harvested as a forage crop before corn seeding can have a positive effect when in a double cropping system with corn silage. These data show that when rye is harvested as a forage crop, the sum of corn silage and rylage is either equal to or greater than corn silage alone. Although ash concentration tended to be greater in corn silage plots where cereal rye was harvested, total milk production was not significantly reduced. Tillage did not affect yields, forage quality, or total milk production. The results of this study show that when incorporating cereal rye as a cover crop into a dairy forage rotation, yields will remain the same or increase when harvesting the rye for additional feed. Some dairy operations might be interested in having a forage crop during a time of year when stored feed stocks are low, which a cover crop could provide. These findings may encourage dairy farmers to use cereal rye as a cover crop in their operation.

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Table 1. Analysis of variance summary of total dry matter corn silage yields as affected by two tillage methods (conventional tillage and no-tillage) and three cover crop treatments (no cover crop, cereal rye terminated, cereal rye harvested) during three growing seasons near Arlington, WI. Total dry matter yields for the cereal rye harvested treatment includes corn plus rye yields.

	Probability > F		
		Year	
Source	**2014**	**2015**	**2016**
Tillage (T)	0.3533	0.4556	0.4266
Cover (C)	0.2849	**0.0389**	**<0.0001**
T x C	0.5403	**0.0423**	0.1327

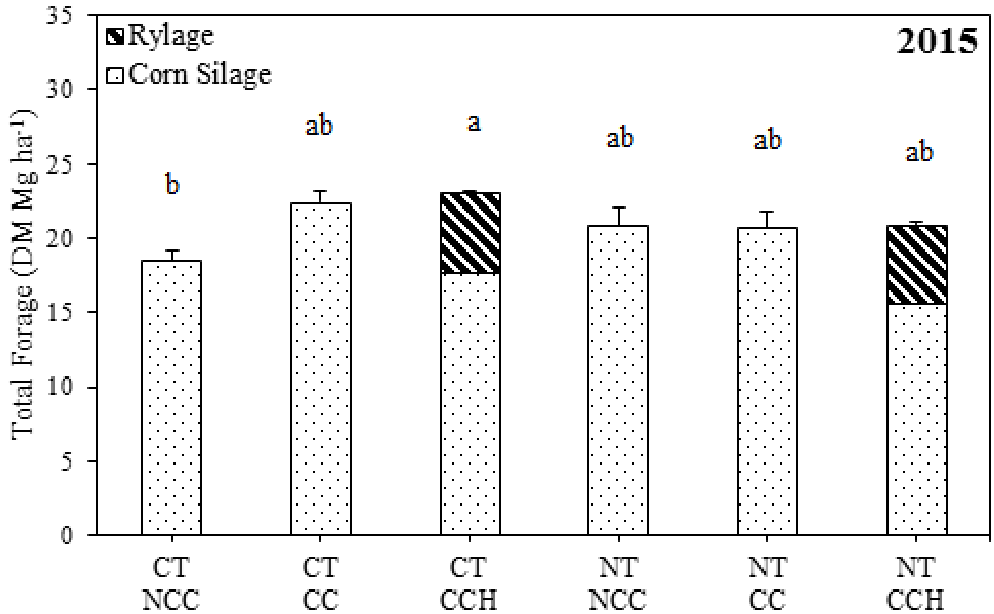

Figure 1. Total corn silage forage yields for two tillage (CT – Conventional tillage; NT – No-tillage) and three cover crop treatments (NCC – no cover crop; CC – Cover crop terminated; CCH – Cover crop harvested) during the 2015 growing season. Different letters above each column indicate statistically significant differences at a 0.05 level of probability.

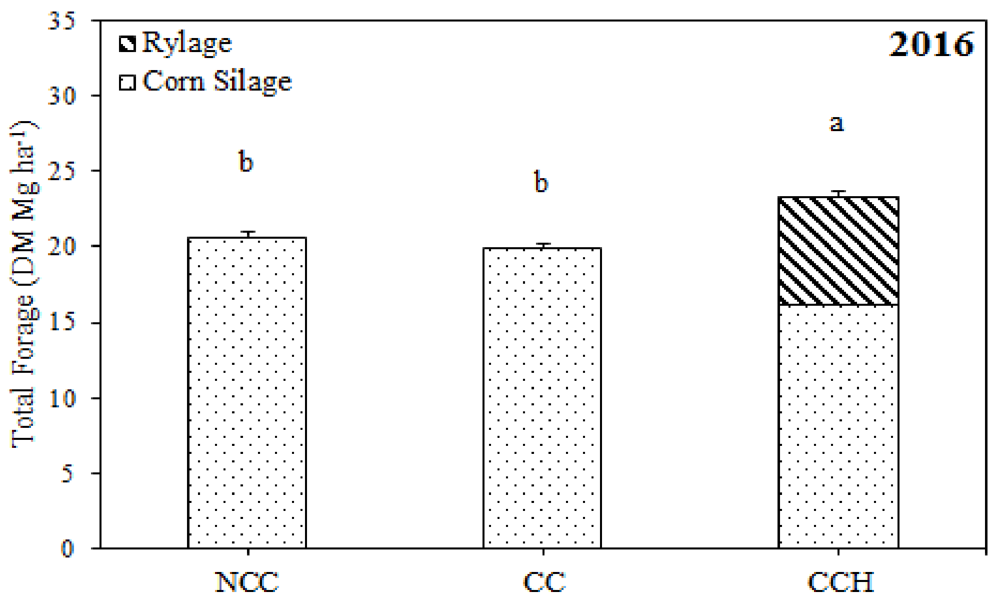

Figure 2. Total corn silage forage yields for three cover crop treatments (NCC – no cover crop; CC – Cover crop terminated; CCH – Cover crop harvested) averaged over two tillage treatments (conventional tillage and no-tillage) during the 2016 growing season. Different letters above each column indicate statistically significant differences at a 0.05 level of probability.

Table 2. Analysis of variance summary of forage quality parameters of corn silage as affected by two tillage (conventional tillage and no-tillage) and three cover crop (no cover crop, cereal rye terminated, cereal rye harvested) during three growing seasons near Arlington, WI. NDF – neutral detergent fiber; ADF – acid detergent fiber.

Year		Protein	NDF	ADF	Fat	Ash
				Probability > F		
2014	Tillage (T)	0.1266	0.8015	0.8724	0.9560	0.0741
	Cover (C)	0.9019	0.9570	0.9284	0.9966	0.1339
	T x C	0.1461	0.2230	0.2505	0.2011	0.1348
	Tillage	0.9915	0.3425	0.2456	0.6686	0.1985
	Cover	**0.0098**	0.3485	0.2309	0.2216	**0.0325**
	T x C	0.8345	0.5784	0.7154	0.7365	0.9403
	Tillage	0.1467	0.9742	0.8451	0.3564	0.1103
	Cover	0.1869	0.8061	0.5132	**0.0282**	**0.0483**
	T x C	0.5518	0.5404	0.6769	0.2326	0.9355

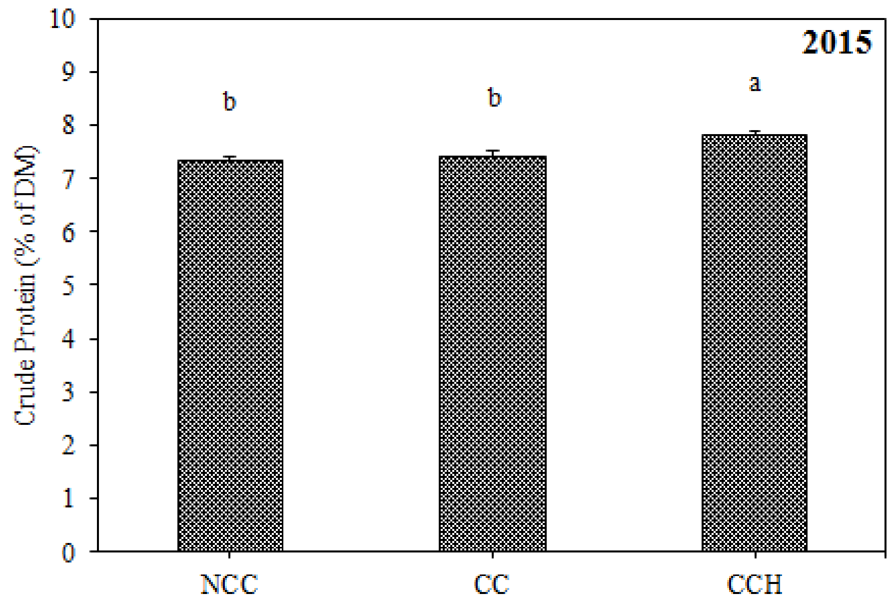

Figure 3. Crude protein concentrations in corn silage for three cover crop treatments (NCC – no cover crop; CC – Cover crop terminated; CCH – Cover crop harvested) averaged over two tillage treatments (conventional tillage and no-tillage) during the 2015 growing season. Different letters above each column indicate statistically significant differences at a 0.05 level of probability.

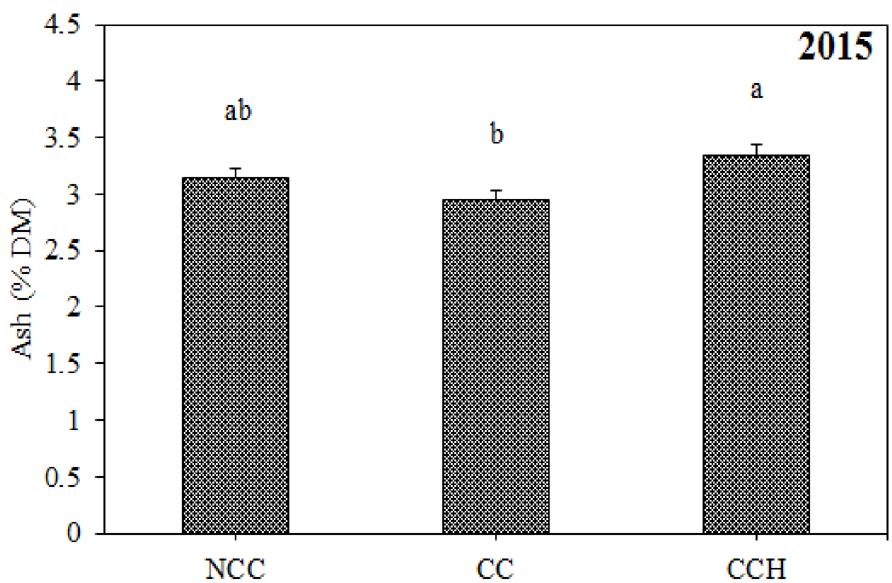

Figure 4. Ash concentrations in corn silage for three cover crop treatments (NCC – no cover crop; CC – Cover crop terminated; CCH – Cover crop harvested) averaged over two tillage treatments (conventional tillage and no-tillage) during the 2015 growing season. Different letters above each column indicate statistically significant differences at a 0.05 level of probability.

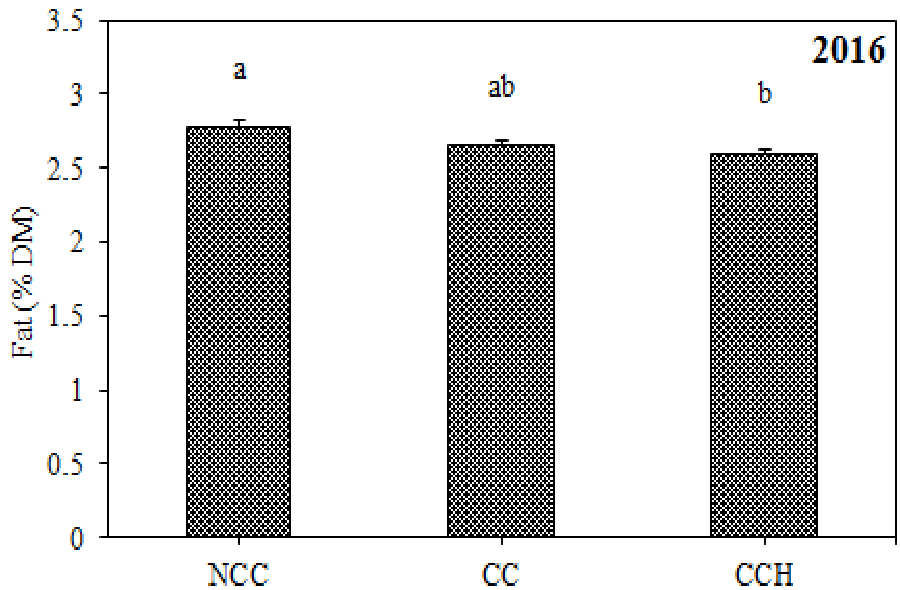

Figure 5. Fat concentrations in corn silage for three cover crop treatments (NCC – no cover crop; CC – Cover crop terminated; CCH – Cover crop harvested) averaged over two tillage treatments (conventional tillage and no-tillage) during the 2016 growing season. Different letters above each column indicate statistically significant differences at a 0.05 level of probability.

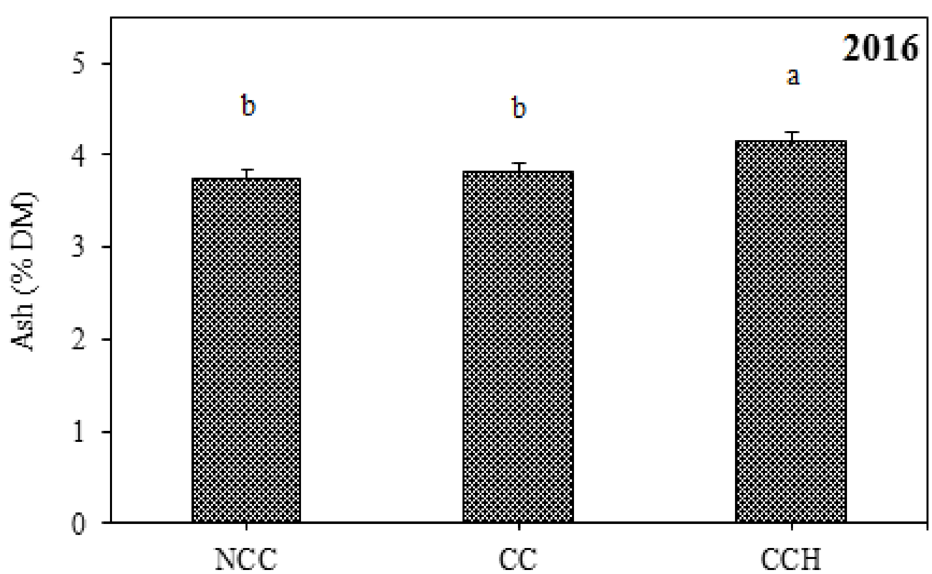

Figure 6. Ash concentrations in corn silage for three cover crop treatments (NCC – no cover crop; CC – Cover crop terminated; CCH – Cover crop harvested) averaged over two tillage treatments (conventional tillage and no-tillage) during the 2016 growing season. Different letters above each column indicate statistically significant differences at a 0.05 level of probability.

Table 3. Analysis of variance summary of estimated total milk production of dairy forage systems that include two tillage (conventional tillage and no-tillage) and three cover crop (no cover crop, cereal rye terminated, cereal rye harvested) during three growing season near Arlington, WI. Estimated total milk production for the cereal rye harvested treatment includes corn silage plus rye yields.

	Probability > F		
		Year	
Source	**2014**	**2015**	**2016**
Tillage (T)	0.1920	0.4496	0.4778
Cover (C)	0.3265	0.0509	**0.0090**
T x C	0.9552	0.4264	0.3012

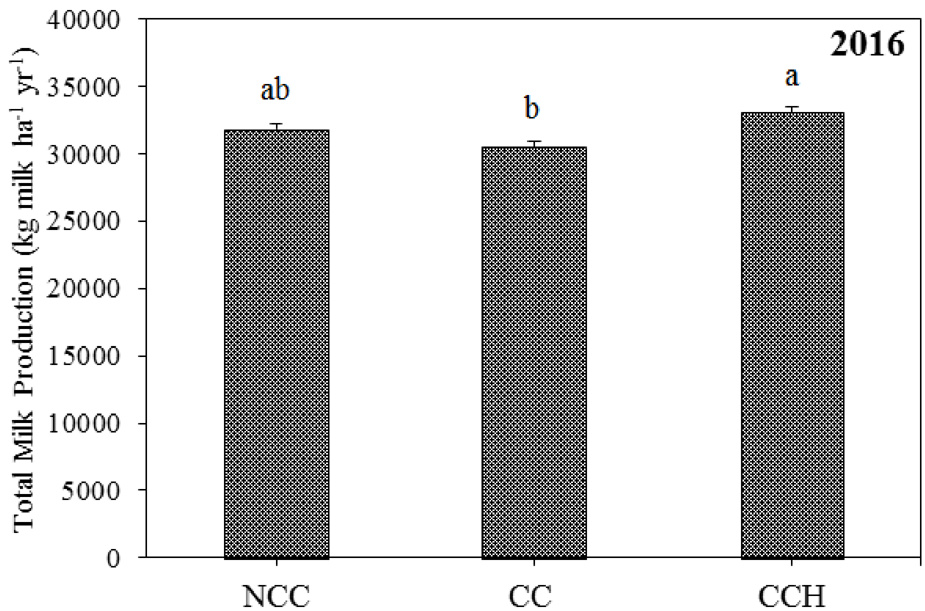

Figure 7. Total milk production of dairy forage systems that included three cover crop treatments (NCC – no cover crop; CC – Cover crop terminated; CCH – Cover crop harvested) averaged over two tillage treatments (conventional tillage and no-tillage) during the 2016 growing season. Letters above each column represent statistically significant differences at a 0.05 level of probability.

Chapter 3: Ability of Conservation Tillage and Cover Crops to Reduce Runoff and Phosphorus Losses on Corn Silage Production in Wisconsin

Abstract

Wisconsin is the second highest producing dairy state in the United States. It is typical for dairy farmers to grow corn (*Zea mays*) silage in rotation with alfalfa and use manure as a nutrient source and management strategy. When corn silage is harvested, the entire crop is removed, leaving soil bare and susceptible to erosion and runoff, potentially impacting nearby freshwater ecosystems. In Wisconsin, 80% of lake and 50% of stream impairments are caused by sediment and/or phosphorus (P), with the US Environmental Protection Agency (EPA) listing agriculture as the largest source of nonpoint pollution. It was found in Chapter 1 of this thesis that cover crops are a conservation method used on Wisconsin farms to help reduce erosion. This study aimed to understand runoff and P losses by comparing two cereal rye (*Secale cereal*) cover crop treatments (no cover crop, cover crop) with two tillage methods (conservation tillage and no-tillage) at three different times throughout the year (June, October, April). Treatments with cover crops reduced total runoff volume by 24.1%, sediment loss by 51.5%, and total P by 42.0%, regardless of tillage when averaged across months. Bioavailable P, which is considered to be the most influential in causing eutrophication, was reduced 33.8% in plots with a cover crop averaged over the three months. Tillage method only had an influence on runoff in June when cover crops were present. These results encourage the use of cover crops in a Wisconsin dairy forage rotation to reduce runoff losses and protect local freshwater ecosystems.

Introduction

Dairy is the largest sector of Wisconsin's agriculture, contributing $43.4 billion to the state's economy each year (Jesse, 2013; Deller, 2014). With over 1.27 million cows, large amounts of feed production is required, as well as management of the manure produced (USDA, 2013). Farmers spread manure onto their fields both as a crop nutrient source and as a waste removal strategy. Manure, with the addition of fertilizers, adds nutrients to the soil and can lead to increased crop yields. However, with such large amounts of manure to manage, enough cropland may not be available and the available land might not efficiently retain these added nutrients. Under these conditions, nutrients are susceptible to move into nearby water supplies (Carpenter et al., 1998). In certain environments, excess nutrients flowing into waterways can cause pollution. The EPA (2016) lists agriculture as the primary source of nonpoint nutrient pollution in the United States.

In systems where runoff is likely, nutrient and sediment losses can be high, creating freshwater contamination in local waterways. It is imperative to maintain healthy freshwater ecosystems, for they provide a range of services, including water purification, nutrient cycling, and biodiversity maintenance (Nunes and Bergh, 2001). The Wisconsin Department of Natural Resources (DNR) lists 408,000 acres of lakes and 17,885 miles of streams not meeting water quality standards. Total phosphorus and/or sediment are often the reason for these impaired waterways, contributing to about 80% of lake and 50% of stream impairments (DNR, 2013). Much of Wisconsin's waterways drain into the Mississippi River Watershed, which then flows into the Gulf of Mexico, helping fuel one of the world's largest hypoxic zones (Rabalais et al., 2000). Both nitrogen and P are essential nutrients for crop growth, with P often found to be the most limiting nutrient in freshwater ecosystems (Powers et al., 1972; Schelske and Stoermer, 1972).

Two forms of P occur in runoff, with the main portion (75-90%) being Particulate P (PP) and the rest as Dissolved P (DP) (Schuman et al., 1973; Sharpley et al., 1987). In terms of eutrophication and plant growth, DP is an instantly available source of P (Peters, 1981; Walton and Lee, 1972). Another P form of concern to surface water quality is Bioavailable P (BAP) because it is available for long periods of time in the water column, and thus has a high impact on algal growth (DePinto et al., 1981; Dorich et al., 1985; Sharpley et al., 1992). Typically, BAP is considered to be the sum of DP plus a portion of the PP (varying from 10-90%). Young and DePinto (1982) found that even with reduced total P (TP) loads entering a lake, the productivity of that lake does not necessarily change. This can occur when a similar amount of BAP still enters lakes, even if TP is reduced. Thus, BAP levels in runoff can serve as a good indicator to compare the impact of soil management practices with other P measures, such as TP, DP, and PP.

During a rainfall or irrigation event, the thin top layer of soil (0.1-0.3 cm) interacts with the water, causing the desorption, dissolution, and extraction of P from the soil. These processes create DP in runoff (Sharpley, 1985). Transformations can occur between PP and DP, and are heightened by the transport of materials that have a greater capacity to sorb P, such as clays (Sharpley et al., 1993). Solubility of P fractions can also fluctuate depending on soil management practices (Tran and N'dayegamiye, 1995) and seasonal change (Magid and Nielsen, 1992). Erosion is the largest determining factor of PP movement from soil to water (Burwell et al., 1977; Garbrecht and Sharpley, 1992; Schuman et al., 1973). By using practices that reduce erosion, such as reduced tillage, Sharpley et al. (1992) found in Oklahoma and Texas soils a reduction in PP, DP, and BAP. It is important to note that practices such as planting cover crops, terracing, or tile drainage effectively reduce erosion, but are more efficient at reducing PP rather than DP (Sharpley et al., 1993).

The predominant forage feed for dairy cattle in the United States is corn silage (Jordan and Fourdraine, 1993). Farming systems under high intensity corn silage rotations are under increased risk of soil degradation. When harvesting corn silage, the entire above-ground biomass is collected, leaving only small amounts of crop residue on the soil surface.

Tillage practices are commonly used in Wisconsin in the fall and/or spring to prepare the seedbed, incorporate fertilizers, and control weeds. However, tillage practices also reduce the amount of crop residue on the soil surface. The energy of raindrops has the ability to detach soil particles, producing a “sealing” effect, which in turn reduces infiltration and increases runoff (Gebhardt et al., 1985). Less biomass left on the surface can also degrade the soil from reduced nutrient cycling and overall, reduce productivity (Jokela et al. 2009).

Soil erosion and runoff can be reduced by the use of conservation tillage (Baker and Laflen, 1983; Cogo et al., 1983). Conservation tillage is defined as keeping at least 30% of the soil surface covered throughout the year (CTIC, 1990). Crop residue left on the soil surface can successfully restores lost SOM in the top few centimeters of soil (Schlesinger, 1985). Having increased amounts of SOM enhances nutrient availability (Stevenson, 1982), soil structure (Oades, 1984), and water holding capacity of soil (Hudson, 1994). In addition, soil temperatures tend to be lower in conservation tillage fields, slowing SOM decomposition rates (Kern and Johnson, 1993). However, under conservation tillage, fertilizer and manure additions stay on the surface of the soil instead of being integrated through the profile, influencing P in runoff (Oloya and Logan, 1980; Blevins et al., 1983). While erosion control reduces TP and PP, tillage type can influence DP and BAP amounts in runoff (Eghball and Gilley, 2001). Griffith et al. (1977) found the DP amounts increased six times in surface runoff in just a few years under no-tillage conditions. In a study where dairy manure was added, Mueller et al. (1984) found that DP and BAP losses were greater in no-tillage systems than conventional and chisel systems.

Cover crops can reduce erosion and nutrient losses (Reeves, 1994). A cover crop can protect the soil as well as suppress weeds, sequester carbon, and protect water quality by reducing sediment and nutrient losses (Dabney et al., 2001). Instead of leaving the soil bare after harvest, the plant residue coverage created by cover crops can considerably reduce wind and water erosion (Frye et al., 1985). Additionally, as cover crops extract excess nutrients and water from the soil, they are successful at reducing leaching and runoff (Reicosky and Forcella, 1998; Dabney et al., 1998).

Agriculture is a vital part of Wisconsin’s economy and livelihood, with dairy being especially valued. Corn silage production and manure application to soil is typical of most dairy farms, which inevitably impacts soil health, erosion rates, and nutrient losses. Conservation tillage practices and the use of cover crops have been widely studied as methods to reduce these negative impacts; however, impacts on runoff P losses have not been well quantified. We found in the first chapter of this thesis that cover crops are being used in a wide variety of Wisconsin operations, supporting the need to investigate their impacts more thoroughly. In these dairy systems, P movement is particularly of concern, due to its ability to transform into various plant available forms and cause eutrophication. This study was conducted to determine how conservation tillage and cover crop practices affect sediment and P losses from corn silage production in Wisconsin.

Materials & Methods

Site Description

Field plots were established in the fall of 2013 in Columbia County. The experimental area comprised a total area of 9.0 ha. All of the soils located in the study site were classified as silt loams, with the primary soil series being Plano. Saybrook and Ringwood series are found in areas where the landscape reaches a 2-3% slope.

Every fall, manure was injected into each plot at 112,200 liters ha^{-1} (12,000 gal ac^{-1}) after corn silage harvest. Cereal rye was drilled into the necessary plots each fall after manure injection using a no-till drill (John Deere 1590, Deere & Company, Moline IL) at a seeding rate of 100 kg ha^{-1}.

Treatments consisted of two tillage practices (conventional and no-tillage) and three cover crop managements. A single pass with a vertical tillage implement (True-Tandem 300 Turbo, Case, IH, Racine, WI) was conducted in the fall and a soil finisher in the spring for the conventional tillage operation. Although a tillage implement was not used in the no-tillage treatment, there was some soil disturbance in the fall from manure injection. Cover crop treatments consisted of a no cover control, rye seeded in the fall and chemically terminated in the spring at least two weeks before corn planting, and rye harvested in early June as a forage crop. Each treatment was replicated three times. Plots were 13.7 m wide (18 rows) by 152 m long to allow the use of farm-scale equipment for field operations. Corn was in a 3-year rotation with alfalfa (*Medicago sativa*) with both phases of the rotation present each year. This study was focused on the corn silage phase of the rotation. Budgetary and time constraints allowed us to conduct rainfall simulations only on the no cover (NCC) and rye chemically terminated in the spring (CC) treatments. Rainfall simulations were also conducted on one alfalfa plot in each replication to compare to corn silage results.

Rainfall Simulation

Metal plot frames (1m wide by 1m long and 0.3 m tall) were carefully pounded into the soil 10-15 cm at least three days before simulations occurred. The frames were placed 5-10 meters into the plot and centered. Each frame location was carefully chosen, taking into consideration where traffic disturbance and a good representation of the treatment occurred. A rainfall simulator comprised of a water nozzle tower (Figure 1a), a main wagon (Figure 1b), a water deionizer system (Figure 1c), and a nurse tank water wagon (Figure 1d) was used to compare treatments. The nozzle tower frame consisted of a steel structure with its sides covered by a tarp to limit wind interference on water droplets. The structure was attached to a tractor via a 3-point hitch allowing to raise/lower and position the outflow to be perfectly centered over the steel frame inserted into the soil. The structure reached a height of 3 m with each side measuring 1.8 m wide. At the top, there was a Veejet 80150 nozzle (Spraying Systems Co., Wheaton IL) operating at 55 kPa and a catch/return system that recycled the water that did not fall over the frame. The nozzle oscillated at a programmable interval and was adjusted to reach a rainfall intensity of 7.6 cm per hour.

A plastic tank with a 945 L capacity was positioned on the control wagon to supply water to the nozzle and to collect excess water gathered by the catch/return system. The control box to adjust the nozzle oscillation rate and rainfall intensity was also on the main wagon. A vacuum system was used to collect runoff water inside the steel frames during each simulation. The vacuum system consisted of a 0.95 m PVC wand with small orifices drilled along its length, which was attached to a vacuum pump with a rubber hose operating at -20 kPa. The PVC wand was placed inside the steel frame and as runoff was generated, it was sucked into the wand and collected into a graduated stainless steel collection tank. Runoff volume was measured every five minutes during each simulation by reading the stage height inside the tank. At the end of each simulation, runoff water was mixed inside the collection tank and a water sample was drawn to represent the entire runoff event. The water sample was placed in an insulated cooler with ice packs soon after collection to transport to the laboratory, where they were stored at 3˚C for analysis.

A deionizer system was connected to the water storage tank located on the control wagon. A nurse tank water wagon was filled each morning using the Arlington Research Station's on-site well. This water was then pumped through a pre-filter to remove particulates, followed by a deionizer, and ending in the control wagon's storage tank. Water used for the simulations was deionized to reduce interference with dissolved solute in the water and P in the runoff (Bohl-Bormann et al., 2010).

The tractor containing the rainfall outflow tower was positioned squarely over the frame, ensuring the nozzle was centered. Soil samples were collected prior to each simulation to calculate antecedent soil moisture. Vegetation coverage (%) was measured in each frame using a residue count transect method using two diagonal transects.

Each simulation lasted for 60 minutes, with a rainfall equivalent of 7.6 cm applied to each frame. This rainfall intensity is similar to a 50-100 year storm event for Central Wisconsin (NOAA, 2014). The simulations were repeated three times: June 6-8, 2016, October 24-28, 2016, and April 11-18, 2017. During these three simulation timings, four treatment combinations (CT NCC, CT CC, NT NCC and NT CC) in each replication were compared. Three additional simulation runs were conducted in the alfalfa to use as a comparison to corn, for a total of 15 completed runs in each simulation timing.

A master timer was started as soon as the oscillating nozzle started producing rainfall. A different timer began as soon as the first amount of runoff was seen inside the frame. The time of the first visible runoff was recorded. Every five minutes after this, the amount of runoff deposited into the collection tank was recorded. The simulation was considered completed when 60 minutes was reached with the master timer. At this point, the system was turned off, a final runoff amount was recorded, and a well-mixed 1L runoff water subsample was collected from the collection tank. After each simulation the entire system, including the collection tank, was cleaned with DI water.

Sample Analysis

All runoff samples collected during rainfall simulations were analyzed in the Sustainable Soil Management Laboratory in the Department of Soil Science, University of Wisconsin–Madison. The water runoff subsample was stored in a refrigerator until analyses were performed. A vacuum filtration system using a 0.45μm cellulose filter was used to filter 100 mL of each sample within three days of the completed simulations to be used for some of the analyses (Pierzynski, 2000). Runoff was analyzed for sediment, total P (TP), dissolved reactive P (DRP), total dissolved P (TDP) and bioavailable P (BAP).

Sediment was determined by depositing 50 mL aliquot of mixed unfiltered runoff sample into a weighing tin and placed in an oven at 43˚C for 48 hours to remove all moisture. The tin was weighed before depositing the aliquot and after reaching dryness to calculate the amount of sediment.

Phosphorus Analysis

The DRP fraction was determined by taking an aliquot of the filtered runoff water and measuring concentrations using the Murphey-Riley (1962) colorimetric method. A persulfate digestion was used to analyze for TP and TDP (Pierzynski, 2000). Unfiltered runoff was used for TP and filtered runoff for TDP. Concentrations were measured by completing a modified molybdate colorimetric procedure using the Murphy-Riley method (1962) after persulfate digestion. Particulate P (PP) was calculated as the difference between TP and TDP. Similarly, dissolved Organic P (DOP) was estimated as the difference between TDP and DRP.

Bioavailable P was determined using the method described by Sharpley (1993). Briefly, a solution of 10g $FeCl_3 * 6H_2O$ in 100 ml H_2O was used to create iron oxide-impregnated paper strips. Whatman no. 5 filter papers were submerged into the solution, air dried, and then immersed in 2.7 M NH_4OH solution. After the filter papers were air dried, they were cut into 10 cm by 2 cm strips. Bioavailable P was determined by placing one strip in 50 mL of unfiltered runoff and placed on a reciprocating shaker for 16 hours at 23˚C. The strips were removed and rinsed with deionized water to remove any attached soil particles. After the strips were air dried, they were placed in 40 mL of 0.1 M H_2SO_4 and shaken for 1 hour. The solution was then analyzed colorimetrically using the Murphey and Riley (1962) procedure. The difference between BAP and DRP was used to calculate bioavailable PP.

Total runoff was calculated by dividing the final volume of runoff collected during each simulation by the area of each frame, and reported as a depth equivalent in millimeters. Total loads were calculated for each parameter by multiplying the total runoff volume times the concentration of the analyte of interest, and then diving by the area of the frame. Sediment load is reported as tons ha^{-1}, while loads for other parameters are reported as g ha^{-1}.

Soil Sampling and Analysis

Soil samples were taken from 0-5 cm and 0-15 cm depths the day rainfall simulations occurred for a particular plot. Six subsamples at each depth were taken in close proximity to the metal frame before the simulation started, mixed to form a composite sample and stored in sealed bags. The soil samples were weighed the day they were collected, placed in a forced air oven at 32°C, until dry (at least 72 hours). Antecedent moisture was calculated by dividing the difference of wet soil and dry soil by the dry weight. The soil samples were then ground to pass a 2 mm sieve and used to determine water extractable P (WEP) and routine fertility analysis. The routine fertility analysis (pH, P, and K) was performed by the Soil and Forage Testing Laboratories in Marshfield, WI.

Water Extractable P

Water-extractable P was determined using a 50:1 water to soil ratio by adding 0.5 g of soil to 25 mL of distilled water into 50 mL plastic centrifuge tubes. The tubes were capped and shaken for 1 hour in a reciprocating shaker. Afterwards, the samples were centrifuged at 3400 rpm for 15 minutes, followed by filtration of the supernatant using a 2.5µm filter paper (Pierzynski, 2000; Pöthig et al., 2010). The filtrate was analyzed for P colorimetrically using the Murphey-Riley procedure (1962).

Statistical Analysis

Treatments were arranged in a complete factorial design (two tillage and two cover crop treatments), with three replications, using a randomized complete block design. Data were analyzed using a generalized linear model in JMP Pro 13 (SAS Institute, Cary, NC) by comparing tillage treatments, cover crop treatments, and rainfall simulation dates across all parameters examined. The data were transformed by square root to meet the normal distribution assumption when necessary. Because one of the plots in April did not receive a rainfall simulation due to equipment failure, Least Squared Means were used for analyzing runoff data. Differences were considered statistically significant when $p \leq 0.05$.

Results and Discussion

Antecedent Soil Moisture

Antecedent soil moisture was significantly different only among rainfall simulation dates ($p \leq 0.001$; Table 1). This highlights that there were no differences among treatments in soil moisture before the simulations within each date, thus among between treatments can be attributed to other treatment factors. These data are reflective of typical soil moisture fluctuations across seasons. October had the highest antecedent soil moisture when rainfall simulations were conducted (Figure 2). The antecedent soil moisture was the lowest in June.

Total Runoff and Sediment Loads

Rainfall simulation date did not have a significant influence on total runoff volume (p = 0.2412; Table 1). However, rye as a cover crop significantly reduced total runoff volume when compared to NCC when averaged across tillage and the three simulation dates (p = 0.0019; Figure 3). Although total runoff amounts were similar among simulation dates, there was an interaction between date and cover crop (p = 0.0083). The greatest total runoff was recorded in April with the NCC treatment, which was significantly different to CC in June and April. However, total runoff depths were similar between the NCC treatment in April and NCC in June, NCC in October, and CC in October. Similarly, total runoff of CC in April was not significantly different to NCC in June, NCC in October, and CC in October. These findings highlight the importance of surface residue from a cover crop in reducing runoff at different times of the year. These results differ from those of Andraski et al. (1985) who found no-tillage reduced runoff by 68% compared to conventional tillage in October. This same study noted that no-tilled plots reduced runoff in the spring as well. Although our April simulations received 45.9% less runoff than the other two timings, this reduction was caused by cover crops and not tillage. However, some trends are observed in the cumulative runoff production (Figure 5). Runoff production in June for the NT CC treatment was lower than the other three treatments. Similarly, in April, CT CC and NT CC had lower runoff than CT NCC and NT NCC. Differences among treatments are not discernable in October. These differences in cumulative runoff show the importance of crop residue on the soil surface for reducing runoff. Also, it appears CT practices can lead to reduced infiltration rates early in the growing season, most likely due to surface seal or soil crust formation.

Total sediment load was significantly ($p = 0.0007$) reduced by 51.7% with rye as a cover crop, averaged over tillage and simulation dates (Table 1; Figure 6). Additionally, there was a significant interaction between tillage and date ($p = 0.0318$; Figure 7). Conventional tillage in June and no-tillage in October were greater than NT in June. According to an eight year study conducted by Stuntebeck et al. (2011) in Wisconsin, the greatest amount of runoff was observed in the month of March, and suspended sediment yield in runoff was highest in May, contributing to more than half of the annual suspended sediment yield. In March, soil is transitioning between frozen-unfrozen conditions with large amounts of snow melt, but May creates the most sediment loss because soil is completely unfrozen and farmers are using tillage practices on their fields. These findings, along with our results, suggest that spring months are most vulnerable to runoff and sediment loss and can benefit most with increased soil cover.

Rainfall simulation data from alfalfa plots were used along with percent cover to investigate the impact of management on soil cover and total runoff and sediment loads. There was a relatively weak linear relationship between percent cover and total runoff among NCC, CC, and alfalfa (Figure 8). In general, greater total runoff was measured with NCC, followed by CC and alfalfa. Similarly, there was an inverse linear correlation between soil coverage and sediment load ($R^2 = 0.1399$; Figure 9), but this relationship was weaker than that with total runoff ($R^2 = 0.6442$). However, data presented in Figures 8 and 9 represent treatments regardless of the time of year. As previously discussed, time of the year is an important factor to consider since cover crop biomass does not persist on the soil surface the entire growing season. Further, Mohammad and Adam (2010) found that reductions in runoff and erosion are impacted most by type of vegetative cover, rather than percent of cover. We explored the relationship between total runoff and sediment loss by type of cover (i.e. corn, alfalfa, or rye) on the day of rainfall simulations. Alfalfa plots that had rye as a cover crop during the April simulations were included in this analysis. The predominate plant tissue on the soil surface was determined visually as corn, alfalfa, or rye (Figures 10 and 11). There was an inverse linear relationship between total runoff and percent ground cover using the predominate plant material on the soil surface (Figure 10), but the relationship was weaker (R^2= 0.5616) than in Figure 8. This points to the importance of having the soil surface cover to prevent runoff, and that there was no residual effect of rye as a cover crop for reducing runoff. However, the relationship between sediment loss and percent ground cover was stronger (R^2 = 0.4112; Figure 11) when considering the actual plant material on the soil surface the day of the simulation event than when classifying ground coverage by cover crop use (Figure 9). This is in agreement with the finding of Mohammad and Adam (2010) and underscores the need to have some type of surface cover during the entire year to reduce erosion.

Soil Test Phosphorus and Water Extractable Phosphorus

Soil test P concentrations, reported as Bray-P, were significantly different between simulation dates (p = 0.0148; Table 1). Soil Bray-P concentrations were greatest in June when compared to April, but not significantly different to October (Figure 12). Likewise, Bray-P concentrations in soil were similar in October and April.

Water extractable P (WEP) followed a similar pattern to Bray-P in that only simulation date had a significant impact ($p < 0.0001$; Table 1). The WEP concentration ranked October > June > April (Figure 13). Not surprisingly, October had the greatest WEP since soil was sampled only a few weeks after dairy manure application. Water extractable P was greater in June than April possibly because of P release of decomposing rye plant tissue and greater manure mineralization. Given these results, it would be expected that runoff P losses be greater in October followed by June.

Phosphorus Losses in Runoff

Total P loads in runoff were significantly reduced ($p = 0.0142$) by 42.0% with the use of rye as a cover crop averaged across simulation dates and tillage (Table 2; Figure 14). This effect of reduced TP loads with cover crop use is similar to the reduction in sediment load with cover crop use described earlier. Further, there was a cover crop by date of simulation interaction ($p = 0.0428$). In April, the rye cover crop played an important role in reducing TP by 68.5% relative to TP load in April with NCC (Figure 15). Nevertheless, TP loads were similar with CC in April, NCC in June, NCC in October, and CC in October.

Overall, TDP load in runoff was affected by simulation date ($p = 0.0002$; Table 2). There were lower TDP losses in June and April when compared to October (Figure 16). This same trend was observed with DRP loads, in which simulation date was the only significant effect ($p = 0.0472$; Table 2). Unlike TDP, DRP loads were lowest in April, but not significantly different to June (Figure 17). June and October DRP loads were similar to each other. These results are similar to a study conducted by Kleinman et al. (2005) who also found that under rainfall simulations, there was no significant difference in runoff TDP with cover crop use. There was greater variability in the measured DRP loads between treatments in October, while DRP loads were similar between treatments in June and April. The most likely explanation for these differences is that the fall manure application generated more variability among treatments. Additionally, it is important to note the range of P losses in the October simulations, contributing to no significant differences of any P fractions at that timing. Figure 20 shows the box plots for DRP losses for all three simulation timings. The October NT CC data shows a range from 70 to over 350 g ha^{-1}. This variability might be contributed to uneven manure injection sites or a difference in injection between conventional and no-tillage plots.

On average, losses of Particulate P were significantly ($p = 0.0154$) reduced with cover crops by 43.8% (Table 2; Figure 19). Simulation date also had a significant effect ($p = 0.0011$) on PP loads with losses ranking June < October ≤ April (Figure 20). A two-way interaction between date and cover was observed ($p = 0.0498$). In general, it appears that most of the TP lost in runoff was from the sediment bound as PP. This was also found in runoff studies by others during rainfall simulations (Reddy et al., 1978; Munn et al., 1973). Likewise, cereal rye as a cover crop was effective in reducing BAP loss overall by 33.8% (Table 2; Figure 21). It is important to note that BAP is commonly associated with algal blooms in freshwater ecosystems, therefore rye as a cover crop can be a useful management option to reduce BAP losses from corn silage production fields.

Focusing on our April simulations, cover cropped treatments significantly reduced TP, TDP, PP, and BAP losses. As stated above, Wisconsin sees the most runoff between the months of March-May, and our April simulations are capturing this phase of the crop cycle and year. If the spring is the most vulnerable time for runoff and sediment losses, we see that cover crops can have a significant impact.

Although our study did not see any tillage effects in P loss, Franklin et al. (2007) found that TP and PP losses were greater in CT plots compared to strip-tilled plots during simulated rainfall on loamy sand soil. However, this study also concluded that DRP losses were much greater in the strip-tilled plots. The authors contributed this difference to P left on the soil surface rather than incorporated to 15cm depths like in conventional systems.

Conclusions

The results of this study show that runoff, sediment, and P losses can be reduced by planting cover crops, encouraging their use. By using cover crops in Wisconsin, there is potential for both farmer and environmental benefits. With less runoff, more water infiltrates the soil and is available for crop uptake. More sediment and P being kept in the soil has the potential to increase yields and soil health. With reduced sediment and P entering local freshwater lakes and streams, it is possible to 6lessen the downstream impact of eutrophication in the Gulf of Mexico.

In this study, the use cereal rye as a cover crop in corn silage production played various roles depending on the timing of the year. However, when averaged across the June, October, and April rainfall simulation timings, rye reduced runoff volumes by 24.1%, sediment loss by 51.5%, and total P by 42.0%. Tillage had an effect only in the June simulations when no-tillage was in combination with cover crops, resulting in a reduction of runoff.

In Wisconsin, soil cover could especially aid in reduced runoff and sediment loss during spring months when snow melt and soil thaw occurs. In the spring, cereal rye produces a thick cover that successfully protected the soil during the April rainfall simulations, supporting their potential to lower impacts during this susceptible time.

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Figure 1. Rainfall simulator components consisted of (a) a water nozzle tower with tarp attached to a tractor, (b) a main wagon that housed the controls, a water tank for applying water to the nozzle, and a stainless steel collection tank to collect runoff with a vacuum hose, (c) a water deionizer system, and (d) a nurse tank water wagon that fed the tank in the main wagon through the deionizer system.

Table 1. Analysis of variance summery for the effect of treatments on various parameters for two tillage types (conventional and no-tillage) and two cereal rye cover crop treatments (no cover crop and cover crop) averaged across three rainfall simulation dates (June 2016, October 2016, and April 2017).

Source	**Antecedent Soil Moisture**	**Total Runoff Volume**	**Total Sediment Load**	**Bray-P**	**Water Extractable P**
			Probability > F		
Tillage (T)	0.8515	0.3749	0.5074	**0.9009**	0.6581
Cover (C)	0.1642	**0.0019**	**0.0006**	**0.8652**	0.1039
Date (D)	**≤0.0001**	0.2412	0.8741	**0.0233**	**≤0.0001**
T x C	0.8335	0.5841	0.1750	**0.8841**	0.1732
T x D	0.9231	0.0702	**0.0318**	**0.6026**	0.6290
C x D	0.9711	**0.0083**	0.0911	**0.1850**	0.1126
T x C x D	0.9593	0.2595	0.2886	**0.6861**	0.3261

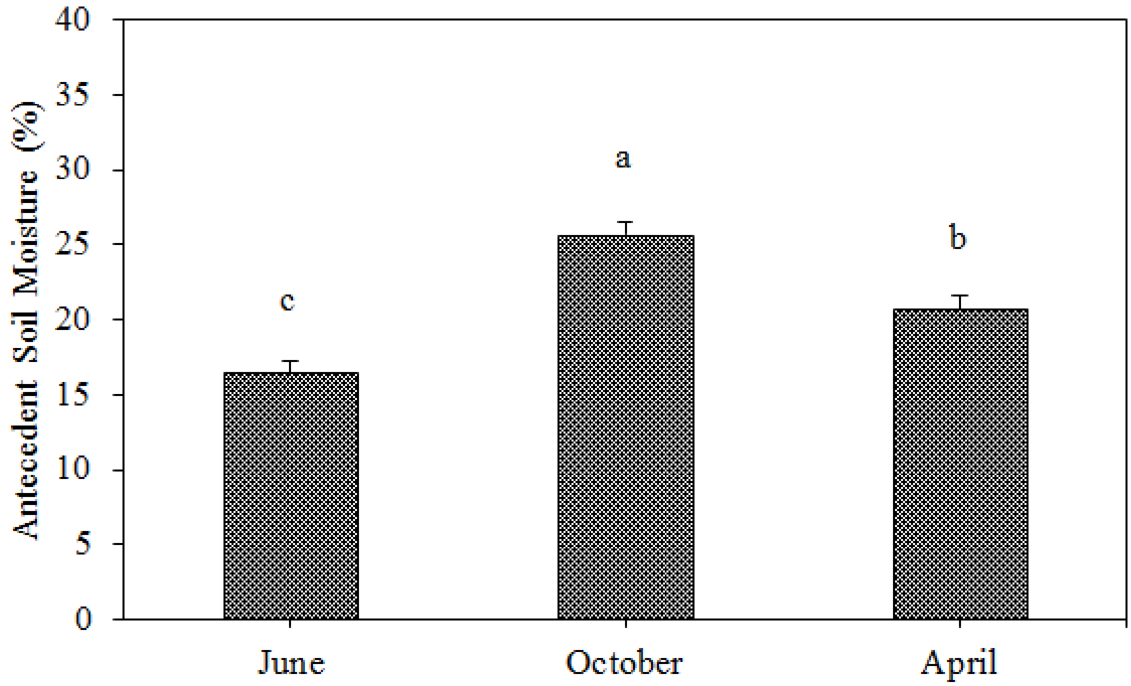

Figure 2. Antecedent soil moisture for each rainfall simulation. Soil samples were collected the day each simulation was performed.

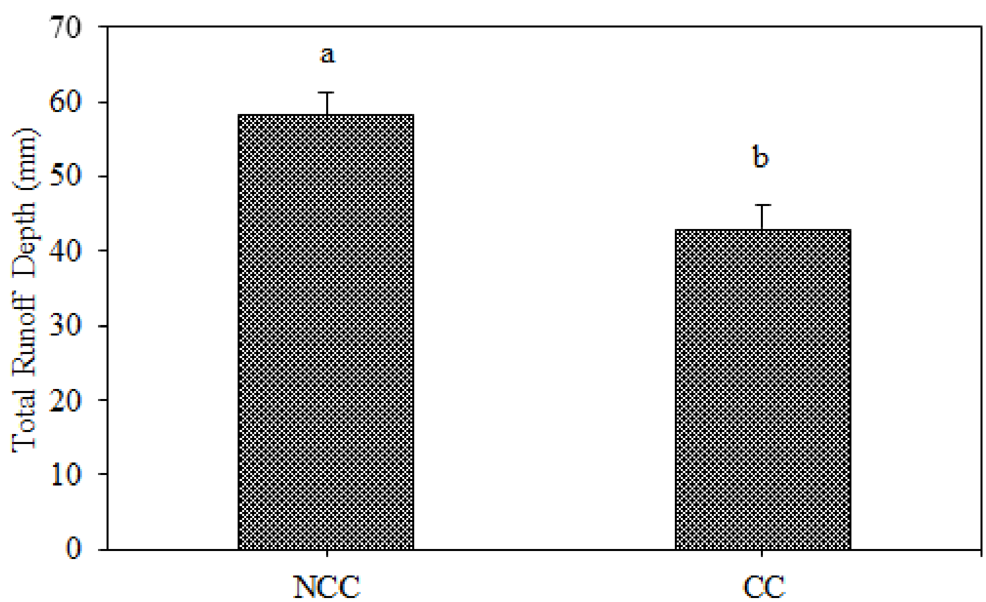

Figure 3. Total runoff depth for two cereal rye cover crop treatments (NCC – No cover crop; CC – Cover crop) averaged across three rainfall simulation dates (June 2016, October 2016, April 2017) and two tillage treatments (conventional tillage and no-tillage).

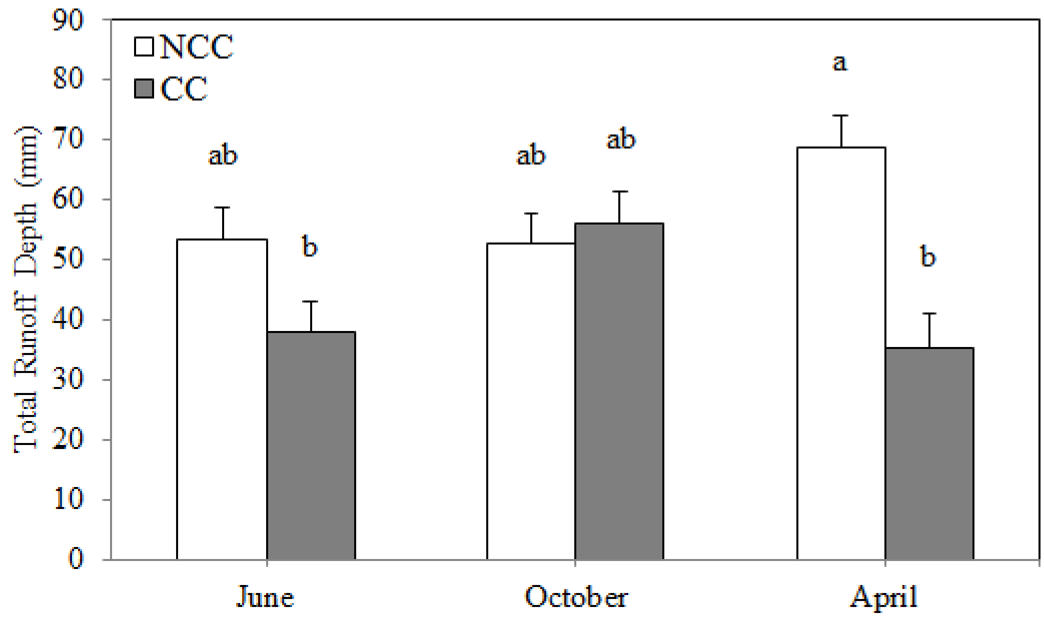

Figure 4. Total runoff depth for two cereal rye cover crop treatments (NCC – No cover crop; CC – Cover crop) and three rainfall simulation dates (June 2016, October 2016, April 2017) averaged across two tillage treatments (conventional tillage and no-tillage).

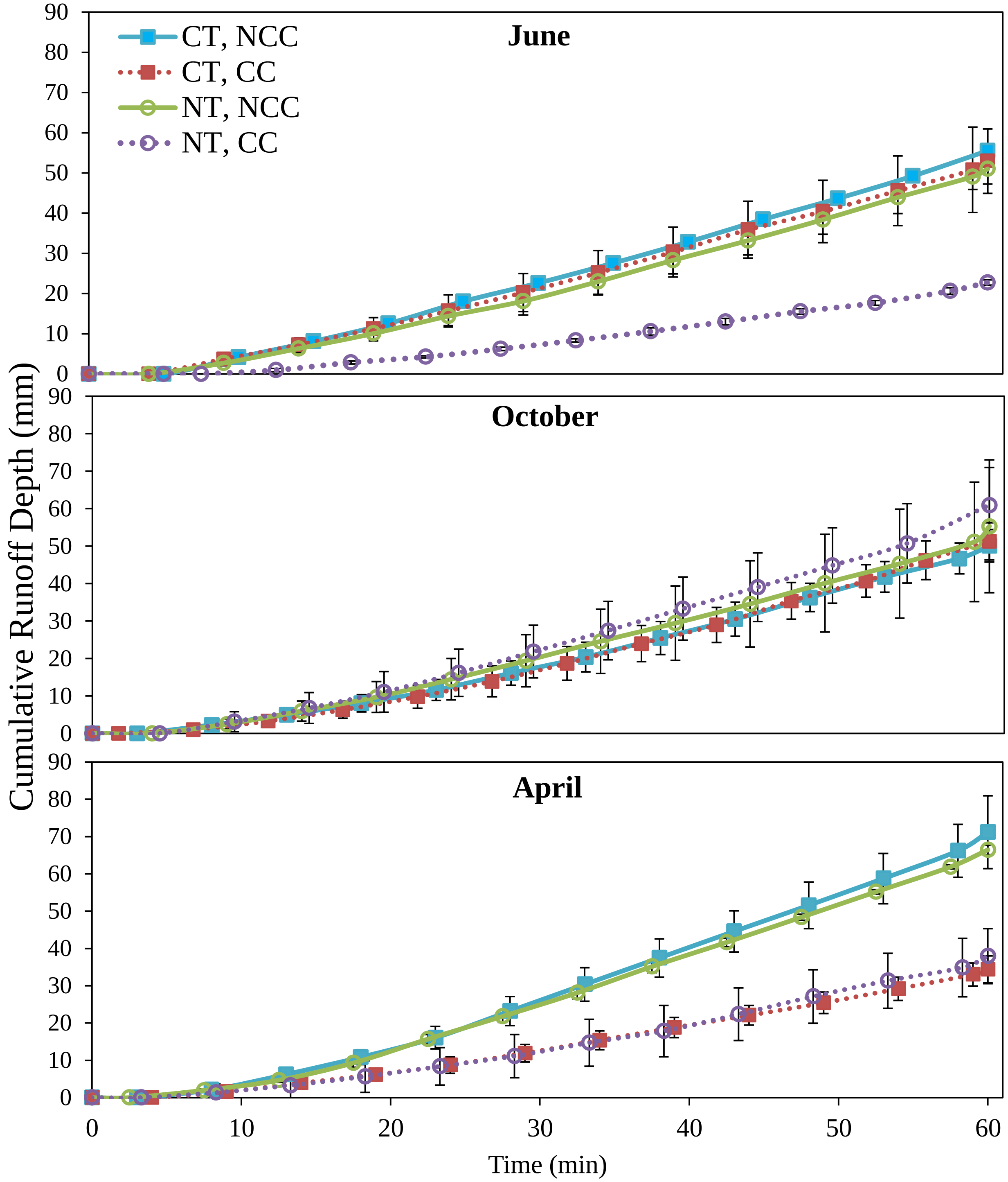

Figure 5. Cumulative runoff for two tillage methods (CT – conventional tillage; NT- no-tillage) and two cover crop treatments (NCC – no cover crop; CC- cover crop) treatment combinations during three different months (June, October, April) for a sixty minute rainfall simulation event near Arlington, WI.

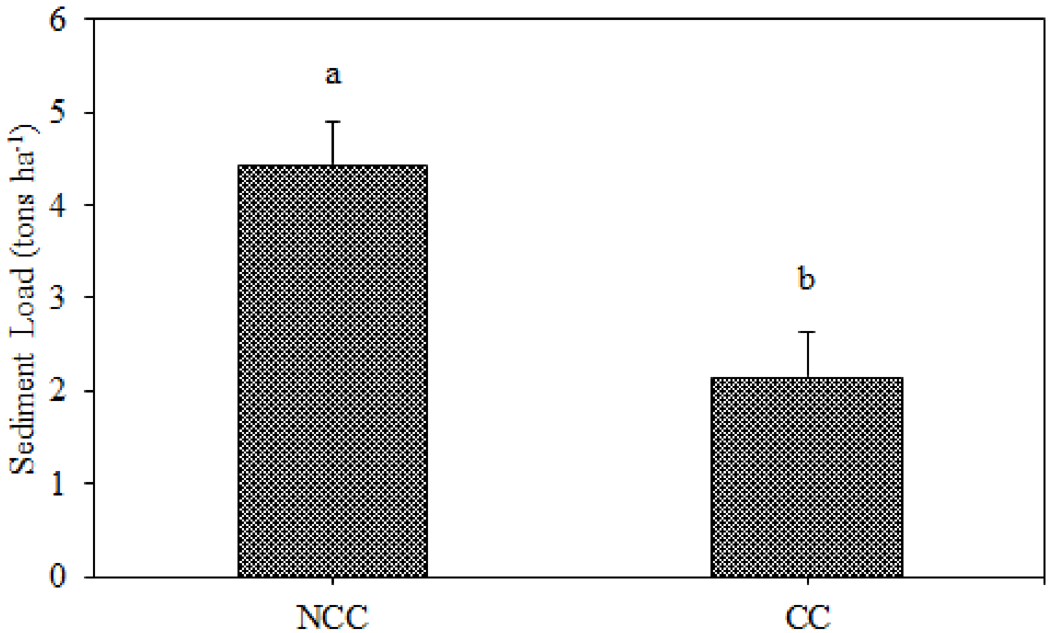

Figure 6. Total sediment load for two cereal rye cover crop treatments (NCC – No cover crop; CC – Cover crop) averaged across three rainfall simulation dates (June 2016, October 2016, April 2017) and two tillage treatments (conventional tillage and no-tillage).

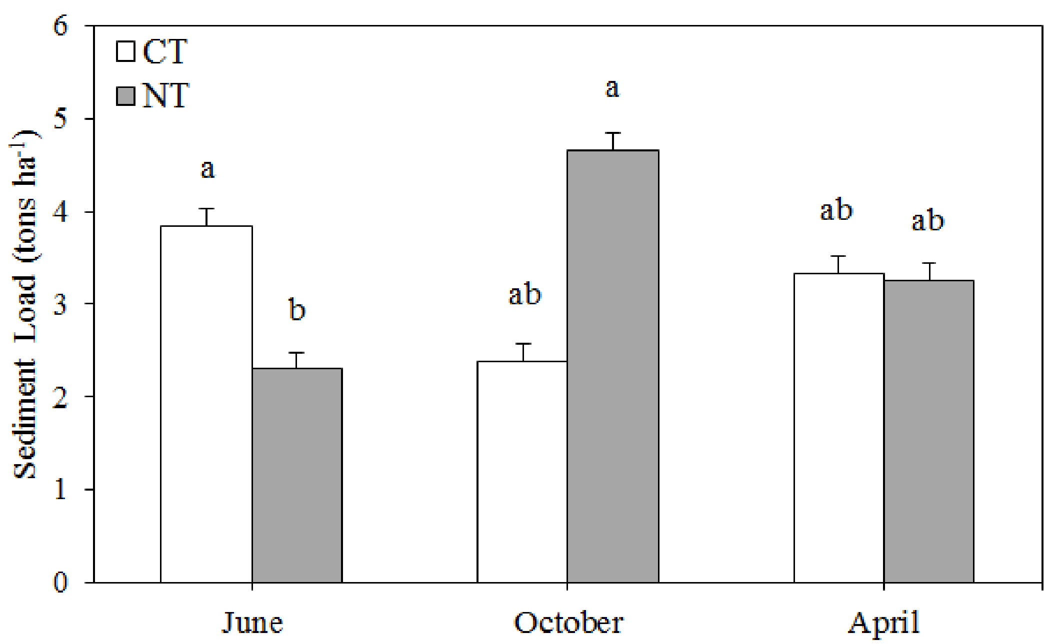

Figure 7. Total sediment load for two tillage treatments (CC – Conventional tillage; NT – No-tillage) and three rainfall simulation dates (June 2016, October 2016, April 2017) averaged across two cover crop treatments (NCC- No cover crop; CC – Cover crop).

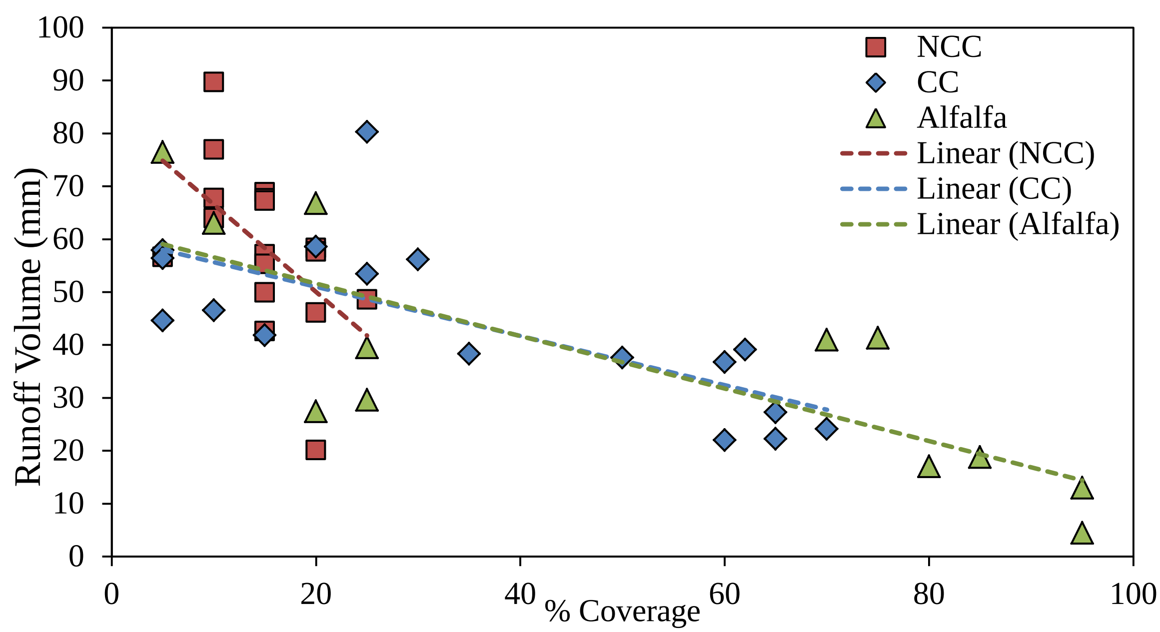

Figure 8. Relationship between total runoff and percent ground coverage for three different management treatments (NCC – No cover crop; CC- Cereal rye as a cover crop; and alfalfa) over three rainfall simulation dates. Overall trend line y = -0.5398 + 64.488; R^2 = 0.5633. NCC trend line y = -0.1.653 + 83.123; R^2 = 0.2896. Cover crop trend line y = -0.4652x + 60.303; R^2 = 0.5202. Alfalfa trend line y= -0.4967x + 61.564; R^2 = 0.6034.

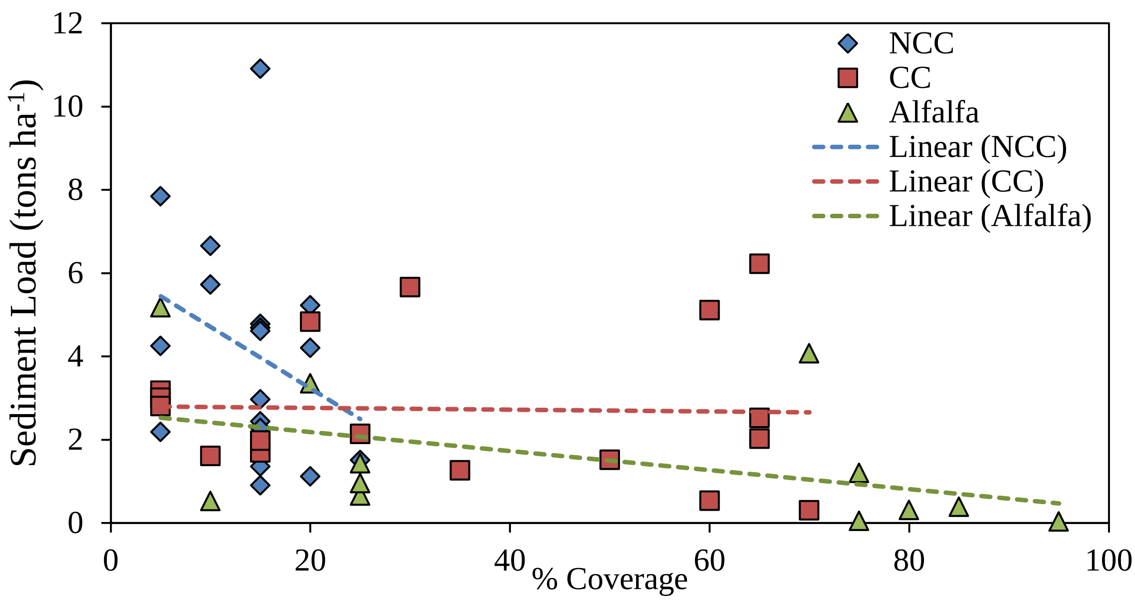

Figure 9. Relationship between sediment load and percent ground coverage for three different management treatments (NCC – No cover crop; CC- Cereal rye as a cover crop; and alfalfa) over three rainfall simulation dates. Overall trend line y = -0.0329x+3.9537; R^2 = 0.1399. NCC trend line y = -0.1473x + 6.1803; R^2 = 0.0956. CC trend line y = -0.0022x + 2.8078; R^2 = 0.001. alfalfa trend line y= -0.0229x + 2.639; R^2= 0.1959.

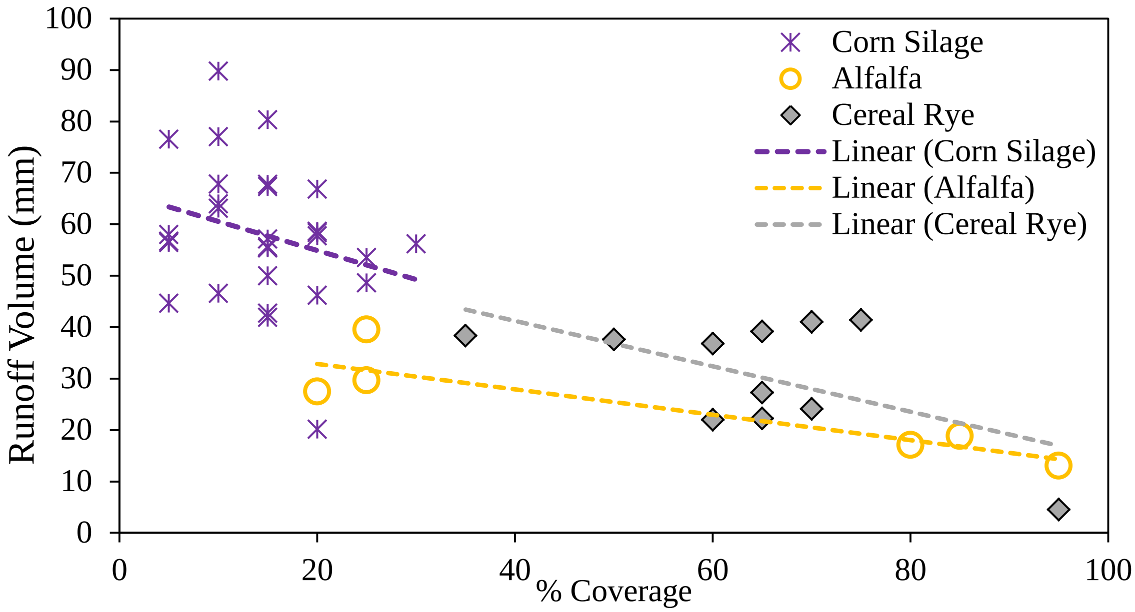

Figure 10. Relationship between total runoff and percent ground coverage of actual predominate plant material on the soil surface (corn silage, alfalfa, or cereal rye). Overall trend line y = -0.5398 + 64.488; R^2 = 0.5633. Corn Silage trend line y = -0.5657x + 66.224; R^2= 0.0749. Alfalfa trend line y= -0.2477x + 37.831; R^2= 0.786. Cereal Rye trend line y = -0.4418x + 58.879; R^2= 0.328.

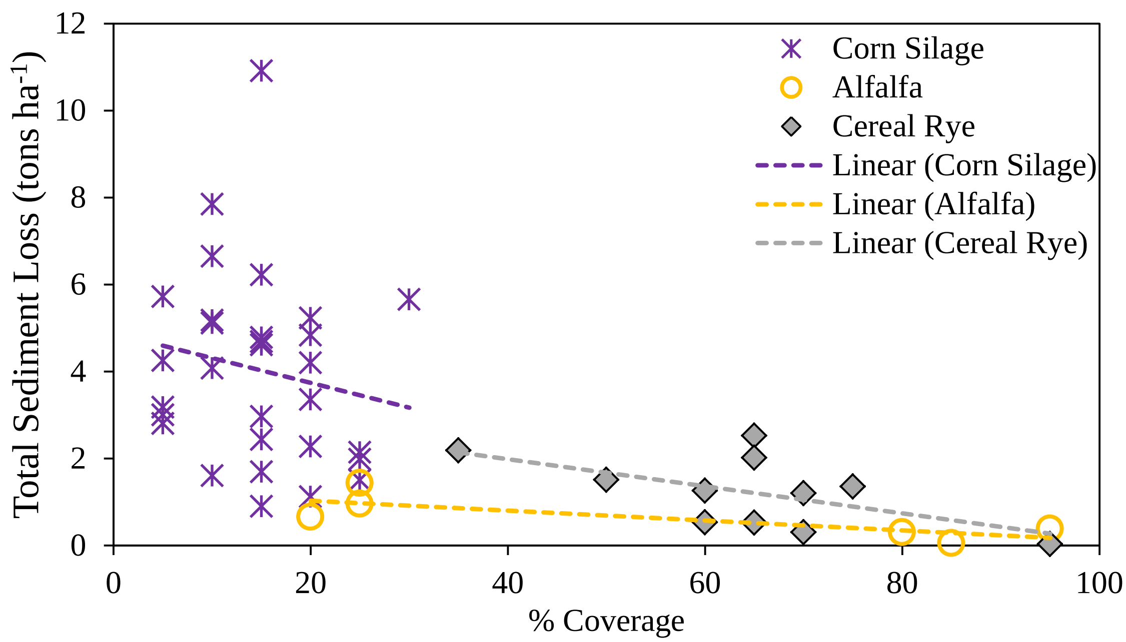

Figure 11. Relationship between total sediment loss and percent ground coverage of actual predominate plant material on the soil surface (corn silage, alfalfa, or cereal rye). Overall trend line y = -0.0329x+3.9537; R^2 = 0.1399. Corn silage trend line y = -0.0571x + 4.8801; R^2= 0.031. Alfalfa trend line y = -0.0114x + 1.2602; R^2= 0.6365. Cereal Rye trend line y= -0.0311x + 3.2311; R^2 = 0.3263.

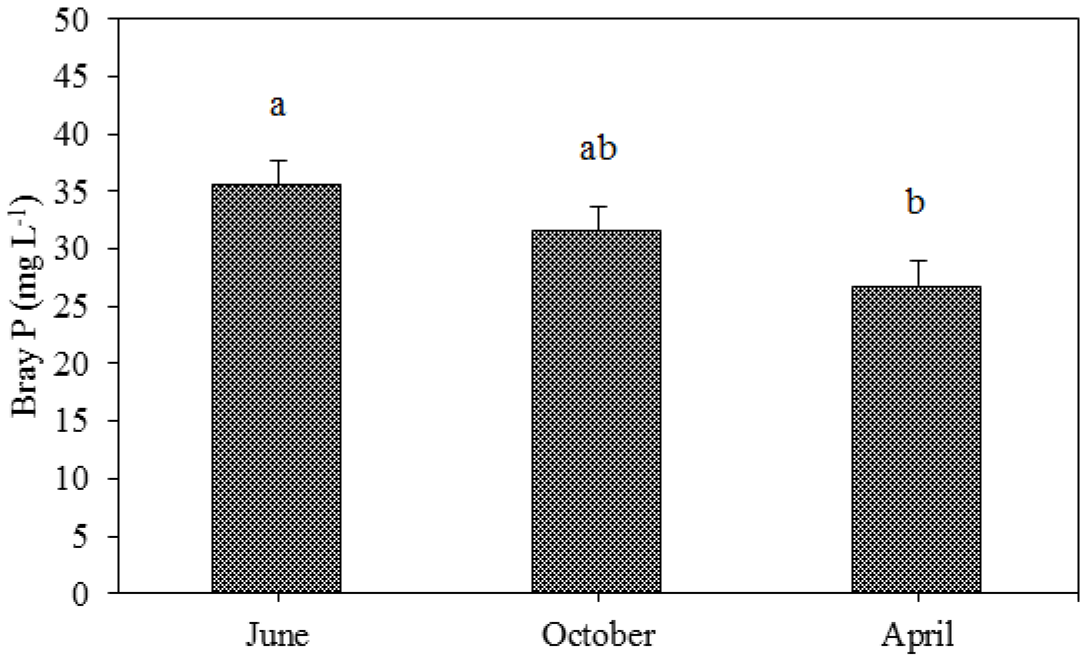

Figure 12. Bray P concentrations for three rainfall simulation times (June 2016, October 2016, April 2017) averaged over two cereal rye cover crop treatments (no cover crop, cover crop) and two tillage treatments (conventional tillage and no-tillage).

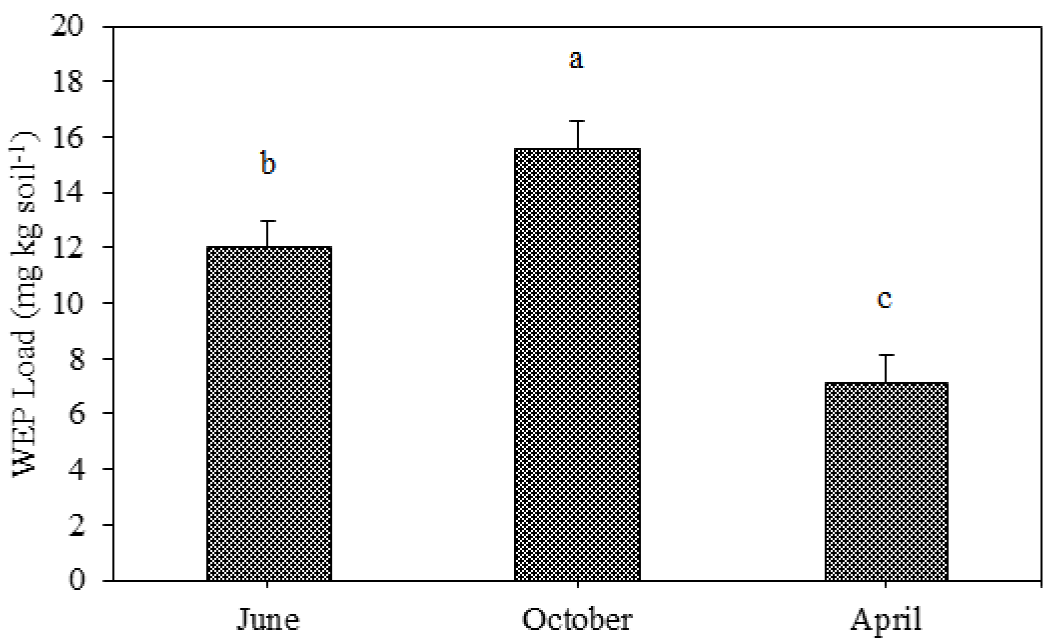

Figure 13. Water Extractable Phosphorus (WEP) for three rainfall simulation dates (June 2016, October 2016, April 2017) averaged over two cereal rye cover crop treatments (no cover crop, cover crop) and two tillage treatments (conventional tillage and no-tillage).

Table 2. Analysis of variance summery for the effect of treatments on various phosphorus amounts for two tillage types (conventional and no-tillage) and two cereal rye cover crop treatments (no cover crop and cover crop) averaged across three rainfall simulation dates (June 2016, October 2016, and April 2017).

Source	**Total P**	**Total Dissolved P**	**Dissolved Reactive P**	**Particulate P**	**Bioavailable P**
		Probability > F			
Tillage (T)	0.9287	0.6010	0.6212	0.9734	0.7783
Cover (C)	**0.0142**	0.2442	0.5381	**0.0154**	**0.0058**
Date (D)	**0.0006**	**0.0002**	**0.0472**	**0.0011**	0.0586
T x C	0.7051	0.2296	0.2862	0.7990	0.2062
T x D	0.1885	0.6358	0.8258	0.1974	0.3524
C x D	**0.0428**	0.0893	0.6385	**0.0498**	0.1016
T x C x D	0.4747	0.3169	0.2308	0.4215	0.4005

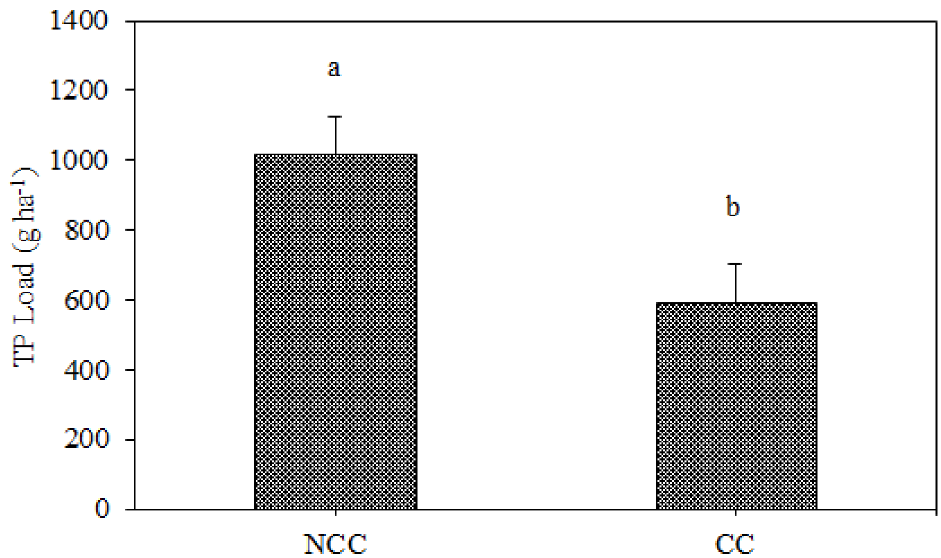

Figure 14. Total P loads for two cereal rye cover crop treatments (NCC – No cover crop; CC – Cover crop) averaged across three rainfall simulation dates (June 2016, October 2016, April 2017) and two tillage treatments (conventional tillage and no-tillage).

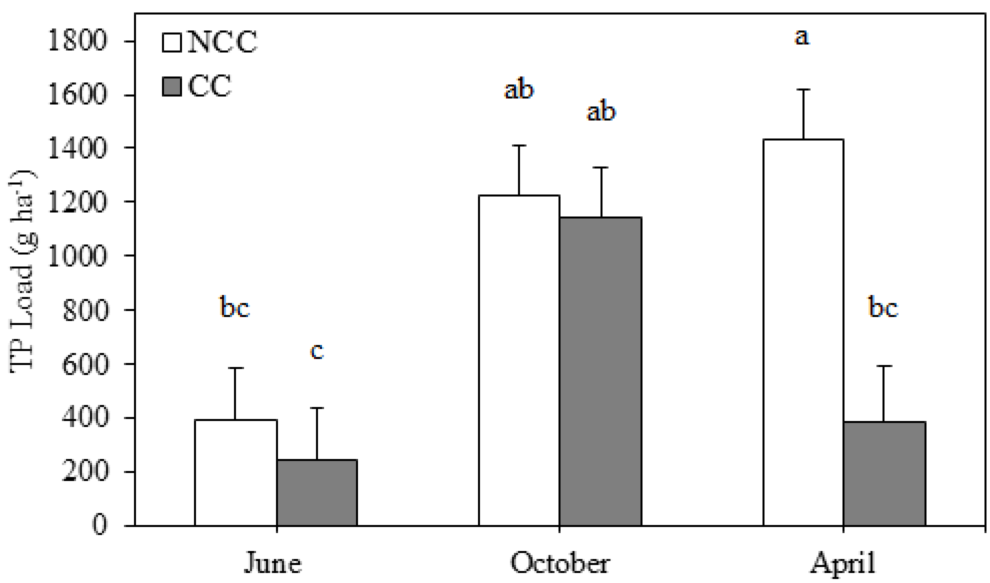

Figure 15. Total P loads for three rainfall simulations dates (June 2016, October 2016, April 2017) and two cereal rye cover crop treatments (NCC - no cover crop; CC- cover crop) averaged across two tillage treatments (conventional tillage and no-tillage).

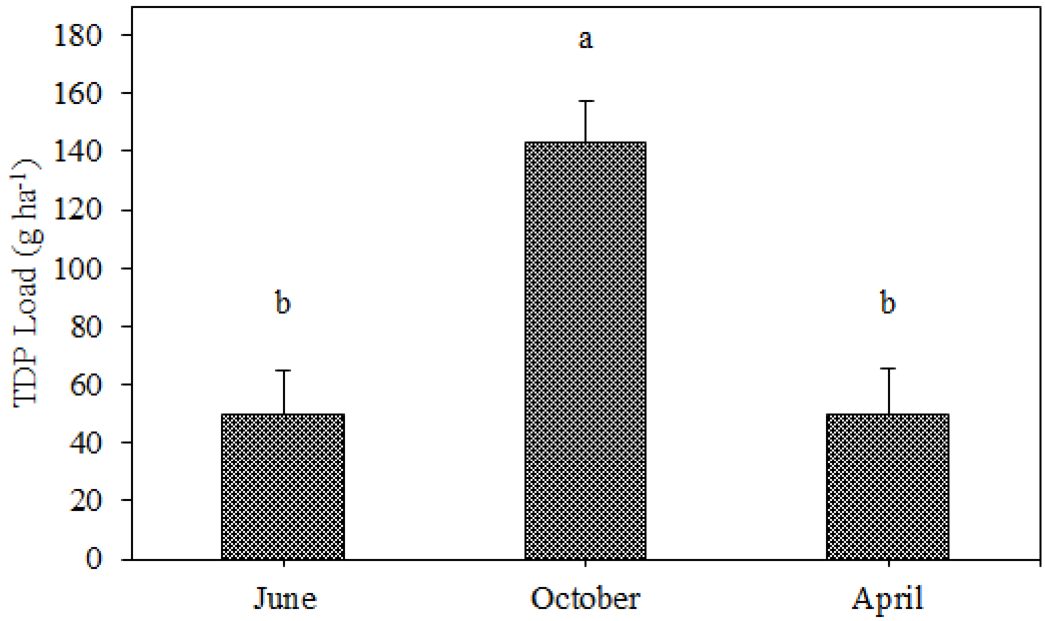

Figure 16. Total Dissolved Phosphorus (TDP) loads averaged across two cereal rye cover crop treatments (no cover crop and cover crop) and two tillage treatments (conventional tillage and no-tillage) during three rainfall simulations dates (June 2016, October 2016, April 2017).

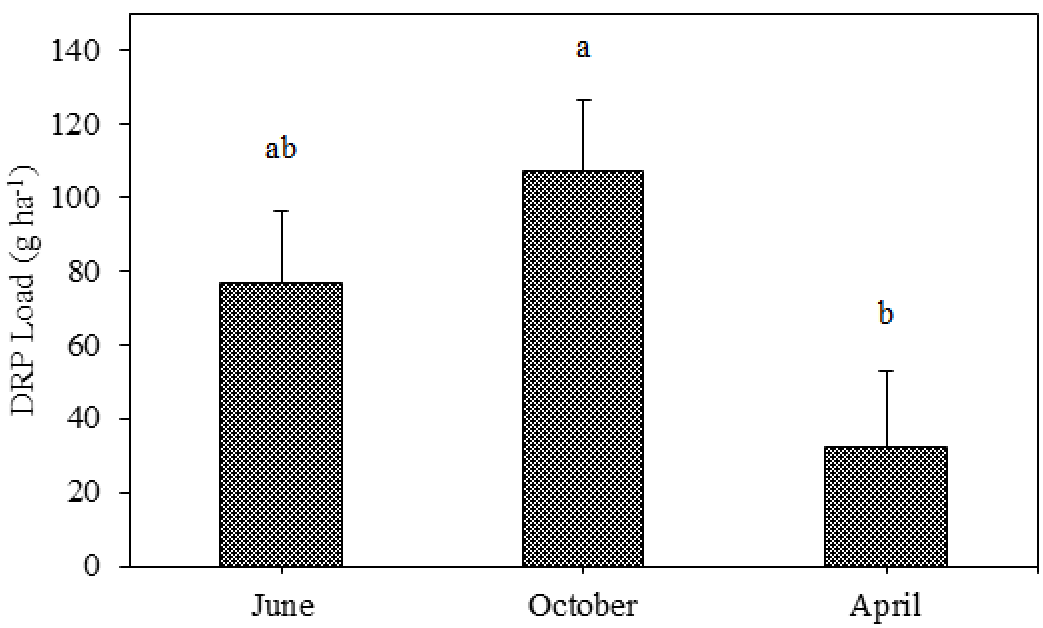

Figure 17. Dissolved Reactive Phosphorus (DRP) loads averaged across two cereal rye cover crop treatments (no cover crop and cover crop) and two tillage treatments (conventional tillage and no-tillage) during three rainfall simulations dates (June 2016, October 2016, April 2017).

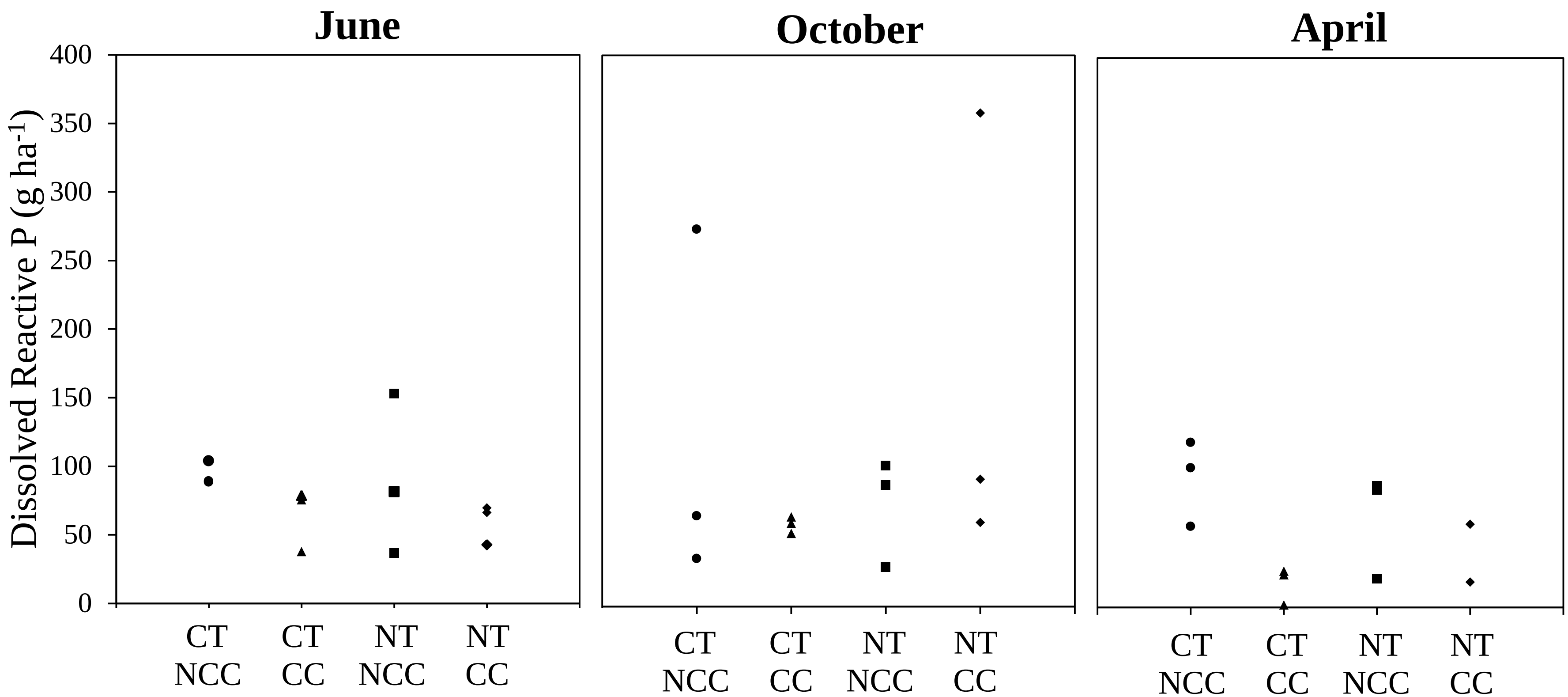

Figure 18. Range of Dissolved Reactive P loads of two tillage methods (CT- conventional tillage; NT- no-tillage) and two cover crop treatments (NCC- no cover crop; CC- cover crop). During each simulation timing (June 2016, October 2016, and April 2017), there were three replications per treatment.

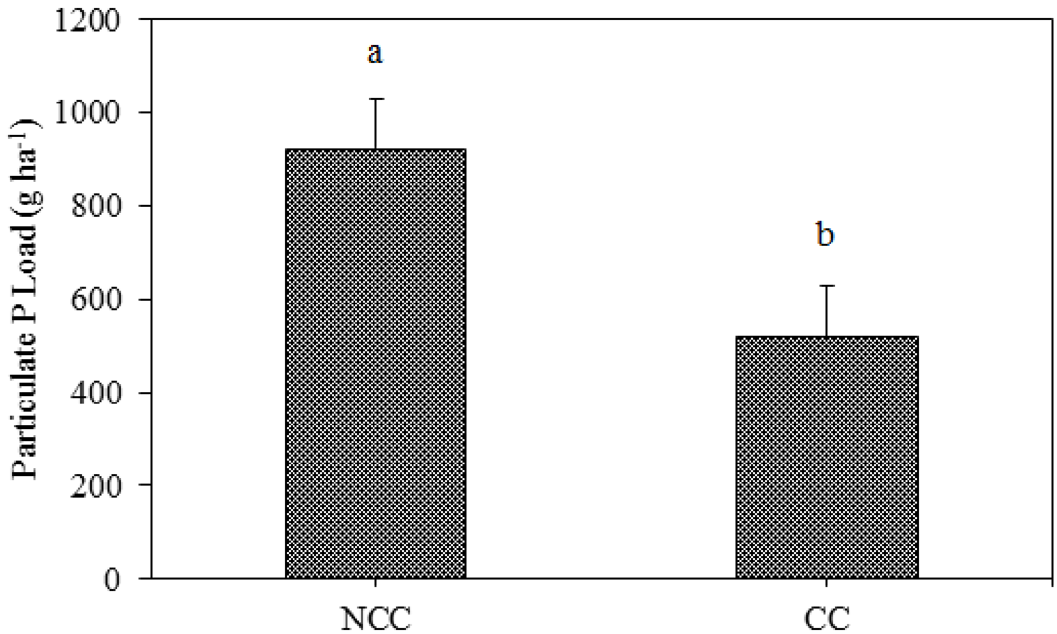

Figure 19. Particulate P (PP) loads for two cereal rye cover crop treatments (NCC – No cover crop; CC – Cover crop) averaged three rainfall simulation dates (June 2016, October 2016, April 2017) and two tillage treatments (conventional tillage and no-tillage).

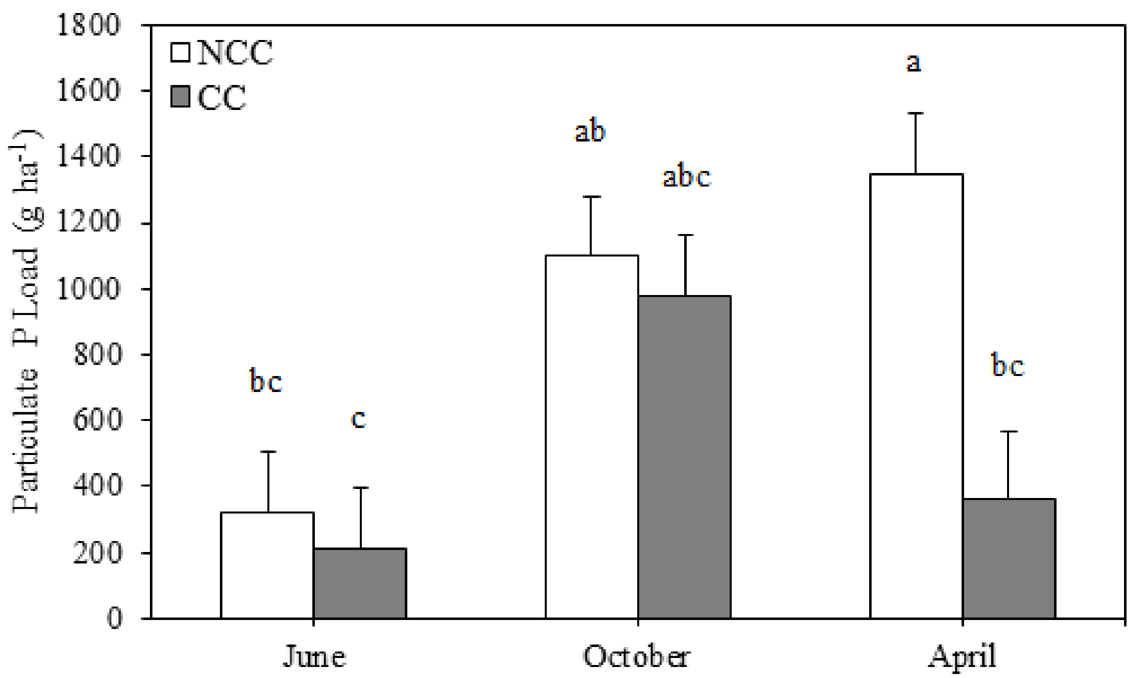

Figure 20. Particulate P loads for three rainfall simulations dates (June 2016, October 2016, April 2017) and two cereal rye cover crop treatments (NCC - no cover crop; CC- cover crop) averaged across two tillage treatments (conventional tillage and no-tillage).

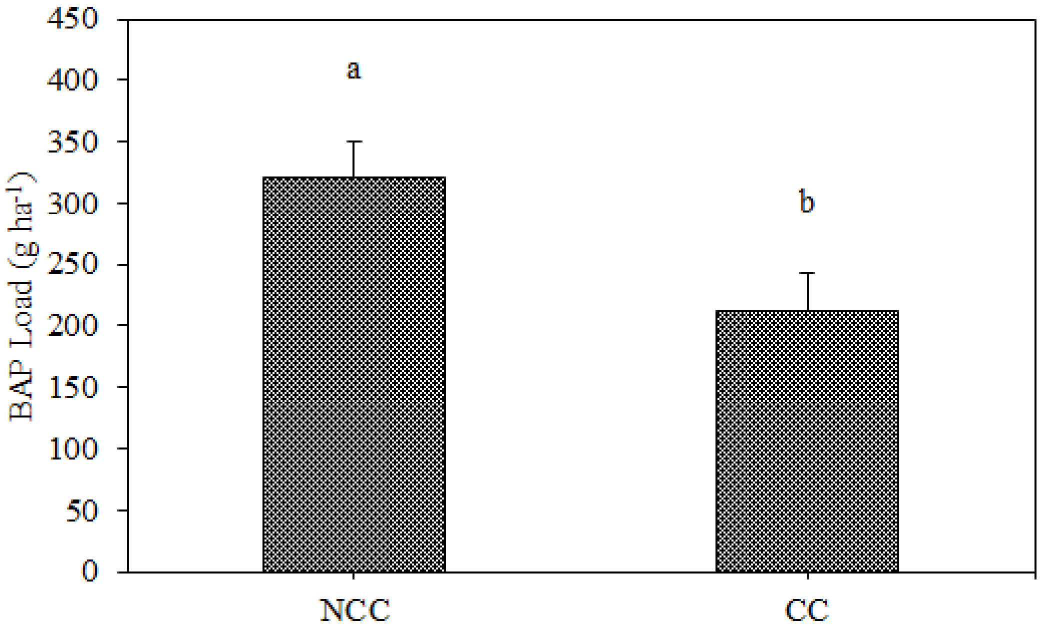

Figure 21. Bioavailable Phosphorus (BAP) loads for two cereal rye cover crop treatments (NCC – No cover crop; CC – Cover crop) averaged across three rainfall simulation dates (June 2016, October 2016, April 2017) and two tillage treatments (conventional tillage and no-tillage).

Appendix A: Supplemental data for Chapter

Table A1. Total number of responses received for each question of the survey.

Question	Total # of responses
1	165
2	139
3	153
4	156
5	165
No CC 6	22
No CC 7	23
No CC 8	23
Yes CC 6	142
Yes CC 7	141
Yes CC 8	142
9	130
10	136
11	130
12	139
13	129
14	131

Pages display the exact survey created in this study and distributed to farmers, crop advisors, and other agricultural professionals.

County you reside in ___________________________

1. How would you describe yourself? (check all that apply)

- o Commodity crop farmer (corn, soybeans, wheat, alfalfa, etc.)
- o Horticultural crop farmer (vegetables, fruits)
- o Livestock producer
- o Crop consultant
- o Researcher
- o Conservation agency employee
- o Other (please specify) ____________________________

2. How many acres do you plant on annually?

- o 1 - 9 acres
- o 10 - 49 acres
- o 50 - 149 acres
- o 150 - 499 acres
- o 500 - 999 acres
- o 1,000 - 1,999 acres
- o 2,000+ acres

3. Please indicate the percentage of acres of your farm(s) that are:

- o ____% Conventional
- o ____% Organic

4. Please indicate the percentage of crop acres that use the following tillage practices.

- o ____% Continuous no-till
- o ____% Rotational no-till
- o ____% Reduced tillage (strip-till or mulch-till)
- o ____% Vertical tillage only (Aerway, Salford, Turbo-till, etc.)
- o ____% Conventional (full-width) tillage

5. Have you used cover crops on your farm or have experience working with cover crops in the past 5 years?

- o No – please complete page 2
- o Yes – please complete pages 3 & 4

<u>If you answered NO to using cover crops</u>

6. What are the three (3) most important factors that **prevent** the use of cover crops on your farm/the farms you work with?

- ☐ Time/labor required for planting and managing cover
- ☐ Cost of planting and managing cover crops
- ☐ Cover crop seed cost
- ☐ No measurable economic return
- ☐ Cover crop seed availability
- ☐ Difficulty establishing cover crops
- ☐ Too wet in spring - fears on delaying planting time
- ☐ Yield reduction the following cash crop
- ☐ Cover crop sometimes uses too much soil moisture
- ☐ Nitrogen immobilization (N not available to the crop)
- ☐ Cover crop becomes a weed the following year
- ☐ Seeding the right species for my operation
- ☐ Increases overall crop production risk
- ☐ Increases insect potential
- ☐ Increases disease potential

Other (please specify) ____

7. If you were to start using cover crops, please choose the top three (3) benefits that would be most important to you.

- ☐ Controls insects
- ☐ Controls weeds
- ☐ Increases soil organic matter
- ☐ Provides a nitrogen source
- ☐ Reduces diseases
- ☐ Reduces soil compaction
- ☐ Reduces soil erosion
- ☐ Attracts pollinators
- ☐ Improves soil health
- ☐ Winter kills easily (no spring burndown required)
- ☐ Winter hardiness/survival
- ☐ Economic return (e.g. haying, grazing, biofuels)
- ☐ Decreases cost of producing the following cash crop
- ☐ Increases yields in the following cash crop
- ☐ Produces fibrous roots
- ☐ Provides deep tap roots

Other (please specify) __________________________

8. What is the importance of each research topic pertaining to cover crops?

	Not important	Somewhat important	Moderately important	Extremely important
Developing cover crops that fit in my cash crop timing				
Developing cover crops that increase nitrogen				
Developing cover crops that enhance cash crop disease resistance				
Developing cover crops that fit common soil types				
Helping cover crop growers develop plans that fit their operation				

END – Thank you for your time.

<u>If you answered YES to using cover crops</u>

6. Cover crop species that you have used (select all that apply):

- Winter cereal grains
- Legumes
- Brassicas (turnip, rapeseed, mustard, etc.)
- Annual grasses (oats, millet, Sudan grass, etc.)
- Other ___________________________

Have you used a two-species or multi-species mix?

- No, never
- On some fields
- Always

7. Cover crops planting method that you have used (select all that apply)

- Broadcast seeding with seeds left on the surface
- Broadcast seeding with light incorporation
- Seeding with a corn or soybean planter
- Drilling
- Aerial seeding
- Seeding with liquid manure application
- Other ___________________________

8. Cover crop termination method that you have used (select all that apply)

- Herbicide
- Mowing
- Tillage
- Roller crimping
- Grazing
- I prefer to plant cover crops that winter-kill
- Other ___________________________

9. Have you received cost-share assistance or incentive payments to plant cover crops?

- Yes, I have only planted cover crops using financial assistance
- Yes, I periodically receive and use financial assistance to plant cover crops
- No, I have never received financial assistance to plant cover crops on my farm

10. What impact does the market outlook for crop prices have on your use of cover crops?

- Heavy impact, expected prices determine whether or not I use cover crops each year
- Moderate impact on my use of cover crops
- No impact on my use of cover crops

11. Do crop insurance rules and restrictions affect the number of acres of cover crops planted?

- No impact, I do not use crop insurance
- No impact, I use crop insurance
- Moderate impact
- Heavy impact

12. Please choose the top three (3) benefits of cover crops that are most important to you.

- ☐ Controls insects
- ☐ Controls weeds
- ☐ Increases soil organic matter
- ☐ Provides a nitrogen source
- ☐ Reduces diseases
- ☐ Reduces soil compaction
- ☐ Reduces soil erosion
- ☐ Attracts pollinators
- ☐ Improves soil health
- ☐ Winter kills easily (no spring burndown required)
- ☐ Winter hardiness/survival
- ☐ Economic return (e.g. haying, grazing)
- ☐ Decreases cost of producing the following cash crop
- ☐ Increases yields in the following cash crop
- ☐ Produces fibrous roots
- ☐ Provides deep tap roots

Other (please specify) ___________________________

13. Please indicate how influential the following groups and individuals are when you make decisions about cover crop purchases.

	No influence	Small influence	Moderate influence	High influence
Farm media				
Neighboring farms				
Local conservation educator				
University/Extension specialist				
Cover crop seed company				
Private crop advisor				
Ag input retailer/fertilizer dealer				
Cash crop seed dealer				
Landlord				

14. What is the importance of each research topic pertaining to cover crops?

	Not important	Somewhat important	Moderately important	Extremely important
Developing cover crops that fit in my cash crop timing				
Developing cover crops that increase nitrogen				
Developing cover crops that enhance cash crop disease resistance				
Developing cover crops that fit common soil types				
Helping cover crop growers develop plans that fit their operation				

END – Thank you for your time.

Appendix B: Supplemental data for Chapter 2

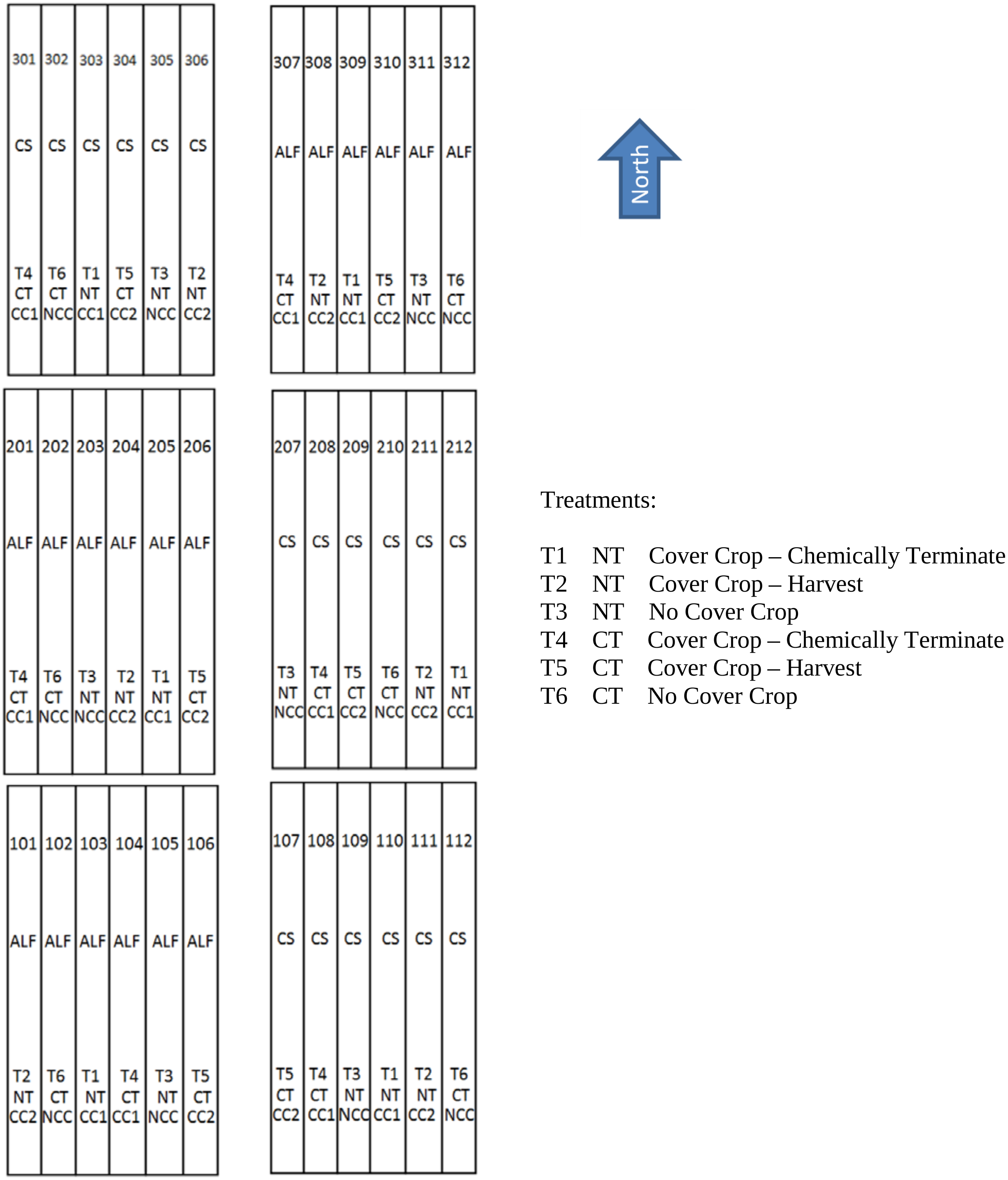

Figure B1. Plot setup from 2013-2016 at a site near Arlington, WI. In 2017, the corn silage and alfalfa plots rotated, with tillage practices applied to the necessary alfalfa plots in the spring of 2017.

Table B1. Total corn silage dry matter yields for two tillage (CT – Conventional tillage; NT – No-tillage) and three cover crop (NCC – no cover crop; CC – Cover crop terminated; CCH – Cover crop harvested) treatments during three seasons near Arlington, WI. Total silage yields for the cereal rye harvested treatment includes corn plus rye yields.

Treatments		**Yield**		
Tillage	**Cover**	**2014**	**2015**	**2016**
		DM Mg ha^{-1}		
CT	NCC	17.2 ns	18.5 b	20.5 b
	CC	17.3	22.5 ab	20.6 b
	CCH	18.3	23.2 a	23.3 a
NT	NCC	18.4	20.8 ab	20.9 b
	CC	17.4	20.7 ab	19.3 b
	CCH	18.3	20.9 ab	23.4 a

Table B2. Estimated total milk production for two tillage (CT – Conventional tillage; NT – No-tillage) and three cover crop (NCC – no cover crop; CC – Cover crop terminated; CCH – Cover crop harvested) treatments during three seasons near Arlington, WI. Estimated total milk production for the cereal rye harvested treatment includes corn plus rye production.

Treatments		**Yield**		
Tillage	**Cover**	**2014**	**2015**	**2016**
		Milk production kg milk ha^{-1}		
CT	NCC	25 280 ns	27 380 ns	31 454 ab
	CC	24 890	26 070	31 180 ab
	CCH	26 190	35 610	33 323 a
NT	NCC	26 460	29 370	32 201 ab
	CC	25 750	32 710	29 877 b
	CCH	27 650	31 280	32 737 ab

Table B3. Corn silage plant moisture at harvest for two tillage (CT – Conventional tillage; NT – No-tillage) and three cover crop (NCC – no cover crop; CC – Cover crop terminated; CCH – Cover crop harvested) treatments during three seasons near Arlington, WI.

Treatments		**Moisture**		
Tillage	**Cover**	**2014**	**2015**	**2016**
		DM Mg ha^{-1}		
CT	NCC	697 ns	681 abc	677 ns
	CC	696	651 c	675
	CCH	679	715 ab	666
NT	NCC	686	671 bc	676
	CC	690	666 bc	692
	CCH	673	727 a	677

Appendix C: Supplemental data for Chapter 3

Table C1. Antecedent moisture of two tillage treatments (CT- conventional tillage; NT- no-tillage) and two cover crop treatments (NCC- no cover crop; CC- cover crop) averaged during three rainfall simulation timings (June 2016, October 2016, and April 2017).

Treatments		**Antecedent Moisture**		
Tillage	**Cover**	**June**	**October**	**April**
			%	
CT	NCC	15.6 ns	25.3 ns	19.9 ns
	CC	17.7	26.6	21.2
NT	NCC	15.8	25.0	20.1
	CC	16.8	25.8	21.7

Table C2. Total runoff volume of two tillage methods (CT- conventional tillage; NT- no-tillage) and two cover crop treatments (NCC- no cover crop; CC- cover crop) averaged during three rainfall simulations dates (June 2016, October 2016, and April 2017).

Treatments		**Runoff Depth**		
Tillage	**Cover**	**June**	**October**	**April**
			mm	
CT	NCC	55.98 a	50.07 ns	71.19 a
	CC	53.95 a	51.26	34.37 b
NT	NCC	50.99 a	55.28	66.44 a
	CC	22.75 b	60.97	40.06 ab

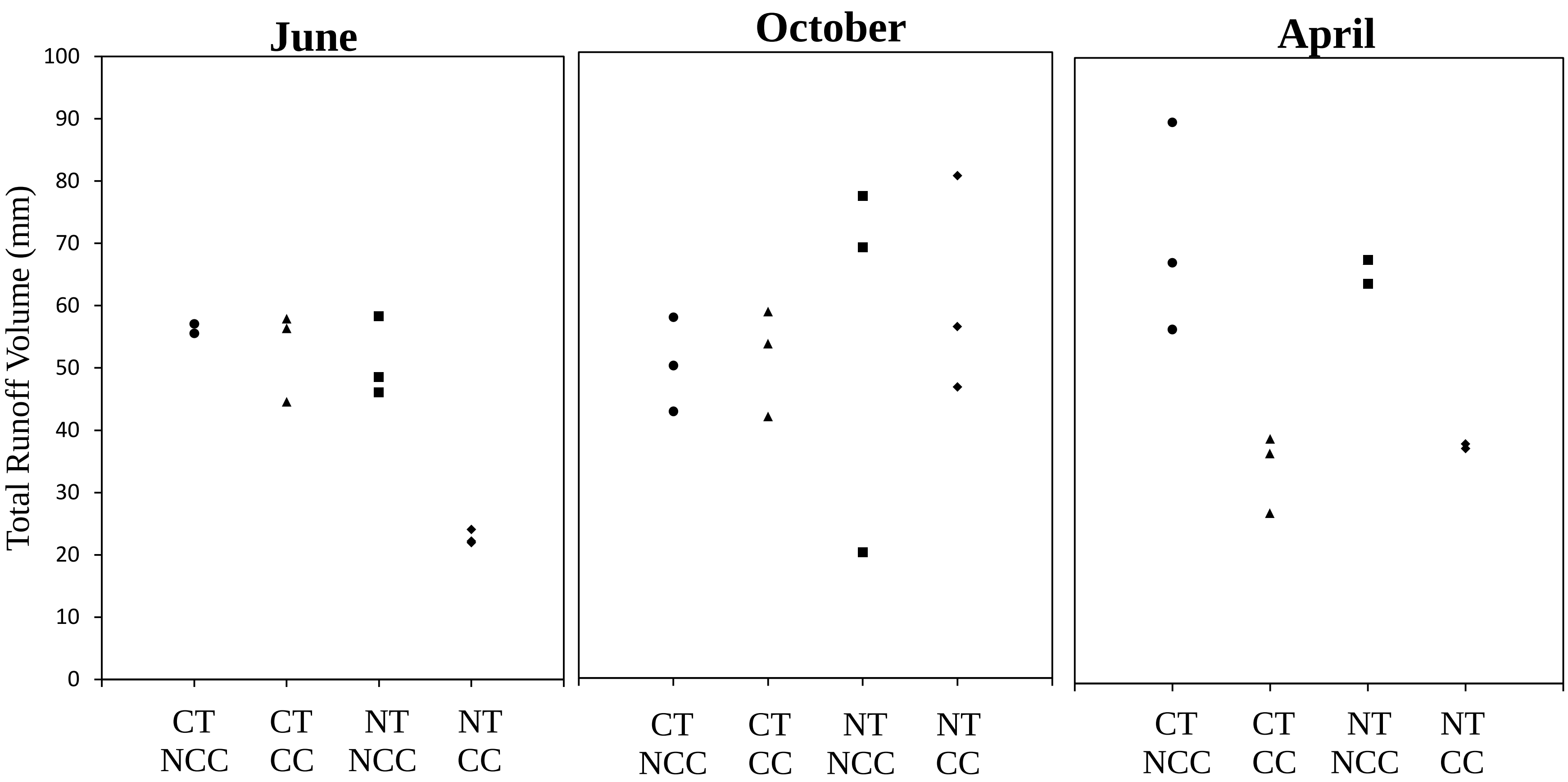

Figure C1. Range of total runoff loss of two tillage methods (CT- conventional tillage; NT- no-tillage) and two cover crop treatments (NCC- no cover crop; CC- cover crop). During each simulation timing (June 2016, October 2016, and April 2017), there were three replications per treatment.

Table C3. Total sediment loads of two tillage methods (CT- conventional tillage; NT- no-tillage) and two cover crop treatments (NCC- no cover crop; CC- cover crop) averaged during three rainfall simulations dates (June 2016, October 2016, and April 2017).

Treatments		**Sediment Load**		
Tillage	**Cover**	**June**	**October**	**April**
		—— tons ha^{-1} ——		
CT	NCC	4.70 a	1.87 ns	5.22 ns
	CC	3.00 ab	2.89	1.44
NT	NCC	3.65 ab	6.23	4.96
	CC	0.95 b	3.08	1.54

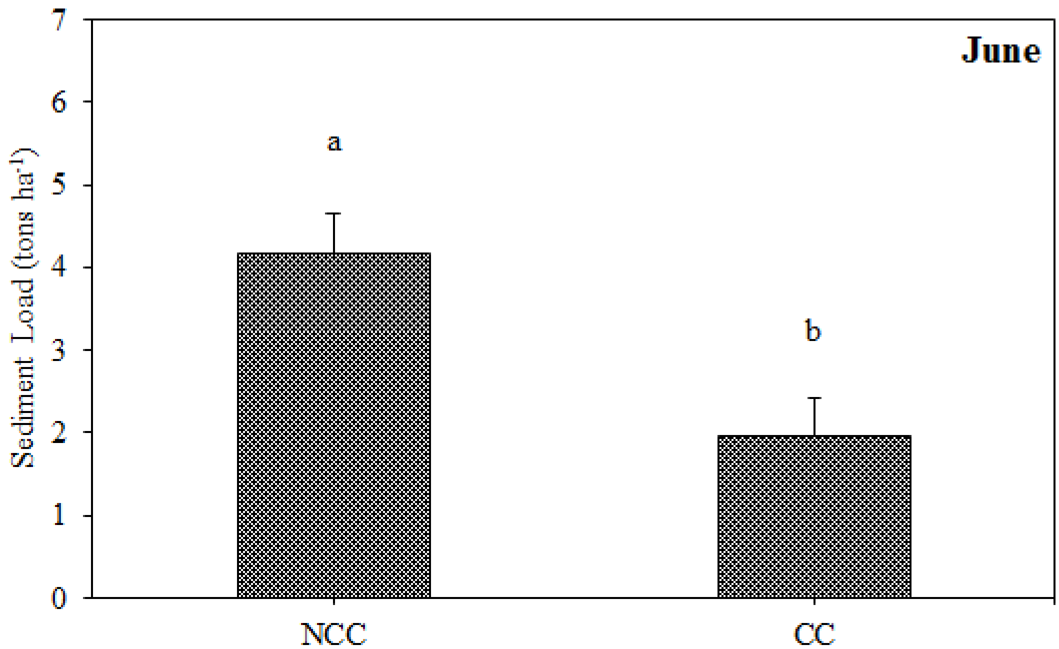

Figure C4. Total sediment load for two cereal rye cover crop treatments (NCC – No cover crop; CC – Cover crop) averaged across two tillage treatments (conventional tillage and no-tillage) collected during rainfall simulations conducted in June 2016.

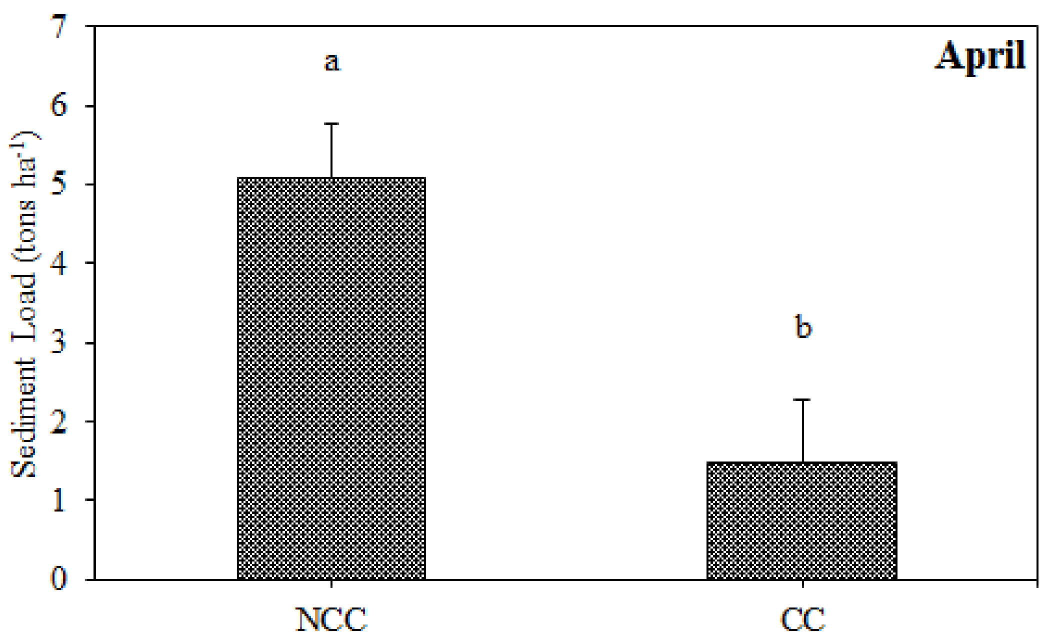

Figure C5. Total sediment load for two cereal rye cover crop treatments (NCC – No cover crop; CC – Cover crop) averaged across two tillage treatments (conventional tillage and no-tillage) collected during rainfall simulations conducted in April 2017.

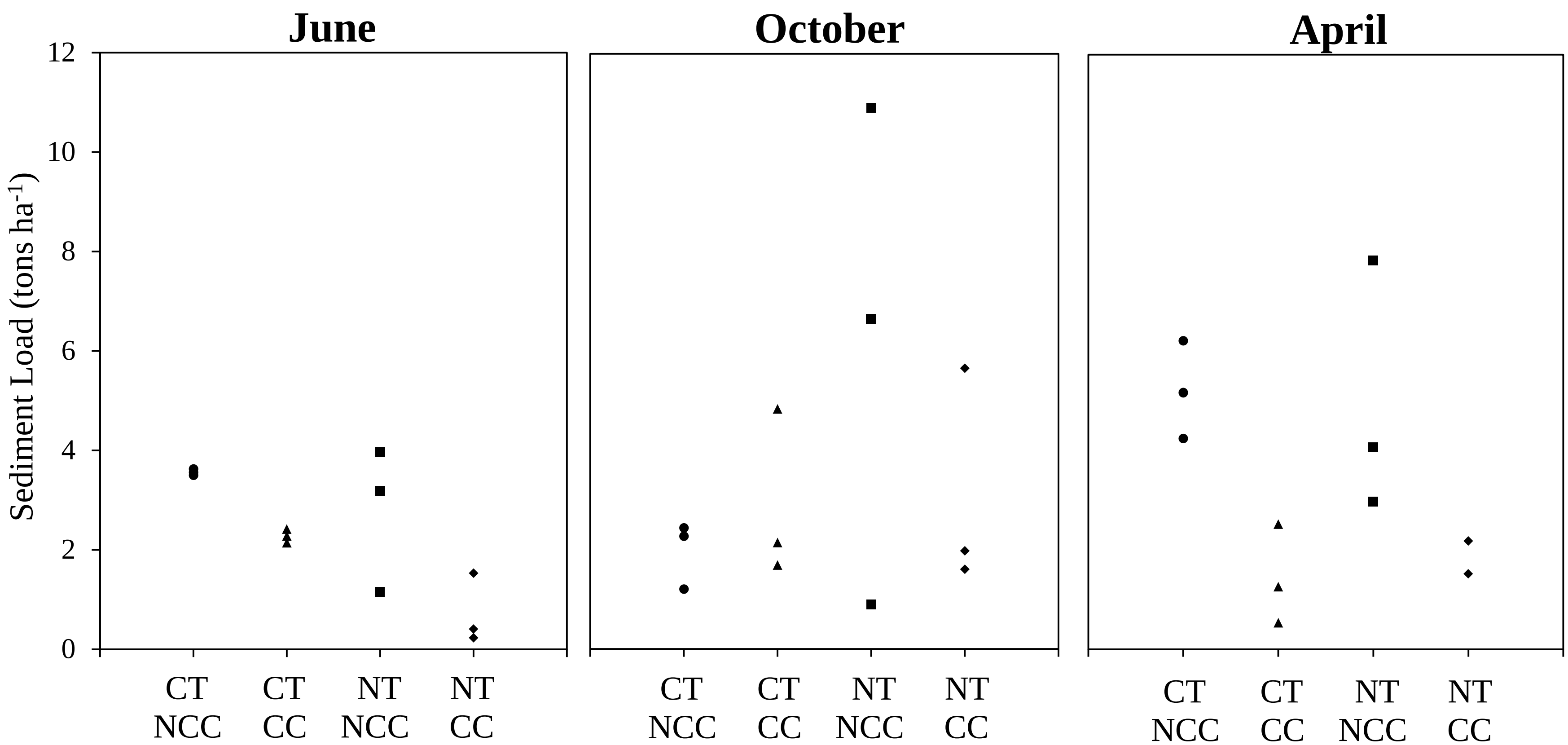

Figure C6. Range of sediment loss of two tillage methods (CT- conventional tillage; NT- no-tillage) and two cover crop treatments (NCC- no cover crop; CC- cover crop). During each simulation timing (June 2016, October 2016, and April 2017), there were three replications per treatment.

Table C4. Bray-P concentrations of two tillage treatments (CT- conventional tillage; NT- no-tillage) and two cover crop treatments (NCC- no cover crop; CC- cover crop) averaged during three dates (June 2016, October 2016, and April 2017).

Treatments		Bray P		
Tillage	**Cover**	**June**	**October**	**April**
			mg L^{-1}	
CT	NCC	38.0 ns	31.3 ns	27.5 ns
	CC	30.0	30.0	26.9
NT	NCC	43.0	43.0	22.2
	CC	31.3	38.0	28.0

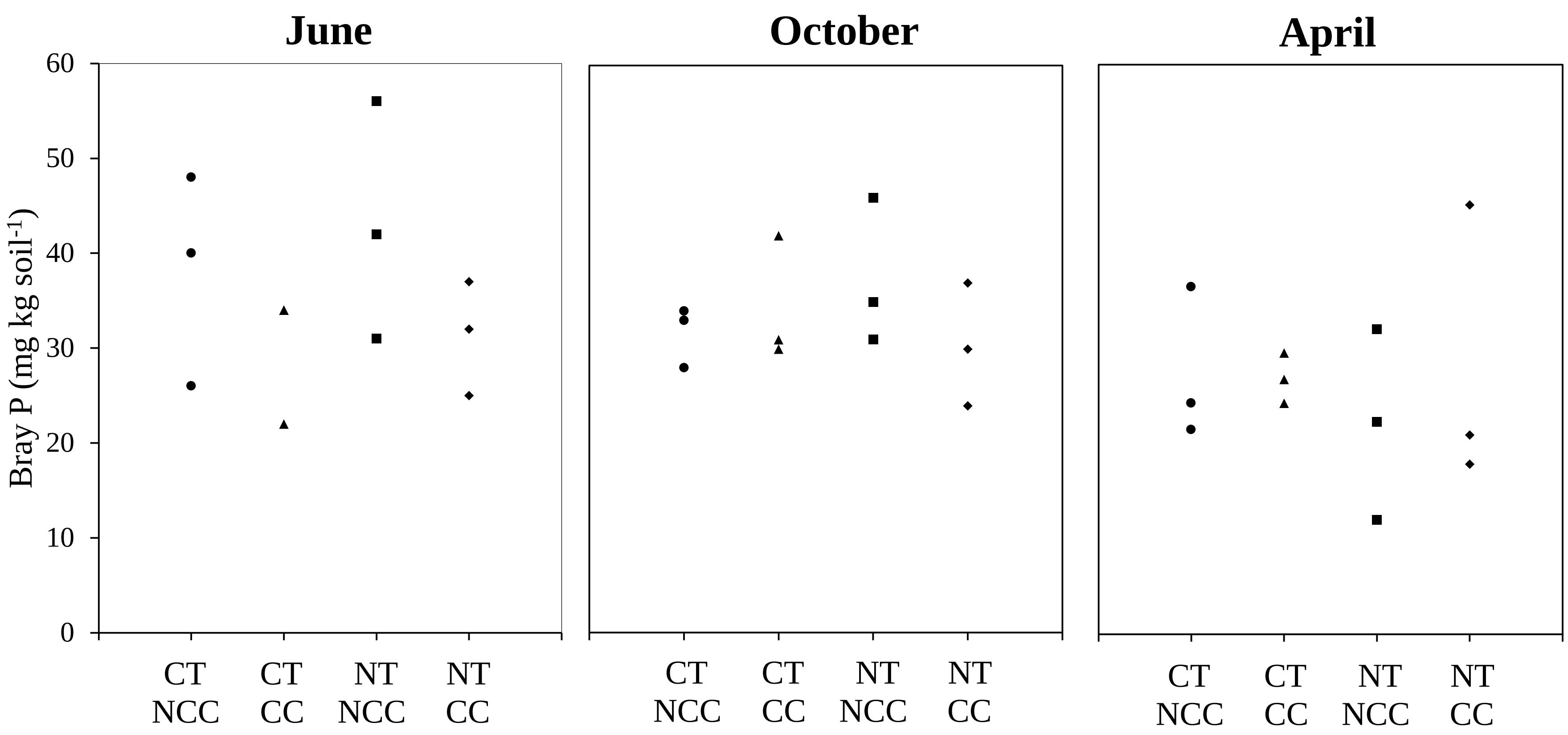

Figure C7. Range of Bray- P of two tillage methods (CT- conventional tillage; NT- no-tillage) and two cover crop treatments (NCC- no cover crop; CC- cover crop). During each simulation timing (June 2016, October 2016, and April 2017), there were three replications per treatment.

Table C5. WEP loads of two tillage methods (CT- conventional tillage; NT- no-tillage) and two cover crop treatments (NCC- no cover crop; CC- cover crop) averaged during three rainfall simulations dates (June 2016, October 2016, and April 2017).

Treatments		**Water Extractable Phosphorus Load**		
Tillage	**Cover**	**June**	**October**	**April**
			mg kg soil^{-1}	
CT	NCC	13.5 ns	15.4 ns	7.05 ns
	CC	9.64	17.6	7.71
NT	NCC	15.9	17.5	6.12
	CC	9.19	11.8	7.53

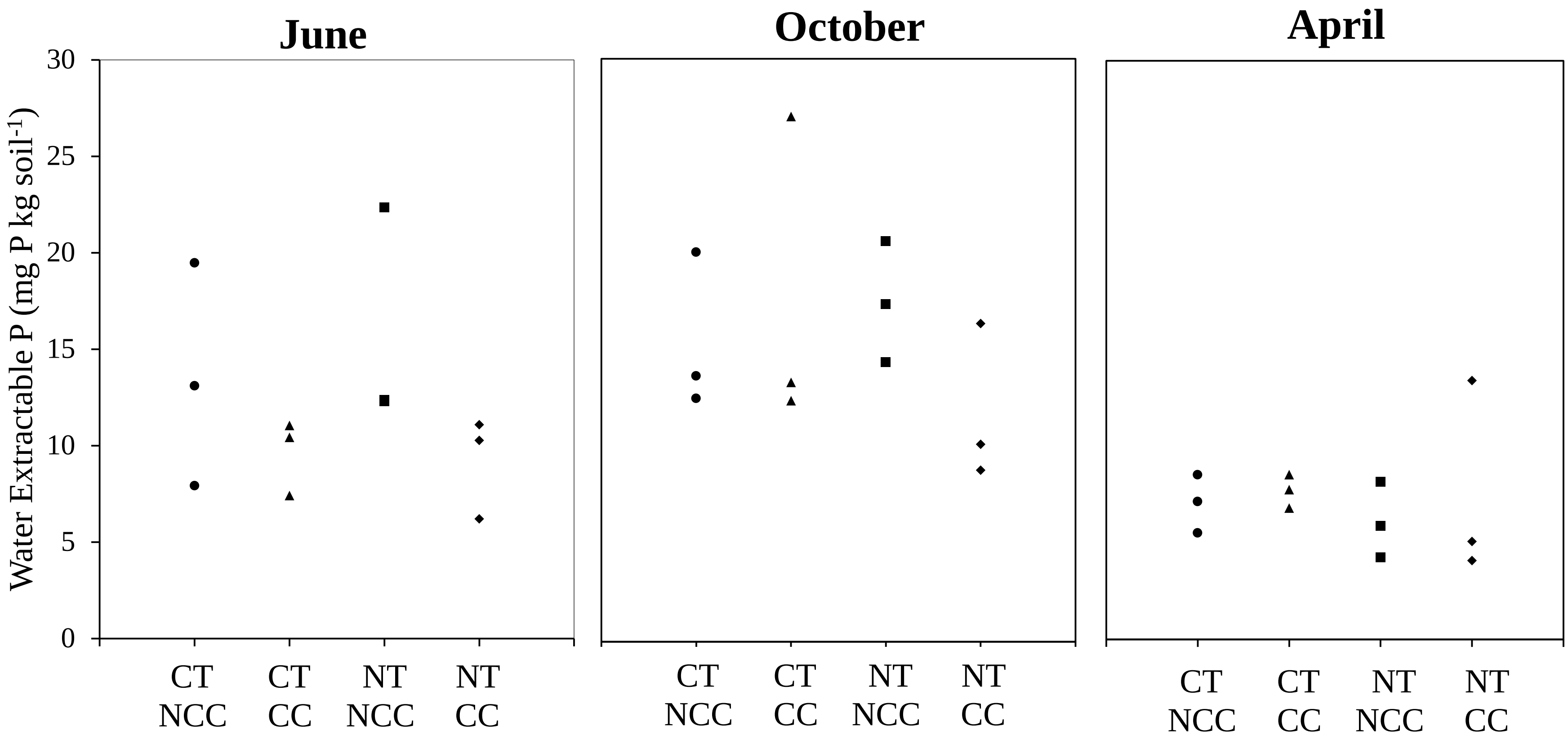

Figure C8. Range of Water Extractable P levels of two tillage methods (CT- conventional tillage; NT- no-tillage) and two cover crop treatments (NCC- no cover crop; CC- cover crop) during three timings (June 2016, October 2016, and April 2017). There are three replications for each treatment during a timing.

Table C6. Total phosphorus loads of two tillage methods (CT- conventional tillage; NT- no-tillage) and two cover crop treatments (NCC- no cover crop; CC- cover crop) averaged during three rainfall simulations dates (June 2016, October 2016, and April 2017).

Treatments		**Total Phosphorus Load**		
Tillage	**Cover**	**June**	**October**	**April**
			g ha^{-1}	
CT	NCC	436 ns	951 ns	1 730 ns
	CC	343	977	334
NT	NCC	348	1 490	1 130
	CC	148	1 310	567

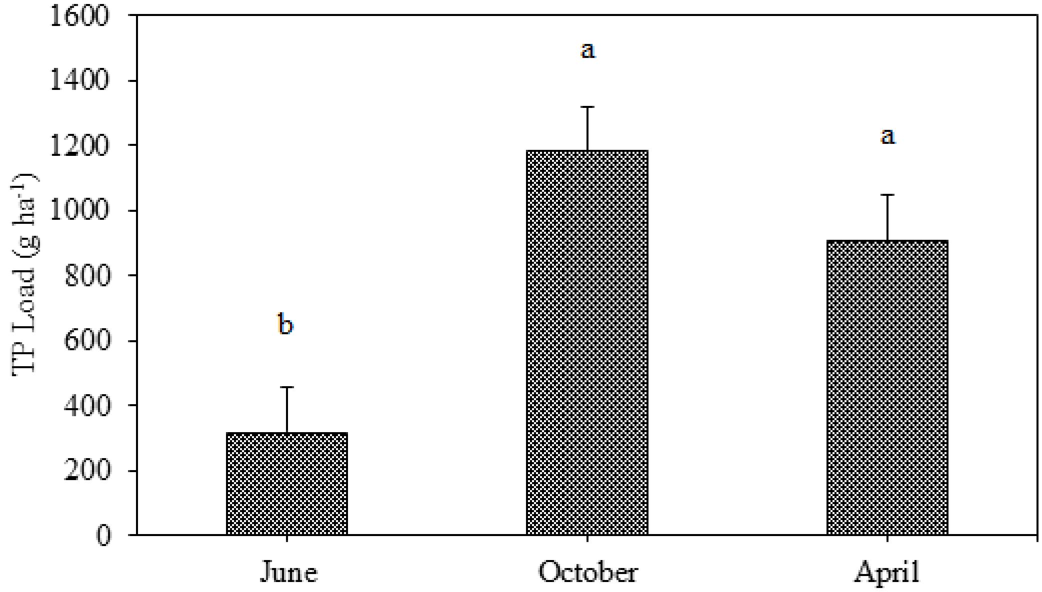

Figure C8. Total Phosphorus (TP) loads for three rainfall simulations dates (June 2016, October 2016, April 2017) averaged across two cereal rye cover crop treatments (no cover crop and cover crop) and two tillage treatments (conventional tillage and no-tillage).

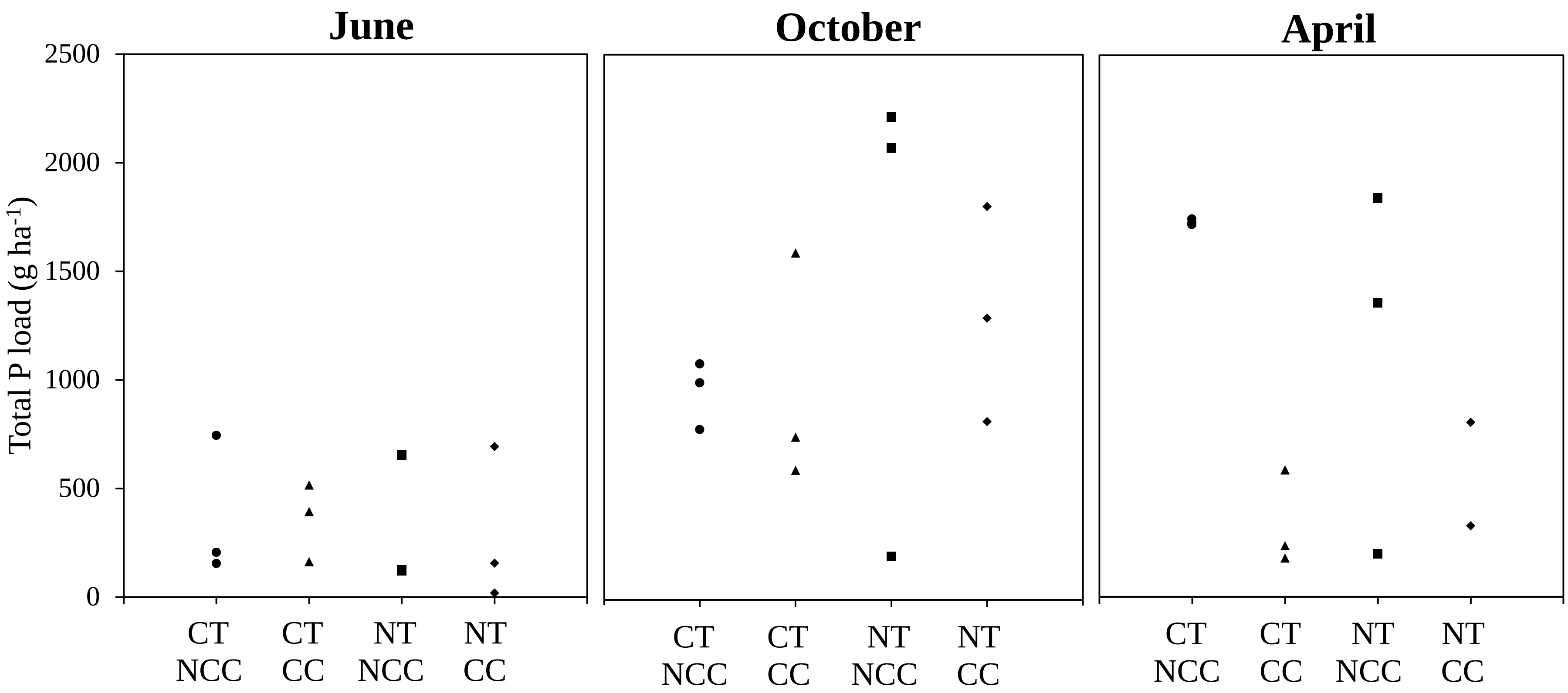

Figure C10. Range of Total P loads of two tillage methods (CT- conventional tillage; NT- no-tillage) and two cover crop treatments (NCC- no cover crop; CC- cover crop). During each simulation timing (June 2016, October 2016, and April 2017), there were three replications per treatment.

Table C7. Total dissolved phosphorus loads of two tillage methods (CT- conventional tillage; NT- no-tillage) and two cover crop treatments (NCC- no cover crop; CC- cover crop) averaged during three rainfall simulations dates (June 2016, October 2016, and April 2017).

Treatments		**Total Dissolved Phosphorus Load**		
Tillage	**Cover**	**June**	**October**	**April**
			$g\ ha^{-1}$	
CT	NCC	60.12 ns	138.53 ns	93.73 a
	CC	30.23	117.42	17.30 b
NT	NCC	78.01	122.21	65.00 ab
	CC	31.38	203.38	23.73 b

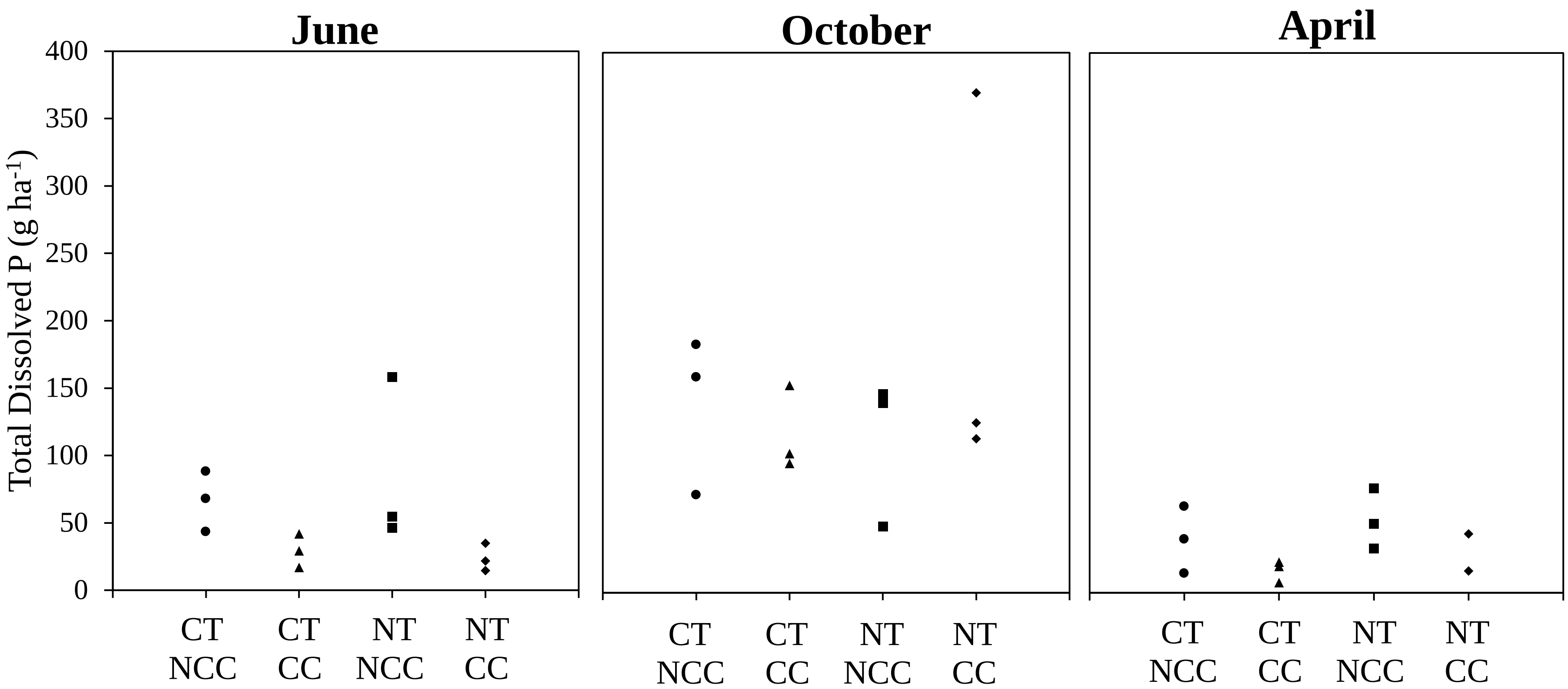

Figure C11. Range of Total Dissolved P loads of two tillage methods (CT- conventional tillage; NT- no-tillage) and two cover crop treatments (NCC- no cover crop; CC- cover crop). During each simulation timing (June 2016, October 2016, and April 2017), there were three replications per treatment

Table C8. Dissolved reactive phosphorus loads of two tillage methods (CT- conventional tillage; NT- no-tillage) and two cover crop treatments (NCC- no cover crop; CC- cover crop) averaged during three rainfall simulations dates (June 2016, October 2016, and April 2017).

Treatments		**Dissolved Reactive Phosphorus Load**		
Tillage	**Cover**	**June**	**October**	**April**
			g ha^{-1}	
CT	NCC	93.70 ns	124.8 ns	39.31 ns
	CC	64.14	59.55	16.63
NT	NCC	90.45	73.03	53.83
	CC	59.63	170.6	32.07

Table C9. Particulate P loads of two tillage methods (CT- conventional tillage; NT- no-tillage) and two cover crop treatments (NCC- no cover crop; CC- cover crop) averaged during three rainfall simulations dates (June 2016, October 2016, and April 2017).

Treatments		**Particulate Phosphorus Load**		
Tillage	**Cover**	**June**	**October**	**April**
		——— g ha^{-1} ———		
CT	NCC	376.3 ns	812.5 ns	1 634 ns
	CC	313.1	859.5	316.5
NT	NCC	269.8	1 383	1 067
	CC	116.4	1 101	554.2

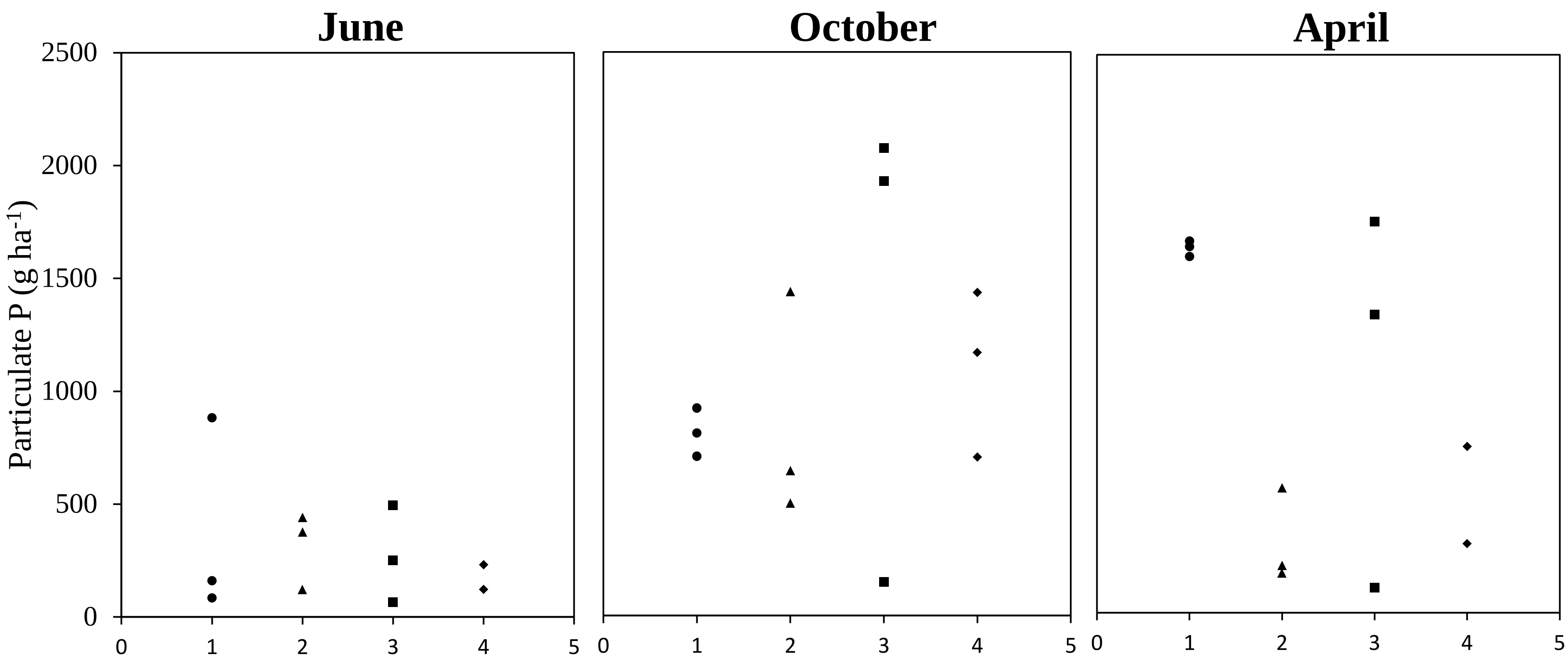

Figure C13. Range of Particulate P loads of two tillage methods (CT- conventional tillage; NT- no-tillage) and two cover crop treatments (NCC- no cover crop; CC- cover crop). During each simulation timing (June 2016, October 2016, and April 2017), there were three replications per treatment.

Table C10. Bioavailable phosphorus loads of two tillage methods (CT- conventional tillage; NT- no-tillage) and two cover crop treatments (NCC- no cover crop; CC- cover crop) averaged during three rainfall simulations dates (June 2016, October 2016, and April 2017).

Treatments		**Bioavailable Phosphorus Load**		
Tillage	**Cover**	**June**	**October**	**April**
			g ha^{-1}	
CT	NCC	290.1 ns	362.6 ns	366.8 a
	CC	218.6	211.8	100.2 b
NT	NCC	254.5	331.7	319.3 a
	CC	175.0	414.4	133.4 b

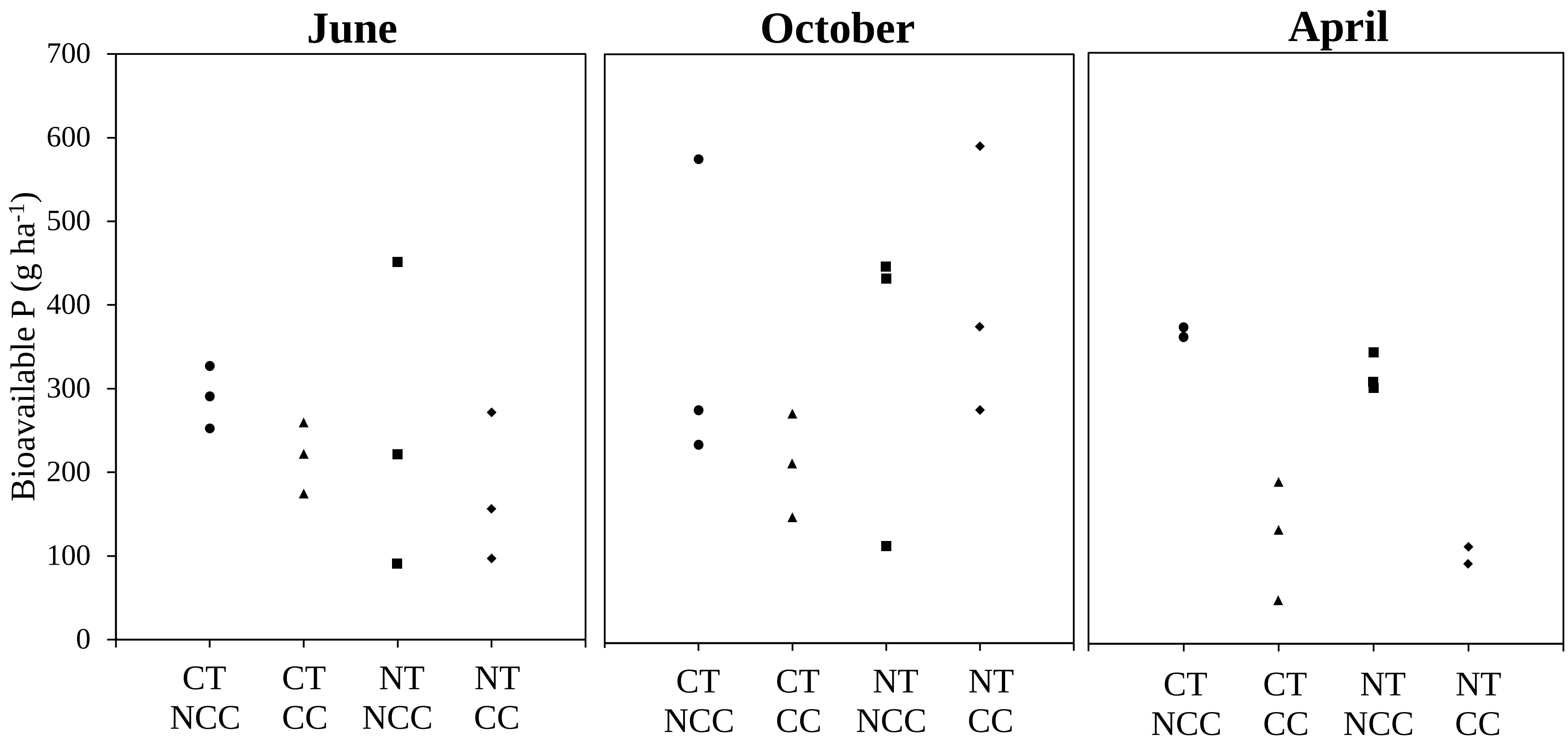

Figure C14**.** Range of Bioavailable P loads of two tillage methods (CT- conventional tillage; NT- no-tillage) and two cover crop treatments (NCC- no cover crop; CC- cover crop). During each simulation timing (June 2016, October 2016, and April 2017), there were three replications per treatment.

Table C11. Deionized rainwater analysis used in three rainfall simulation timings. Samples were collected in the mornings and afternoons of days rainfall simulations were performed. Data were averaged together for each timing.

	B	Ca	Cu	Fe	K	Mg	Mn	P	S	Zn
	mg L^{-1}									
June	0.07	1.09	0.07	0.00	0.77	0.19	0.00	<0.05	0.17	0.39
October	0.11	1.43	0.10	0.00	0.67	0.23	0.00	<0.05	0.14	0.51
April	0.16	0.40	0.03	0.08	0.68	0.19	0.00	<0.05	0.14	0.18