EFFECT OF WINTER COVER CROPPING PRACTICES ON MAIZE YIELD AND NUTRIENT CYCLING

BY

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THESIS

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ABSTRACT

The Illinois Nutrient Loss Reduction Strategy has set Phase 1 reduction milestones for nitrate-nitrogen and total phosphorus of 15 percent and 25 percent, respectively, to the Mississippi River by the year 2025 with the ultimate goal of a 45 percent reduction for both nutrients when compared to average annual riverine loading for years 1980-1996. With estimated levels of 80 percent and 48 percent of nitrate-N and total-P nutrient loads coming from agriculture, the reduction strategy stresses the importance of farmers' voluntary implementation of best management strategies in order to reach these goals. The purpose of this study was to compare the differences in nutrient cycling of nitrogen and phosphorus from an annual rye winter cover-cropped treatment to a conventional tillage control (fall chisel and spring field cultivation) by measuring preseason fertility, nutrient flux in subsurface tile lines, end of season soil fertility, and crop yields for each treatment. Best management practices consisted of a no-till cover crop scenario with side-dressed nitrogen application at vegetative growth stage 4 (V4). Soil fertility and crop nutrient uptake was measured prior to cover crop termination and again at crop maturity. Throughout the growing season, tile water was collected and analyzed for nitrate and phosphate concentrations. Cumulative losses from April-July 2015 of nitrate nitrogen were calculated at 10.61 and 11.69 kg ha^{-1} NO_3-N for the annual rye treatment and conventional treatment, respectively. Weighted mean nitrate-nitrite nitrogen concentrations in subsurface drainage tile were 4.41 and 6.10 ppm for annual rye and conventional treatments for the same time period. Soil fertility measures of organic matter, nitrogen, and phosphorus did not have a conclusive impact on the final yields of each representative treatment, however, seven out of the top ten yielding annual rye treatments were on the soil with a higher Illinois Soil Nitrogen Test (ISNT). Nitrogen fertilizer rates and timing had a significant impact on final yields with the

highest yield being 16.9 Mg ha^{-1} (271 bu ac^{-1}) at a nitrogen fertilizer rate of 177 kg ha^{-1} (158 lb ac^{-1}) for the conventional tillage treatment and 16.4 Mg ha^{-1} (261 bu ac^{-1}) for the no-till annual rye winter cover treatment at a fertilizer rate of 206 kg ha^{-1} (184 lb ac^{-1}). These results indicate a higher nitrogen rate is necessary for equal yields when a no till winter cover is compared to a conventional tillage plot if water is not a yield limiting factor.

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Contents

CHAPTER 1. Introduction

Modern maize (*Zea Mays* L.) production and increases in production to feed an ever growing population depend on maximizing uptake efficiency of soil fertility and fertilizers, utilizing land drainage where needed, improving plant genetics, and advancing technology and soil testing procedures. Currently, fertilizers are not always effectively managed and natural soil fertility is too commonly unaccounted for. This combination leads to nutrient losses by overland flow or drainage, both natural and man-made, and their losses are becoming more of a concern. The improvement in managing fertilizer and soil fertility, specifically nitrogen and phosphorus, in row crop agriculture in Illinois is necessary to meet nutrient loss reduction strategies proposed by the Illinois Environmental Protection Agency (ILEPA, 2015). Given the dynamic interaction among weather, agronomic practices, and soil composition, the success of reduction losses will be challenging. However, a better understanding of how these systems interact is necessary if we are to reduce the negative impact on the environment while being able to maintain crop production at a profitable level.

Channelization of streams and waterways paired with the increased use of subsurface drainage tile has made agriculture possible in many areas, but unfortunately it has resulted in increased losses of nutrients into surface waters. These losses are not simply from misapplied fertilizers, but can also be a combination of nutrients naturally produced from organisms living in soils, chemical and physiochemical processes such as ion exchange, and variability in crop yields and nutrient uptake year to year. The Illinois Nutrient Loss Reduction Strategy has set Phase 1 reduction milestones for nitrate-nitrogen and total phosphorus of 15 percent and 25 percent, respectively, to the Mississippi River by the year 2025 with the ultimate goal of a 45 percent reduction for both nutrients when compared to average annual riverine loading for years

1980-1996. With estimated levels of 80 percent and 48 percent of nitrate-N and total-P nutrient loads coming from agriculture, the reduction strategy stresses the importance of farmers' voluntary implementation of best management strategies in order to reach these goals (ILEPA, 2015).

Specific management practices that can be used to reach these goals are the use of cover cropping, reduction in soil tillage, delayed timing and/or decreased rates of fertilizers, and controlled drainage or bioreactors. Cover crops can be grown in rotation with cash crops. They are seeded during the growing season or following a cash crop and can be used for many processes in nutrient cycling. They can uptake excess nutrients left from previous crops and also nutrients naturally created during the cover crops growth period. Cover crops can improve the diversity of crop rotations, increase nutrients through plant fixation, decrease erosion, fracture subsoil hardpans, out compete weeds, and reduce soil evaporation after termination. However, cover crops can also compete with cash crops for nutrients, water, and sunlight and it is important to understand their growth cycles and manage them appropriately. Reduced tillage or no-till agriculture can reduce erosion, limit soil evaporation, increase subsurface aeration, and reduce labor and fuel from limited tillage needs. However, reduced tillage can also lead to hard to control weeds and extra pesticide applications, delayed planting timing, require more expensive planters or drills to manage no-till successfully, and significantly increase losses of surface applied fertilizers. Delaying fertilizers can help limit losses by synchronizing application with greater plant uptake demands, or limiting weather impacts by reducing the time the fertilizer is exposed to losses before crop uptake. Delaying fertilizer application can also limit microbial utilization of fertilizers and organic matter decomposition as a result. However, delaying fertilizer will risk undesired adjustments in application equipment or fertilizer source if timing is limited for application from weather events and crop growth. Reducing fertilizer rates would subsequently result in reduced nutrient losses and improved profits by limiting excess fertilizers, but reducing rates could also lead to reduced crop yields if weather and rainfall are adequate to support larger yields. Reducing rates may also require additional soil testing. Controlled drainage can be a valuable method to increase available water to cash crops. It can also be used as a method to reduce nutrient leaching and losses. Unfortunately, controlled drainage is more of a challenge for fields with much variability in topography and it is possible the water could simply choose alternate routes than that of drainage tile. Bioreactors are a proven technology in the reduction of nitrogen losses from field tiles, but their cost can be deterring and generally it would be more beneficial to the grower to utilize the nitrogen versus relying on a system to decrease losses at the tile outlet. Bioreactors may be a requirement if nitrates need to be reduced to levels below levels which soils naturally produce nitrogen.

There is a need for research in high yielding agriculture which utilize best management practices to reduce nutrient losses. In addition, it is necessary to include research on soils in southern regions of Illinois. There is also limited research available which compares conventional tillage to winter cover crop for yield potentials and water quality with variable soil types and varying fertilizer rates at a field scale. This project is meant to provide data from field-scale research which compares conventional tillage to no-till/winter cover crop management and studies soil data, water quality, and corn yield returns for multiple rates and timings of fertilizer applications where management practices are focused around limiting nutrient losses and maintaining high yields.

CHAPTER 2. Objectives

The overall goal of this research is to compare the nutrient cycling effects and maize yield response from a conventional tillage control treatment with a no-till, annual rye winter cover crop treatment. The specific objectives are to:

- Quantify maize yield response differences between a conventional tillage treatment and a no-till, annual rye winter cover crop treatment at four different nitrogen rates.
- Compare maize yield response of four different nitrogen application schemes (differing in both rate and timing of main application), on two soil types.
- Determine the differences in daily cumulative drainage flow, daily nitrate-nitrogen flux, sample nitrate-nitrogen concentration and summarized sample results of total nitrogen, orthophosphate phosphorus, and total phosphorus collected from isolated subsurface tile drainage underlying the conventional tillage treatment and no-till annual rye winter cover crop treatment.

CHAPTER 3. Review of Literature

The objectives of this literature review are to 1) inform the reader about the general characteristics of the plot in which research was performed, 2) provide fundamental details regarding the nitrogen and phosphorus fertility dynamics of crop uptake, losses, and environmental consequences and 3) detail best management farming practices and promising soil tests which can be used to mitigate nutrient losses.

3.1 Land Transformation for Agriculture

3.1.1 Subsurface Drainage

Subsurface tile drainage makes modern agriculture possible in many areas of the Midwestern United States, especially much of central Illinois. According to United States Department of Agriculture (USDA) National Agricultural Statistics Service census (2012), there were approximately 19.65 million hectares (48.56 million acres) of drained land in the United States. Of this, 16.143 million hectares (38.89 million acres) are grain and oilseed production. Illinois has 3.41 million hectares (8.43 million acres) of subsurface-drained grain and oilseed land (USDA NASS, 2012). Although these documents were produced using a 2012 census, and it is commonly assumed this number is growing, it is difficult to differentiate between new systems being added to lands that were not drained and new systems replacing old and failing system.

Detailed reviews presented by King et al. (2014), King et al. (2015a), and King et al. (2015b) summarize the necessity of tile drainage through historical expansion of arable land, increases in efficiencies by extending the time available to complete field work in the busy spring and fall seasons, maximizing productivity in the lands by stimulating mineralization, limiting denitrification and increasing nutrient availability to growing crops, minimizing crop stress from anoxic root conditions, and reducing the extent of surface erosion by allowing infiltration. However, along with its many benefits, there are inherent environmental risks associated with tile drainage. Most notably, subsurface tiles promote soil organic matter depletion and provide a shortcut from agricultural fields to nearby streams for infiltrated water. These alterations to natural soil processes pose risks to the environment due to the elevated concentrations of nutrients and pesticides in the drained water.

3.1.2 Tillage

The practice of tillage has been an important supplement to historical agricultural practices and continues to be a large driver of high yields in present day practices. Prior to the availability of herbicides, tillage was the most used practice to control weed pressures. Tillage also breaks the surface crust to allow for quicker soil drying, accelerates soil warming, controls pathogens by burying residues, remedies soil compaction, and is a method for seedbed preparation (Dinnes et al., 2002; Peters et al., 2003). A common form of tillage is conventional tillage. In the Midwest, conventional tillage is a combination of fall and pre-plant spring tillage.

All tillage practices break down naturally formed macropores, leave the ground more vulnerable to erosive forces, and exposes soil organic matter (SOM) to increased levels of mineralization. Tillage increases the surface area of residue exposed to soil and can place it at deeper depths in the soil profile where heterotrophic microbes, the microbial community most associated with residue decomposition, activity is greater due to more available soil moisture less extreme temperatures (Doran, 1987; Paul et al., 1996).

3.2 Soil Fertility

3.2.1 Soil Organic Matter

Soil organic matter, which is comprised of soil organic carbon (SOC) and soil organic nitrogen (SON), is an indicator of soil fertility (Allison, 1973). Soil organic matter is a dynamic product of parent material, climate, topography, soil type, soil organisms, land use, and farm management practices such as drainage, cropping regime, fertilization method and rates, and tillage practices. The long term ability of the earth's soils to feed the world's growing population is increasingly dependent on the management practices being used to protect and sustain its production. Soil organic matter plays a key role in soil cation-exchange capacity and buffer capacity, physical components of hydraulic conductivity and water availability, soil aggregation, and aeration (Mulvaney et al., 2009). The amount and turnover of SOM in a soil is a quantifiable value used in determining soil quality and crop production potential (Duxbury et al., 1989; Sanchez et al., 1989). Soil organic matter also acts as an important source for energy for heterotrophs (Paul et al., 1996), and mineralization of SOM results in a release of many required plant nutrients, especially nitrogen, phosphorus, and sulfur (McGill and Cole, 1981).

3.2.2 Nitrogen

Nitrogen is an essential element that is required by all plants and animals largely because of its structural composition of proteins and essential role in enzymes. Some plants have formed symbiotic relationships with soil microbes in order to meet their nitrogen demand through N_2 fixation (Harper, 1974). If there is no such relationship, as is the case for cereal grains, it is made available in the soil through atmospheric deposition from precipitation events, inorganic (synthetic fertilizers), organic (manure) applications, but mainly from the mineralization of the soil's indigenous organic reserves. Prior to the green revolution and the invention of the Haber-

Bosch process, fertility levels sufficient to support crop growth were made by available by green manure, livestock manure, and leaving the land fallow to accumulate fertility levels from organic matter mineralization (Dinnes et al., 2002). Now, however, most supplemental nitrogen applications are with synthetic fertilizers. Globally, this largely comes in the form of granular urea, but in the United States, anhydrous ammonia is the most used form (IFA, 2013).

3.2.3 Phosphorus

Native phosphorus fertility varies by geological formation, soil texture, plant growth, and many other factors. A fine textured clay soil will have a higher native phosphorus content than a course texture sand, assuming fertility practice has not drastically changed the fertility levels. Stratification is common in agricultural lands due to a combination of broadcast fertilizers being surface applied and roots mining the lower A and upper B horizons and returning phosphorus through residue to the surface (Crozier et al., 1999). Like nitrogen, mineralization of soil organic matter produces plant-available phosphorus. On a mass basis, phosphorus is third only to nitrogen and potassium in amount of fertilizer removal by grain (Bender et al., 2013). Phosphorus serves many functions in plant development and is a fundamental requirement of energy transfer in plant and human metabolism. Also, it is required in cell division and development of meristematic tissue due to it being a constituent in nucleic acids. In plants, it is a requirement for root growth and vigor and essential in N fixation and seed formation (Havlin et al., 2005; Whitehead, 2000). The removal of native phosphorus is often replaced with phosphorus fertilizers in the form of mined rock phosphates, but a significant source is animal manure. Unfortunately, animal manures are often limited to locations near to animal production facilities due to the high cost of transportation (Eghball and Power, 1999).

3.3 Fertilizer Use by Maize

3.3.1 Nitrogen Removal

The nitrogen demand by maize varies widely within the genetic diversity of the crop and the season growth environment the crop is exposed to. A study by Ma et al. (2006) gave a general N (nitrogen) removal rate of 12 kg N for each Mg of harvested grain, but this value ranged from 7-16.7 kg N per Mg harvested grain and was dependent on the year, fertility and nitrogen mineralization of the soil, nitrogen fertilizer rate, crop health, and weather. However, weather being unpredictable and mineralization capacity changing as a response, yield will often vary, as do nitrogen fertilizer application rate demands. Common rate determination is dependent on a yield goal, and if the goal is too high or the fertility levels of the soils are not considered, the excess nitrogen is susceptible to losses into the environment.

Soil nitrogen removal can be estimated through conversion factors and yield. While the variability in the nitrogen removal can be quite large through grain removal, it can be estimated using the protein composition for starchy maize (9.1%) with the nitrogen composition of protein (16%), which provides an estimated removal rate of 14.6 g N kg^{-1} grain removed for maize (Landry and Moreaux, 1970, Laudry and Moreaux, 1980; Cortez and Wild, 1972). For example, a 12.56 Mg/ha (200 bu/acre) maize grain yield will remove 183 kg/ha (163 lbs/acre) N.

$$12.56\,\frac{Mg}{ha} * 0.0146 * 1000\,\frac{kg}{Mg} = 183\,\frac{kg}{ha}$$

$$200\,\frac{bu}{acre} * 0.0146 * 56\,\frac{lb}{bu} = 163\,\frac{lb}{acre}$$

More recent work has given values of 12.9 g N kg^{-1} (Heckman et al., 2003) and 11.4 g N kg^{-1} grain (Bender, et al. 2013). Hybrid uptake and allocation of grain is not only variable across environments, but it is also continually evolving with new hybrid development.

3.3.2 Phosphorus Removal

Much like nitrogen, the phosphorus demand by a maize crop varies widely by growing environment, hybrid development, and fertility levels. Recent studies estimate phosphorus removal by grain of 3.19 g P kg^{-1} (Bender et al., 2013), and a median value from work by Heckman et al. (2003) as 3.8 g P kg^{-1} (0.35 or .49 lb P_2O_5 Bu^{-1} at 15.5% grain moisture). A standard accepted by Food and Agriculture Organization of the United Nation is 2.996 ± .578 g P kg^{-1} (Bressani, et al. 1989). The removal increases if all above ground biomass is removed, but the values vary considerable by biomass production and plant fertility.

3.4 Fertilizer Losses

3.4.1 Nitrogen Losses

It is important for crop producers to understand the nitrogen supplying capacity of the soil and the implications synthetic fertilizer and organic fertilizer have on this process. Loss of nitrogen is a wasted economic resource that is the most or second most expensive input in maize production. These losses also result in environmental consequences and leave producers subject to public scrutiny.

The many studies involving economic losses make it clear that a fertilizer used in an unnecessary, excessive, or untimely manner will result in either loss into the environment and/or loss in profitability (Rendall et al., 2003; Ma et al., 1999; Moll et al., 1982). While it is possible to collect information throughout the year, analyze water, air, and plants for their fertility levels, and place a multiplier on these based on the value of the fertilizer examined, it is nearly impossible to predict field level weather patterns and subfield soil nutrient mineralization levels. Utilizing the ISNT as a basis of soil mineralized nitrogen has shown effectiveness although predicting nitrogen need ahead of planted crop is extremely challenging.

Soil nitrogen losses can be attributed to erosion, runoff, leaching, volatilization, denitrification, and nitrogenous gas emissions from plants. While most focus is placed on erosion, runoff, or leaching losses, studies by Francis et al. (1993) reported losses ranging from 49 to 78 kg N ha $^{-1}$ for nitrogenous gas emissions of aboveground plant material in maize. Volatilization is more common when ammonia (NH_3) is applied to wet soils and the NH_3 is then lost as an evaporated mixture with water, when urea is applied to soils without timely incorporation methods, or when ammonium (NH_4) fertilizers are applied to coarse soils with a low cation exchange (Fan et al., 2011; Hargrove and Kissel, 1979). Denitrification happens when soils are above field capacity and anoxic conditions provide insufficient oxygen for denitrifying organisms to meet their metabolic requirements, forcing denitrifying bacteria to resort to using nitrate instead of oxygen (Dinnes et al., 2002). The losses not only have environmental consequences, but also result in negative economic impacts on crop producers.

Work by the Agronomy Department at Purdue University summarized nitrogen management in this way, “The bottom line on N use in maize is that it is part of a complex biological system that interacts with everything under the sun, including the sun. We cannot accurately predict soil N supply throughout the year. Yet, we cannot afford (financially or environmentally) to simply apply ‘more than enough’ N” (Camberato and Nielsen, 2014). This paper gives a thorough interpretation of current works, soil tests, and research-in-progress on understanding fertilizer relationships between yields, soils, and N fertilizer rates. It reflects on the concern crop producers should have regarding environmental implications of mismanagement of N fertilizer applications.

The losses of nitrate through leaching, as N_2 or N_2O through denitrification, NH_3 through volatilization or as organic and ammonium nitrogen through erosion are not only economic losses in the field, but they also result in downstream consequences such as eutrophication or hypoxia (Dale et al., 2010), increase water treatment costs (Kapoor and Viraraghavan, 1997), and become heat trapping greenhouse gases (Robertson and Grace, 2004). Eutrophication and hypoxia are well researched areas and many of the large rivers, especially in the United States, have their nitrogen flux measured. Year to year, the nitrate flux will depend on the nitrogen use efficiency and the amount of rainfalls. The highest fluxes will happen when a wet year follows a dry year with little nitrogen uptake and nitrogen management practices remain unchanged. Nitrous oxides losses are directly linked to fertilizer applications and are a natural incomplete process of denitrification and nitrification. Nitrous oxides losses will be highest when highly fertile soils are in an anoxic environment. Millar et al. (2010) offers an extensive review of current nitrous oxide research. Soil erosion will be most serious when heavy rainfall occurs on steeply sloping soils that are left bare. Proper stewardship, also known as best management practices, of the landscape will protect soils from losses of nitrogen.

3.4.2 Phosphorus Losses

Soil phosphorus losses are largely in the form of erosion given the strong association with the solid phase of soils, but other significant forms can include surface runoff and leaching losses (Frossard et al., 2000). Surface losses are largely attributed to lack of incorporation and will be an issue in no-till soils. Leaching losses have not historically been an issue largely because the concentrations in tile waters are quite low; however, recent research has shown losses through tile lines can be as high as surface runoff and even low concentrations (0.025-0.10 mg P L^{-1}) result in environmental interactions (King, et al. 2015). Phosphorus serves as the rate-limiting factor in eutrophication and hypoxia (Schindler, 1974).

3.5 Best Management Practices

3.5.1 Winter Cover Crops

Cover cropping utilizes the fallow period of an annual cash crop to grow a secondary crop which can scavenge residual fertilizers, reduce erosion, and improve the overall health of the soil by increasing the diversity of a normal maize-maize or maize-soybean [*Glycine max* (L.) Merr.] rotation in the Midwest. Benefits of cover crops include improved soil tilth, reduction in nutrient losses from erosion, leaching, or denitrification. Cover crops improve soil tilth by adding organic matter to both aboveground and belowground soil horizons, but also act to improve soil biodiversity of the soil. Cover crops increase the infiltration of water and the added surface residue can reduce evaporation losses, with the result that more water is available for the following crops. Cover crops can compete with winter annual weeds and can be used an alternative to fall herbicides (Clark, 2008). Legume cover crops are capable of fixing nitrogen from the air while other cover crops scavenge and release nitrogen if a proper carbon-to-nitrogen ratio favors nitrogen availability. Many aspects of nitrogen availability are discussed in Sulivan and Andrews (2012).

Cover crops can act as a weed if not properly managed or if weather events prevent timely termination. Cover crops, if there is inadequate rainfall, can decrease the available water in the subsoil or they can leave the ground too cool and wet to properly establish a cash crop if they are terminated and rain continues to fall. Both scenarios may result in yield losses. Cover crops are also an added cost to cropping practices and may not return added profits.

3.5.2 Side-Dress Nitrogen Application

An alternative to applying nitrogen preseason is to apply the nitrogen fertilizer source to an actively growing cash crop. One such method of this action is to inject anhydrous ammonia between the established rows. Other methods include broadcast of solid forms, injecting or surface dripping other less volatile forms. Side-dressing nitrogen fertilizers allows producers to get a better understanding of their crop production potential and application can be reduced if yield potential is decreased. Also, applying the nitrogen fertilizer while the crop is growing decreases the amount of losses into the environment because of the shorter period of losses and improves the fertilizer nitrogen use efficiency which allows for reducing application rates.

Side dressing nitrogen also comes at a risk. Weather can delay side dress application and can reduce yield potential if fertilizer is not available during critical periods of development. It is also much more challenging to apply fertilizer between rows of an actively growing crop especially on hills or curves and may result in root pruning to actively growing plants and successful management of side dressed nitrogen could require more expensive equipment.

3.5.3 Illinois Soil Nitrogen Test

Utilizing the Illinois Soil Nitrogen Test (ISNT) provides an alternative measure of soil fertility that predicts the mineralization of a soil with a sampling frequency of normal soil testing. The ISNT test determines the amino sugar N and was developed to be simple and inexpensive. It is primarily thought to predict sites that would be non-responsive to fertilizer nitrogen thus reducing nitrogen which could be lost to the environment (Khan et al., 2001). It can also be used to determine less productive soils and provide information for increasing fertilizer rates. Unlike tests of soil nitrate, the ISNT is not drastically affected by weather events.

CHAPTER 4. Methodology

4.1 Site Selection

The research site and data collection was made possible through the conversion of a private field under normal agricultural production into a one-year research site.

4.1.1 Agronomic Requirements

A site was selected in Crawford County, IL, which met the requirements of 1) four consecutive years of no-till or minimum tillage, in which macropore drainage channels had not been compromised, 2) subsurface drainage in parallel pattern, 3) relatively level ground to maximize uniformity, 4) productive soils with drought tolerance and flood protection, and 5) previous crop harvested prior to October to allow for the proper cover crop fall establishment period.

4.1.2 Soil Location

Soil, geological and climate information were found in the Soil Survey of Crawford County, Illinois (Cochran and Werner, 2007). The two soil series studied for the purposes of this research were Muren and Virden. These soils are part of the Central Mississippi Valley Wooded Slopes in Crawford County, Illinois.

4.1.3 Geology

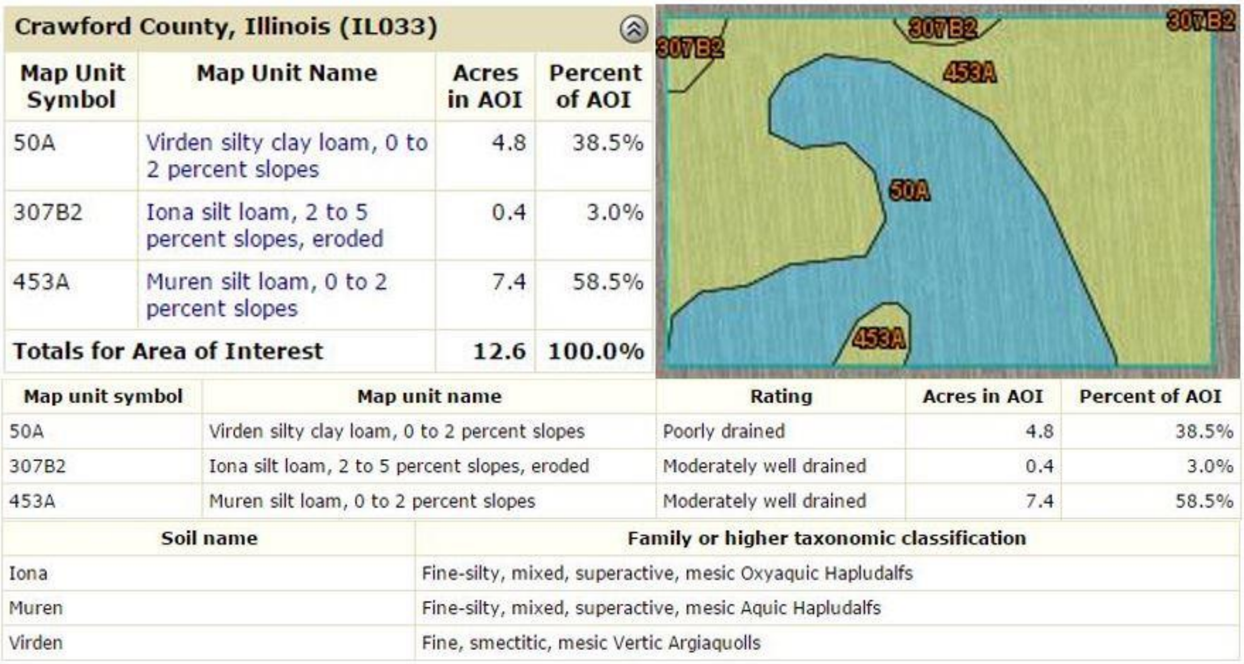
Muren is a fine silty, mixed, superactive, mesic Aquic Hapludalf having a loess parent material approximately 2.03 meters (80 inches) thick and forming at the summit of loess hills. It is a soil that is moderately well drained and formed from deciduous hardwood forests. The available water capacity is approximately 27.94 cm (11 inches) to a depth of 1.52 meters (60 inches), and it can have a seasonal high water table of 45.72 cm (18 inches) from February to April. The Virden soil series is a fine, smectitic, mesic Vertic Argiaquolls having loess parent material approximately 1.52 meters thick and forming at the toeslopes of interfluves and till planes. It is a poorly drained soil formed from prairie grasses. The available water capacity is about 26.17 cm (10.3 inches) to a depth of 1.52 meters and the water table can rise to the surface from January to May resulting in brief ponding. Virden is specifically mentioned as being part of the five percent of soils different from Muren in the Map Unit Composition category. (Cochran and Werner, 2007)

4.1.4 Climate

Crawford County has a temperate, humid, and continental climate. It has an average temperature during the winter months of about 0 degrees Celsius and approximately 24.2 degrees Celsius during the summer months. The average annual precipitation is 109.07 cm (42.94 inches), of which 68.07 cm (26.8 inches) falls April through October during the crop growing season. (Cochran and Werner, 2007)

4.1.5 Drainage Features

A parallel, subsurface drainage system with 30.5-meter (100-foot) spacing underlies the soil surface at an expected depth of between 0.76 and 1.22 meters (30 and 48 inches). The drainage lines would be utilized for flow and nutrient leaching analysis. See Figure 1 for soil map of experimental plot site location and Figure 4 for a view of the subsurface drainage lines.



Crawford County, Illinois (IL033)

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
50A	Virden silty clay loam, 0 to 2 percent slopes	4.8	38.5%
307B2	Iona silt loam, 2 to 5 percent slopes, eroded	0.4	3.0%
453A	Muren silt loam, 0 to 2 percent slopes	7.4	58.5%
Totals for Area of Interest		**12.6**	**100.0%**

Map unit symbol	Map unit name	Rating	Acres in AOI	Percent of AOI
50A	Virden silty clay loam, 0 to 2 percent slopes	Poorly drained	4.8	38.5%
307B2	Iona silt loam, 2 to 5 percent slopes, eroded	Moderately well drained	0.4	3.0%
453A	Muren silt loam, 0 to 2 percent slopes	Moderately well drained	7.4	58.5%

Soil name	Family or higher taxonomic classification
Iona	Fine-silty, mixed, superactive, mesic Oxyaquic Hapludalfs
Muren	Fine-silty, mixed, superactive, mesic Aquic Hapludalfs
Virden	Fine, smectitic, mesic Vertic Argiaquolls

Figure 1. Site location and soil details (NRCS Web Soil Survey)

4.2 Site Preparation

All site preparation was complete with farm equipment and field study was treated as it were a field under normal production.

4.2.1 Annual Rye Winter Cover Crop

The site was planted with an annual rye cover crop with a single coulter, no-till, air seeder drill at a depth of 1.3 cm (0.5 inch) and a rate of 15.1 kg/ha (13.5 lb/acre) on September 27, 2014. No tillage practices were carried out on the annual rye treatments. Field conditions were ideal for planting with a dry surface and adequate soil moisture for germination at seed placement. A period of warm and dry weather following planting allowed the rye to quickly germinate and emerge. Planting direction was 0 degrees, North and perpendicular with tile lines. Rye was terminated at elongation stage with herbicide on April 17, 2015.

4.2.2 Conventional Tillage

Primary tillage was completed November 18, 2014 with a chisel plow fitted with straight points. The working depth was in the range of 28-33 cm (11-13 inches). Soil conditions were frozen less a centimeter from the surface and covered with 0.06 cm (0.15 inches) of snow. Tillage direction was 90 degrees, East, and parallel with tile lines. Herbicide was applied on April 17, 2015. Seed bed was prepared with secondary tillage by a field cultivator at a depth of approximately 10 cm (4 inches) just prior to planting on May 6, 2015. No tillage was performed on the annual rye plots.

4.2.3 Liming

Calcium carbonate agricultural limestone was surface broadcast at a rate of 4.5 Mg ha^{-1} (2 ton ac^{-1}) the week of April 17, 2015. The lime would not be incorporated in on the cover-cropped treatment, but would be incorporated on the conventional treatment during the spring tillage event.

4.2.4 Pre-Plant Fertilization

The first pre-plant anhydrous ammonia application was completed May 2, 2015 at a rate of 224 kg ha^{-1} NH_3 (200 lbs/acre) with a 17-row knife applicator on 76-cm (30-inch) spacing. Plots 4, 5, 6, and 7 received pre-plant NH_3. The-17 row knife applicator, with a width of 12.95 meters, would need to be treated like a 12.19 meter applicator to be divisible by an 18.29 meter planter. This was possible by overlapping one knife with each pass, making three passes of 17-knife applicator equal to two passes of a 24-row planter. However, with this method, one out of every 16 rows received double the 224 kg ha^{-1} NH_3 rate in plots 4-7. This excess rate is not accounted for in calculations. The fertilizer was applied west to east, counting from plots 4 – 8, so row 17 (row 17, plot 4), 33 (row 10, plot 5), 49 (row 1, plot 6), 65 (row 18, plot 6), and 81 (row 9, plot 7) were double pre-plant fertilized. Row 97 would represent row 1 in plot 8, although this was not double applied, it will bring the application up to 224 kg NH_3 ha^{-1} instead of 191 kg NH_3 ha^{-1} for plot 8. Figure 2 visually represents the spring fertilizer application and management details.

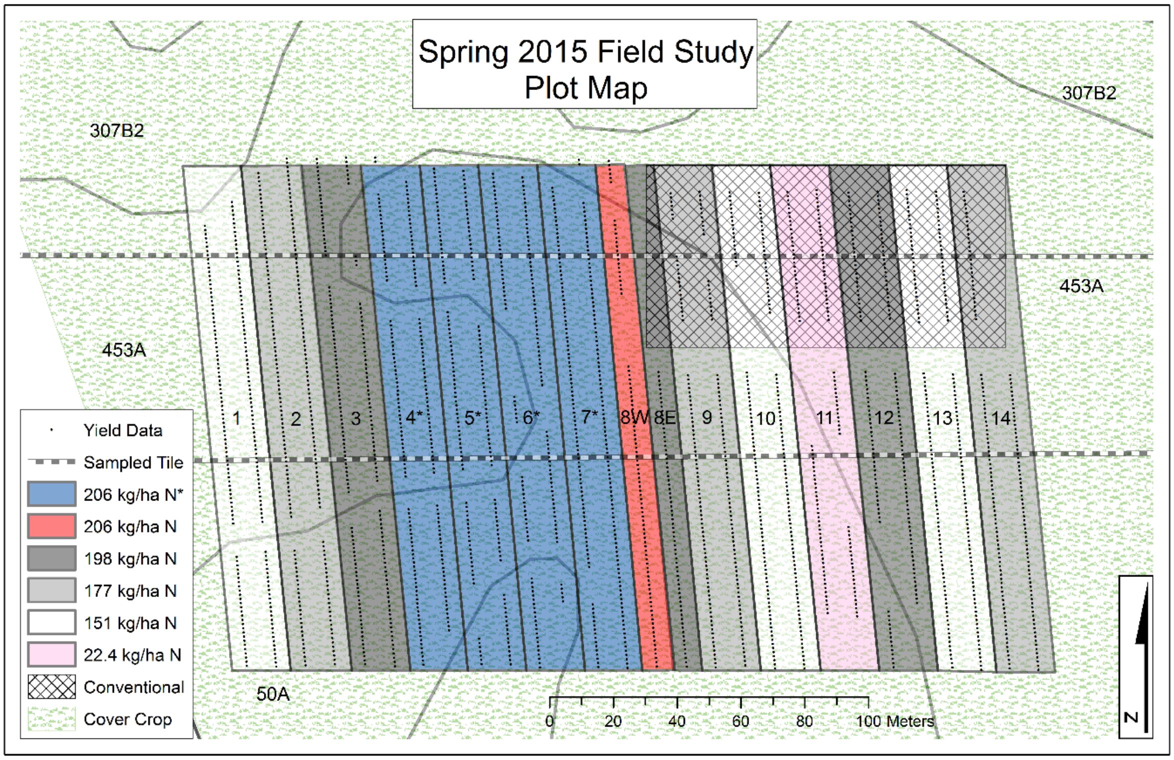


Figure 2. This plot details the plot layout. Items worth noting are the conventional tillage plot (Chisel) is located in northeast corner of site location.
* represents preseason timing of anhydrous ammonia.

4.2.5 Starter Fertilization

All plots had liquid starter fertilizer applied with the maize planter on May 6, 2015 at a depth of 50.8 mm (2 inches) below the surface and 50.8 mm laterally distanced from the rows. The liquid fertilizer was a mixture of 28% urea-ammonium-nitrate (75 L ha^{-1}), ammonium polyphosphate (75 L ha^{-1}), and ammonium thiosulfate (18.7 L ha^{-1}). The starter fertilizer contained 22.4 kg ha^{-1} (20 lbs acre^{-1}) nitrogen and 16.8 kg ha^{-1} (15 lbs acre^{-1}) P_2O_5.

4.2.6 Side-Dress Fertilization

Plots which did not receive a pre-plant fertilizer application were side-dressed with variable rates of anhydrous ammonia on June 3, 2015 (Figure 2). These side dress rates were 129, 155, and 176 kg NH_3 ha^{-1}. The lower values of 129 and 155 kg ha^{-1} represented values obtained by verbal communication with extension Dennis Bowman and were the lower and upper range values for the maximum return to nitrogen (Sawyer et al., 2015). Side dress applications made with a 23 row single blade opener at depths of 75 mm (3 inches).

Figure 3. Side-dress anhydrous ammonia application.

4.3 Soil Sampling

Soil sampling was collected at different periods throughout the 2015 growing season in order to determine effect of tillage treatment on soil nutrient cycling.

4.3.1 Grouping and Sample Timing

The study area was separated into groups based on soil types (noted in site selection), tillage practices (conventional tillage and annual rye cover-crop), and distance from drainage tile (0-3 meters and greater than 3 meters). For all preseason sampling groups, with the exception of the conventionally tilled Virden soil because of limited treatment area, five soil samples were collected. Soil samples were also collected at side-dressing of nitrogen application, and at relative maturity. Each soil sample or group of collected samples was geospatially mapped during sampling events.

4.3.2 Preseason

Preseason soil sampling was accomplished on March 20-21, 2015, during which soil was collected from 33 locations at three depths from regions described above. A 34th location was chosen because of the visual variability. These depths were 0-15 (0-6 inches), 15-45 (6-18 inches), and 45-76 centimeter (18-30 inches). All samples were collected with a 2.5-cm (1-inch) diameter probe measuring 46 cm (18 inches) in length.

4.3.3 Pre-sidedress

Pre-sidedress soil samples were taken June 3, 2015 on the control plot. These samples were collected in a diagonal orientation across the plot. Eighteen samples were collected, 6 from the Virden cover crop soil, and 6 from both the conventional tillage cover crop soil on the Muren soil. These samples were collected to a depth of 0-25 cm (10 inches) and with a 2.5-cm (1-inch) soil probe measuring 25 cm in length.

4.3.4 Relative Maturity

On September 20, 2015, approximated relative maturity of the crop, a final soil sample was taken while the maize crop remained in the field. These locations were selected based on their fertilizer rates and the plots being minimally compromised from compaction or other biases that could have impacted the crop during its growth period. These samples were collected to a depth of 0-76 cm (0-30 inches) with a 2.5-cm (1-inch) soil probe measuring 46 cm in length.

4.4 Flow Monitoring and Sampling Stations

The tile flow and nutrients were continuously monitored using in-line v-notch weirs and submerged pressure transducers for flow. ISCO® 6712 autosamplers were used for water collection.

4.4.1 Sampling Locations

Flow monitoring stations were located in order to isolate the Muren silt-loam soil type that had equal area in the conventional tillage and the cover-crop management practices. The upstream flow monitoring station on each line was used to measure upstream flow and grab samples were intermittently collected for nutrient analysis. Nutrient and flow measurements from the upstream station were then subtracted from the downstream monitoring stations, from which water was collected every 4 hours. The goal was to accurately measure the infiltration rates and nutrient losses from plots 12 – 14. Figure 4 shows the locations of flow monitoring stations within the experimental plot.

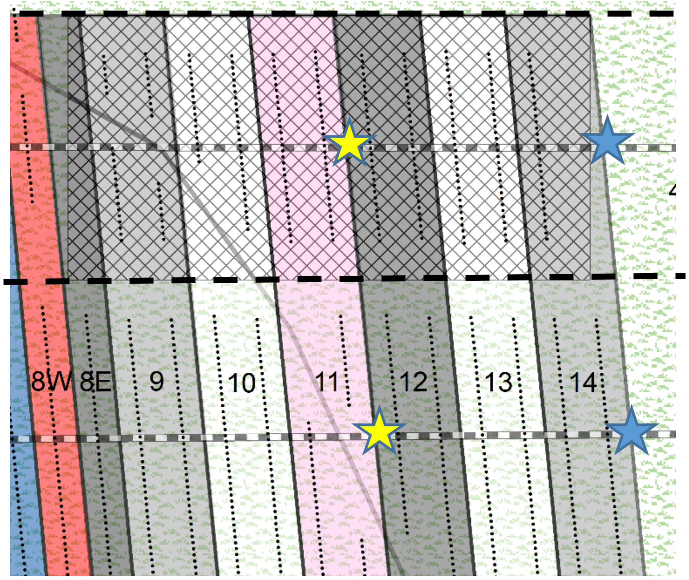


Figure 4. Specific locations of flow monitoring stations. Blue Stars represent autosampler locations, yellow stars represent upstream measurement sites.

4.4.2 Flow Measurement

Flow measurement was needed to measure the drainage contributed by each treatment. When collected samples were analyzed for nutrient concentrations, the flow measurements would be used to determine the total nutrient masses lost from each treatment, or nutrient flux. Four in-line v-notch weirs were utilized and installed in the drainage tiles, two to measure upstream flow prior to plots 12-14 (West of plot 12, Figure 4) and two to measure downstream flow of plot 14 (East of plot 14, Figure 4). Any upstream measurements of flow or flux would be subtracted from downstream measurements. The v-notch weirs were originally sized to handle a drainage area of 1.14 ha (2.81 acre) with a drainage coefficient of 19 mm/day (0.75 inches/day). Giving an expected tile flow of 2.51 liters per second (39.74 gallons per minute).

Figure 5. Testing stages and flow for v notch weir.

4.4.3 Installation of V-Notch Weir

The installations of the v-notch weir flow monitoring stations began on April 11, 2015 and ended on April 12, 2015. In order to make room for the flow monitoring stations, sections of working 10.2-cm (4-inch) tile line had to be removed. The flow monitoring sections were 15.4-cm (6-inch) diameter, non-perforated dual wall tile with a v-notch weir section (Figure 6). The sections removed from both monitoring stations were approximately 2 degrees slope and were replaced with a section with no slope. In order to allow the upstream flow monitoring section to meet the zero slope standard, an immediate drop was sectioned where the 15.4-cm tile coupled with the 10.2-cm tile, leaving the tops of the tile lines flush and the 15.4-cm section dug below grade of the 10.2-cm tile. A laser level was used to measure the elevation of the 10.2-cm tiles and ensure the monitoring stations were level.

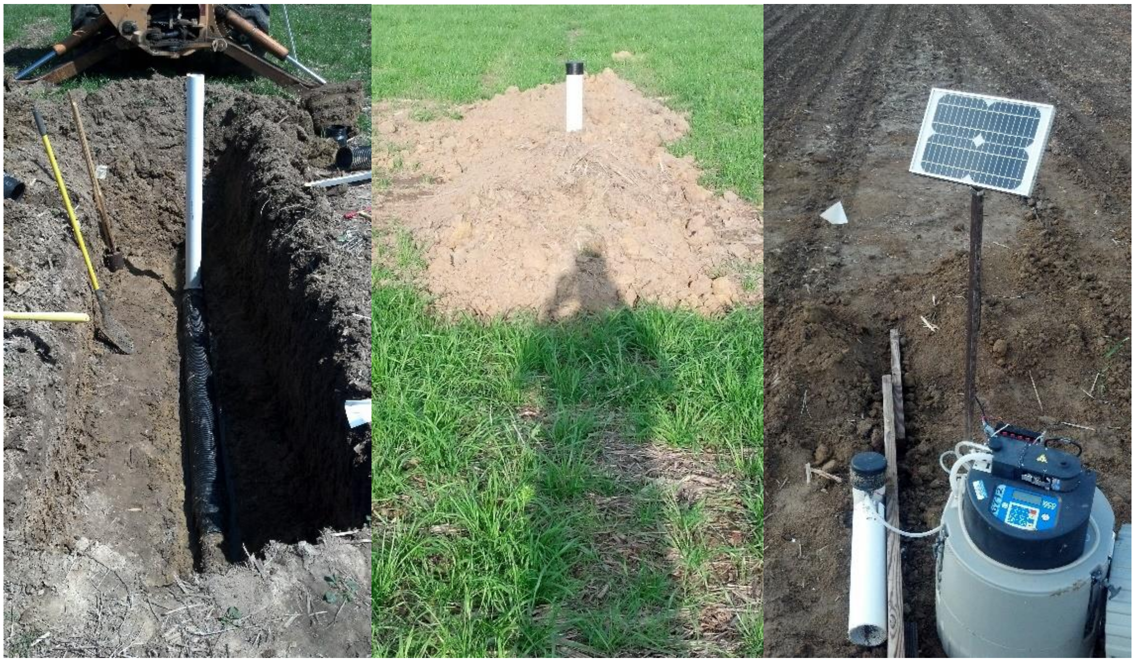


Figure 6. The replacement of tile with flow monitoring station and complete setup.

Non-perforated tile was chosen for the flow monitoring section to prevent disturbed soils from entering tile lines where water was to be collected and measured. A 6-inch tile was chosen to replace 4-inch because it allowed a v-notch weir to be built with a higher precision and range in height while reducing the risk of backing up tile flow.

4.4.4 Measuring Flow

Each flow monitoring weir system was tested prior to field installation. Following testing for each unique weir and their similar values, it was determined one flow curve would best represent all v-notch weirs (Equation 1). Care was taken in installing the flow monitoring stations in the field with the same standards as they were tested in the laboratory. The flow of water in L s^{-1} for each v-notch weir, for the purposes of the field study, was determined by the following calculation:

Equation 1. Flow equation

$$Q_{ALL} = [3.007e^{-5} * H^3 + 2.175e^{-3} * H^2 + 2.8233^{-2} * H] * 0.06309$$

where
Q_{ALL} = Flow from v notch weir (liter/second)
H = water depth above the nappe of the v (mm)

HOBO® U20L-04 pressure transducers were used to determine the water depth (H) in the tile lines. These pressure transducers measure absolute pressure with an accuracy of 0.1% full scale or 4 mm, but in order to do this, they must have another pressure transducer reading for barometric compensation. This study had four flow monitoring stations which required four pressure transducers, and a fifth pressure transducer for barometric compensation. The fifth pressure transducer was placed approximately 2 feet below the surface and above the flowing water in the riser of the downstream rye monitoring station. Placing the fifth pressure transducer below surface kept it at a more constant temperature relative to the submerged pressure transducers. All other pressure transducers were placed at the bottom of the flow basins, or at a depth of approximately 215 mm below the nappe of the “v” of the v-notch weir. The pressure transducers recorded absolute pressure and temperature at 15-minute intervals throughout the study and collected nearly 44,400 flow values from April 12, 2015 through August 5, 2015. Pressure transducer data were stored internally, but were routinely downloaded using HOBOware® Pro™ software in which the data were processed from absolute pressure, to water depth for each individual, submerged pressure transducer. These data were then converted to comma delimited files and imported to Microsoft® Excel® for further analysis.

4.4.5 Support for Risers

Upstream and downstream risers (10.2 cm, schedule 40 PVC pipe) connecting subsurface drainage tile to the surface for sampling procedures were supported with liquid nail and silicon at junction of drainage tile line and riser. The upstream cover crop riser was secured with self-tapping screws in addition to the liquid nail and silicon. The heights from the tops of the risers to the bottom of the collection basins was measured at the time of installation. Follow-up measurements revealed the risers were settling with the surrounding soils. This was corrected by additions of wood platforms which were secured to the risers and supported by surrounding, undisturbed soils.

4.4.6 Rerouting Upstream Tile Flow

Flow events on April 19, 2015 were above the downstream monitoring station's maximum flow tolerances for both the conventional and cover cropped tile lines. The upstream portion of the tile lines (upstream of entrance to the experimental plot) were rerouted to bordering tile lines (outside of the isolated section of experimental plot) on April 30, 2015 (see arrow in Figure 7). This change minimized upstream contribution and allowed the majority of the flow from the silt-loam soil while also reducing the risk of a flow overtopping tolerable values.

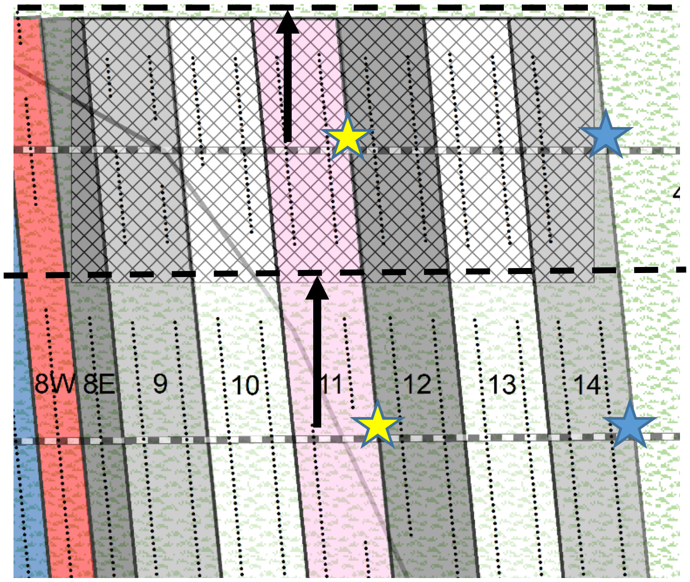


Figure 7. Final setup is shown on right. Black arrows represent rerouted subsurface tile lines

4.5 Water Samples

Collected samples retrieved from the autosamplers were immediately placed on ice during transport and then refrigerated at the Agricultural Engineering Sciences Building. Two 50 mL aliquots, one as a backup sample, and one chosen to be analyzed for NO_3-N, total N, and total P were placed in 50 mL plastic centrifuge tubes. These samples were either analyzed upon collection or frozen and thawed later for analysis. All samples analyzed for orthophosphate were filtered with a 2 micron filter and labeled accordingly. Samples were brought to pH neutral if stabilized with H_2SO_4 prior to analysis and this was normally done the day of sample analysis.

4.5.1 Sample Identification

All samples had a unique alphanumeric identification. The first character was a letter of either “C”, “R”, “F” or “T” which represented Conventional (C), Annual-Rye (R), Field tile outlet (F) or (T), gave the identification of the treatment or that it was collected from a field tile. The second character was either a number from 0 to 20 or the letter U, representing the number of days the sample set idle in the autosampler before collection date, or representing that the sample was collected from the upstream riser (U) and the idle time was assumed zero days idle. The third character was a letter of either “G”, “A”, or “B” which represented Grab (G), Autosampler collected (A), or Autosample grab sample (B). The fourth character represented either no acid as stabilizer (0) or H_2SO_4 (1) as stabilizer. The fifth character was a six digit number representing the date. For example, a sample labeled C2A1071015, identified the sample was collected from the conventional treatment, stayed idle for 2 days, was collected with the autosampler, had H_2SO_4 as a stabilizer, and was collected on July 10, 2015. The character representing the number of days in the autosampler was necessary to determine the sampling date of the tile water. In this case, the sample date was July 8, 2015. This sample identification method began with autosampler installation on May 9, 2015.

4.5.2 Autosampler Procedure

Autosamplers were programmed to collect a sample every 4 hours starting at 12:00 am each day, giving approximately 150 mL “sips” at 00:00, 04:00, 08:00, 12:00, 16:00, and 20:00 in each bottle. Autosamplers were programmed to take sips that were composited versus one large sample a day in order to collect water at different stages of flow. The autosamplers used in this study were ISCO® 6712.

4.5.3 Grab Samples

Grab samples were taken by three methods 1) “G” denoted the use of a 2.54-cm (1-inch) schedule 40 PVC pipe that was inserted down the risers and into the sample basins, 2) “B” denoted use of the grab sample feature on the autosampler and were suctioned from the basin and through the autosampler intake and pump tubing, and 3) “T” or “F” denoted collection from the field tile outlet into a 20-liter glass carboy. “G” samples were collected with bottles labeled and secured (taped) to the end of a PVC pipe, then submerged into the sample basin and rinsed twice prior to final submersion and sample collection.

4.6 Plant Biomass Samples

Plant biomass samples of the annual rye were collected prior to the termination event of the cover-crop in order to determine the above ground nutrient uptake and total biomass accumulation dynamics between two different soil types.

4.6.1 Annual Rye

Aboveground biomass sample was collected from each annual rye plot on April 16, 2015. The area of collection was 1175.8 square centimeters (182.3 square inches) of rye. These sample locations were approximately 15 meters north of the southernmost drainage tile of each plot and geospatial coordinates and soil types were also recorded from each collection point. Lateral locations of the collection point were based on soil types and not necessarily consistently located for each plot. The rye biomass was weighed fresh then dried in a forced-air oven for 24 hours at 80 degrees Celsius. The dried biomass was then weighed a second time to determine the water content. Designated biomass samples from the Virden and Muren soils were sent to Agvise Laboratories (Northwood, ND) for analysis for orthophosphate, total P, nitrate-N, total N, and total C. Nitrogen and carbon were determined by combustion method on a carbon/nitrogen analyzer (NUT.02.107). Other nutrients were determined by digesting the sample with 30% Hydrogen Peroxide and Nitric Acid with heat and then analyzing on an Inductive Coupled Plasma Spectrophotometer (ICP). After determining the mass and nutrient values of the aboveground biomass, extrapolation was used to determine the amount of biomass and nutrients taken up by the crop on a per hectare basis for each soil type.

4.7 Cash Crop Establishment

4.7.1 Planting

Maize was planted with a double-disk no-till planter at a target population of 83,980 plants per hectare (34,000 plants per acre) with a 116-day hybrid (Dekalb® 66-40) on May 6, 2015 at a seed depth of 44.45 mm (1.75 inches). Planting population was recorded with planter instrumentation and a final stand count was determined at relative maturity.

4.8 Site Flow Data

4.8.1 Flow Analysis

Flow was analyzed for the entire season and then segregated into three periods: prior to cover crop termination (April 12 – April 18, 2015); cover crop termination to full crop canopy (April 19 – June 18, 2015), and full crop canopy to study end (June 19 – September 28, 2015). All flow was analyzed using Minitab® statistical software comparing conventional tillage (CT) and annual rye (AR) in liters/day.

4.9 Nutrient Analysis

4.9.1 Water Nutrient Analysis

Water flowed through tile lines intermittently due to rain events from the date of installation on April 12, 2015 through the July 17, 2015. During this period, approximately 402,516 liters and 320,393 liters drained through the annual rye and conventional tillage treatments, respectively. For the annual rye and conventional tillage treatments, nitrate/nitrite-N (generally known as NO_3-N) water sample analysis was completed for 53.5% and 55.1%; orthophosphate water analysis was completed for 52.3% and 55.6%; total N water analysis was completed for 38.0% and 48.8%; and total P water analysis was completed for 45.0 and 38.9%; of total flow, respectively. The majority of the water left unanalyzed was from the month of April in which all samples collected showed little variability in nutrient concentrations regardless of flow. Total N and total P samples were a focused subset of samples tested for NO_3-N and orthophosphate which coincided with high flow events. Missing water quality data led to variability in flow volumes of samples tested for total N and total P.

Nutrient analysis was conducted by ABE Water Quality Laboratory Manager/Analyst, Duane Kimme. Samples were analyzed for NO_3-N and total N using the Automated Hydrazine Reduction Method (Standards Methods 4500-NO3-H, NEMI) and for orthophosphate and total P using the Ascorbic Acid Reduction Method (Standard Methods 4500-P-F, NEMI). Spiked samples, duplicate samples, and standard solutions were incorporated into nutrient analyses for quality control.

4.9.2 Periods of Nutrient Analysis

Much like the procedures described in the “Flow Analysis” section, the nutrient concentrations were evaluated in the same manner. The NO_3-N concentration differences were calculated for each date in mg-N L^{-1}. Differences in nutrient flux were also calculated in kg ha^{-1} NO_3-N.

4.9.3 Soil Nutrient Analysis

Soil was analyzed for total N, Illinois Soil Nitrogen Test (ISNT), nitrate nitrogen, available phosphorus, and organic carbon. Total N was analyzed by Kjeldahl Digestion and Diffusion (^{15}N Analysis Service, 2000); ISNT by protocol specified in technical note (^{15}N analysis Services, 2006); nitrate nitrogen using the Automated Hydrazinne Reduction Method (Standards Methods 4500-NO3-H, NEMI); available phosphorus by Bray P_1 (Bray and Kurtz, 1945); and organic carbon by the method of Mebius (1960).

4.10 Maize Biomass Samples

4.10.1 Maize

On September 20, 2015, approximate relative maturity for maize, harvestable stand count was recorded and select above ground portions of plants were collected and weighed. The stand count was done by measuring a length of 5.31 m (17 ft 5 in) and counting plants with a harvestable ear on rows 6, 5, and 4 of each treatment. Following a stand count, the 6th, 16th, and 26th plants were cut off at ground level and collected for analysis. All samples had a fresh weight recorded and they were then stored at 4 C until they could be chopped and dried. Plant samples were run through a tree chipper prior to drying. Samples were dried using a forced air oven at 60 degrees Celsius for 7 days. They were then weighed again and chopped into 5 mm pieces using a knife mill in preparation for shipping and analysis. They were sent to Agvise Laboratories (Northwood, ND) for analysis for total P, total N, and total C. Refer to lab procedures in 4.6.1 for lab analysis procedures.

4.11 Harvest Data

4.11.1 Collection

The focus on yield analysis was to use the mass flow sensor and internal software in a John Deere™ combine to determine yield. This method creates a much larger yield dataset than would otherwise be possible using a weigh wagon for each plot or hand harvesting. Harvest was completed on September 28, 2015 at a constant speed of 4.7 km/hr (2.9 mph) despite treatment harvest appearance or yield monitor readings. Each 24-row treatment was harvested by two, 12-row passes (9.14 meters). Yield monitors in the combine collect data at a 1-second interval, or every 1.3 meters, which creates a harvest area of 11.85 m^2 (127.6 ft^2) for each point collected.

4.11.2 Data Referencing and Selection

Harvest monitor data, before calibration, returned 129,867 kg, compared to scale total of 121,953 kg. This weight was recalibrated in John Deere® Apex™ to better reflect actual values. Following this adjustment, the data was exported in a CSV file and uploaded to ArcMap 10.3.1, a software of Esri™, where all data was transformed from tables to visual graphics. Using geospatial coordinates from the harvest data, yield data were referenced with SSURGO soil type and all other variables such as fertilizer rates and timing, soil fertility values, conventional or cover crop management practices, and planting data also collected from John Deere Apex™.

Yield data that was within a radius of 4.57 meters (15ft) of the soil boundaries was removed from the data analysis. This distance reflected double distance from the yield data point to the outside of the maize head which gave room for error in soil boundaries and assured there was no yield attribute with the wrong soil attribute. Yield data was also considered a transitional area between the conventional tillage and the cover crop management areas. The data removed resembled 5 seconds of transitional time between the management areas.

Planting data was utilized for planting down force margins, a measure of ground resistance to v-opener blades. These margins read the difference in force applied by pneumatic bags and the resistance force from the soil by a load sensor on the gage wheels. All data that read less than 30 pounds (compacted soil) was removed from analysis since it resulted in yield reductions. This compaction was the result of wheel traffic.

CHAPTER 5. Results and Discussion

5.1 Weather Analysis

Weather plays a critical role in crop production and many of the natural processes of the plants and the soil are dependent on the temperature and precipitation.

5.1.1 Observed Climatological Data

The time period of interest for this study spanned from September 2014 through October 2015. The weather conditions, in terms of temperature and rainfall, were well suited for high maize yields during this time. While the cover crop was growing, adequate rainfall throughout the winter months and into the early spring months replenished soil moisture removed from the 2014 cropping season (Figure 8). Following termination of the winter cover crop in mid-April, there was a period of warm and dry weather, which allowed planting in optimal soil conditions and an even germination and emergence of maize plants (Figure 9). The growing season for the maize crop from emergence to maturity brought above normal rainfall patterns during the months of June and slightly below average rainfall during the months of July and August (Figure 8). The rainfalls were frequent which minimized plant water stress. The monthly temperature averages throughout the maize growing season were warmer during the months of May and September and cooler for the months of June, July, and August than historically average (Table 1). The cooler temperatures during grain pollination and filling were critical in maximizing the maize yield potential.

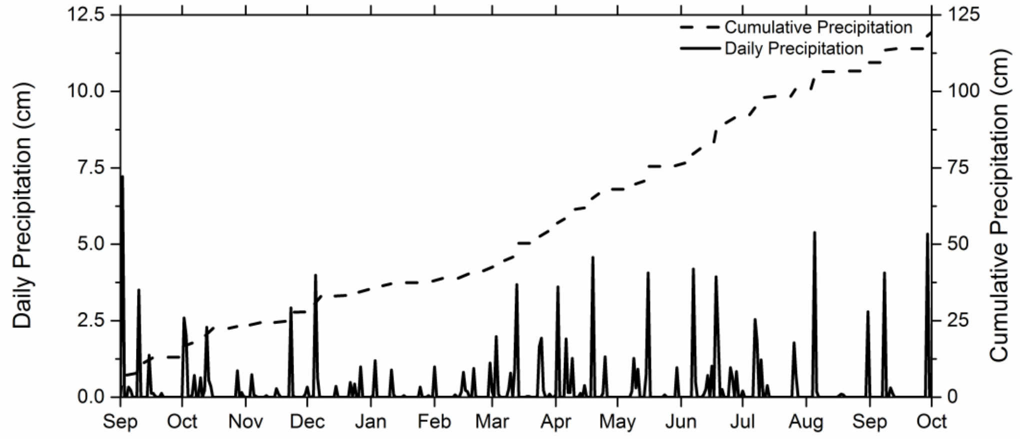


Figure 8. Daily and Cumulative precipitations for research plot.

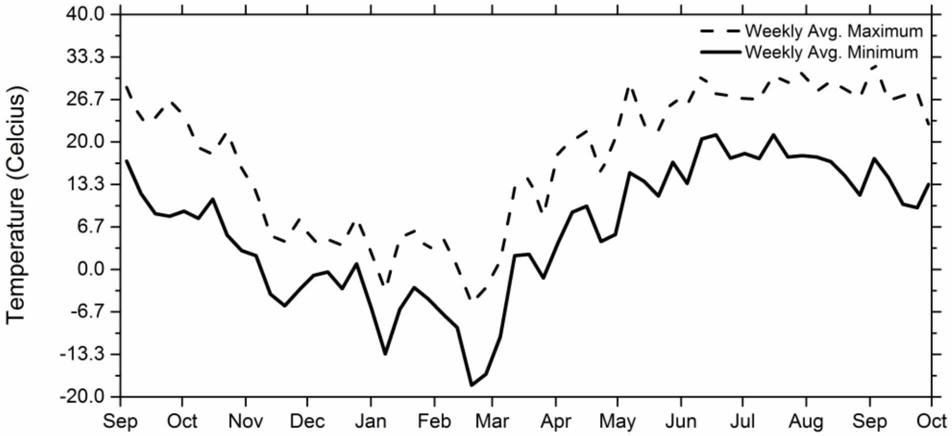


Figure 9. Weekly average temperature highs and lows for the research plot.

Table 1. Comparing the observed monthly average temperature and precipitation to average historical values.

Weather Observations vs. Historical Averages						
Date	Temperature				Precipitation	
	Observed Avg Low	Historical Avg Low	Observed Avg High	Historical Avg High	Observed	Historical Avg
Month	°C	°C	°C	°C	cm	cm
Sept. 14	11.4	14	25.7	27	13.1	8.6
Oct. 14	7.8	7	19.8	21	10.5	8.8
Nov. 14	-2.7	3	7.7	12	4.3	9.9
Dec. 14	-1.6	-3	4.7	6	7.3	8.4
Jan. 15	-6.5	-6	2.9	3	2.7	7.8
Feb. 15	-12.5	-3	-0.5	7	4.5	6.5
Mar. 15	-1.6	2	9.5	13	11.9	9.3
Apr. 15	6.6	7	18.7	19	13.7	11.1
May 15	13.7	12	25.1	25	8.5	12.8
June 15	18.1	18	27.7	29	15.6	10.4
July 15	18.6	19	28.9	32	8.7	9.9
Aug. 15	15.3	18	28.4	31	8.6	8.9
Sept. 15	13	14	27.9	27	9.8	8.6

5.2 Subsurface Drainage Flow Analysis

Subsurface drainage flow meters were used to measure the interaction between rainfall and infiltration for the conventional and annual rye treatments. All rainfall data was collected from a manual rain gauge.

5.2.1 Analysis Periods

The flow analysis looked at the entire 2015 study period and also looked at three individual periods of interest; (1) active cover crop growth, April 12 – April 18, 2015; (2) post cover crop termination when soil evaporation values are affected by surface residue cover, April 19 – June 18, 2015; and (3) period when soil evaporation values are no longer affected by cover crop residues, June 19 – September 30, 2015.

5.2.2 Full Season Analysis

Subsurface drainage continued for a large portion of the growing season, with the final period of flow happening in mid-July. This was largely a combination of adequate rainfall and the size of the events, which provided excess soil water. Most daily rainfall events that triggered large flows were greater than 3.8 cm (1.5 inches). During much of the growing season, flow would cease in the conventional tillage plot prior to the annual rye no till. It was not until mid-June that the flow patterns were more uniform and equal between the two treatments. Figure 10 displays the cumulative flow comparison with the gray dashed line representing the annual rye treatment and the black line representing conventional tillage treatment.

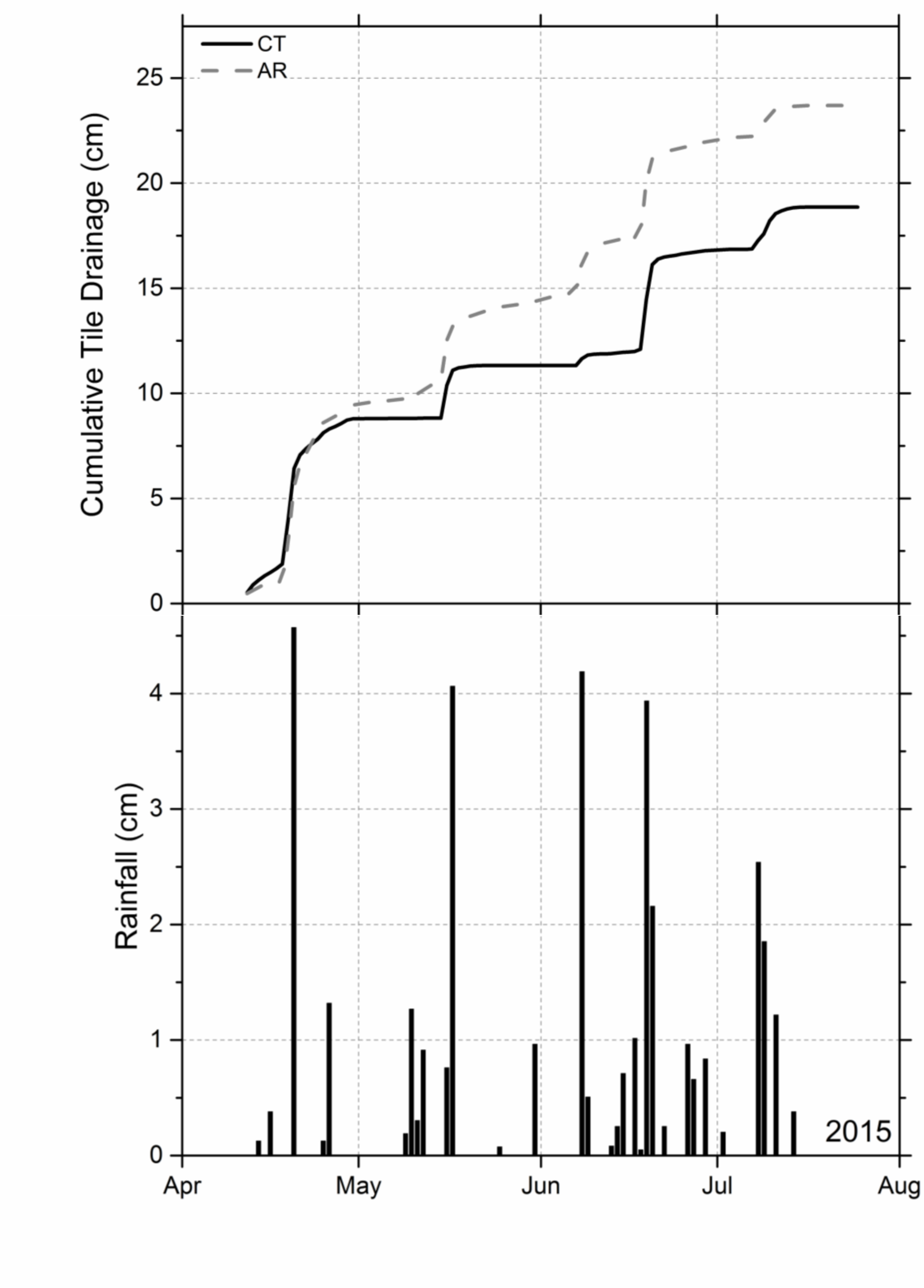


Figure 10. Cumulative tile drainage and site daily rainfall for 2015 growing season comparing conventional tillage (CT) to annual rye (AR).

The seasonal comparison of daily flow means (Table 2), return mean daily flow values greater for AR than CT. This signifies the AR treatment either maintained a greater value of water in the soil profile through reduced evaporation or the undisturbed macropore flow paths allowed a less resistant path towards the drainage tile.

Table 2. Daily flow values from annual rye (AR) and conventional tillage (CT) flow monitoring stations from entire season.

Descriptive Statistics						
	N	Mean	SE Mean	Standard Deviation	Minimum	Maximum
AR Daily Flow [L]	111	3626	729	7680	0	44050
CT Daily Flow [L]	111	2886	703	7409	0	41145

5.2.3 Living Cover Crop

The daily flow measurements were collected and analyzed to look specifically at the period cover crop growth, April 12 – April 18, 2015. This period marks the portion of the growing season in which the tile flow was measured while the cover crop was still living. The double mass curve for this analyzed period, represented by Figure 11 shows flow was greater for the conventional tillage.

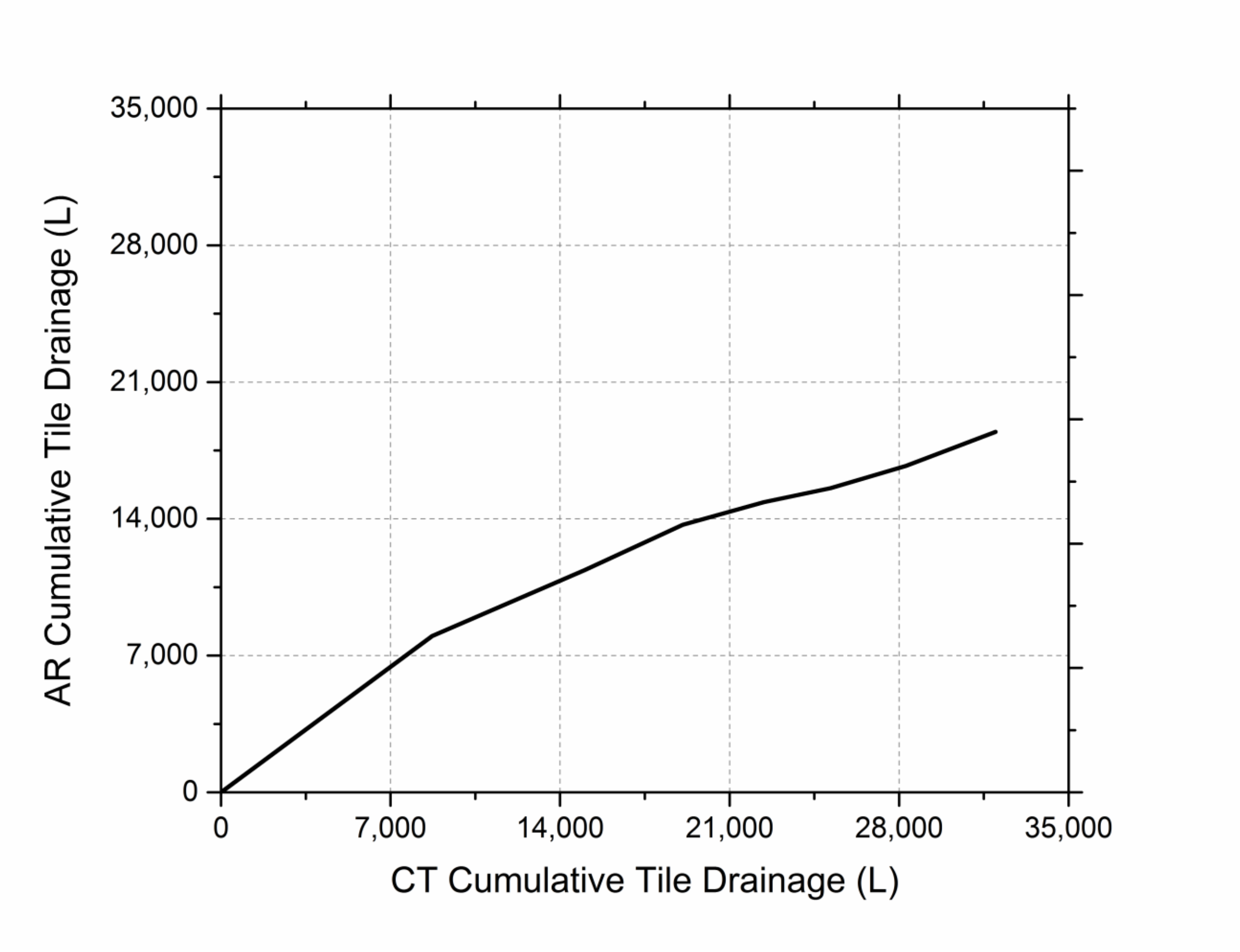


Figure 11. Double mass flow curve for April 12 – 18, 2015 comparing conventional tillage (CT) to annual rye (AR).

Table 3 lists statistics regarding the daily flow values. Flow was less from the annual rye treatment than the conventional treatment during the period when the winter cover crop was actively growing. The growing crop has a greater transpiration coefficient than bare ground evaporation and thus, the water deficit of the annual rye plot was greater than that of the conventional plot, which led to larger values of subsurface flow from the conventional treatment.

Table 3. Daily flow data values for April 12 – 18, 2015.

Descriptive Statistics						
	N	Mean	SE Mean	Standard Deviation	Minimum	Maximum
AR Daily Flow [L]	7	2635	956	2528	720	8000
CT Daily Flow [L]	7	4570	820	2169	2748	8722

5.2.4 Early Vegetative Maize Growth following Cover Crop Termination

The daily flow measurements were analyzed for the period which immediately followed cover crop termination up to point of assumed evapotranspiration equilibrium (full crop canopy of both treatments). This period was April 19 – June 18, 2015. Figure 12 shows flow was greater for the annual rye treatment than for the conventional plot.

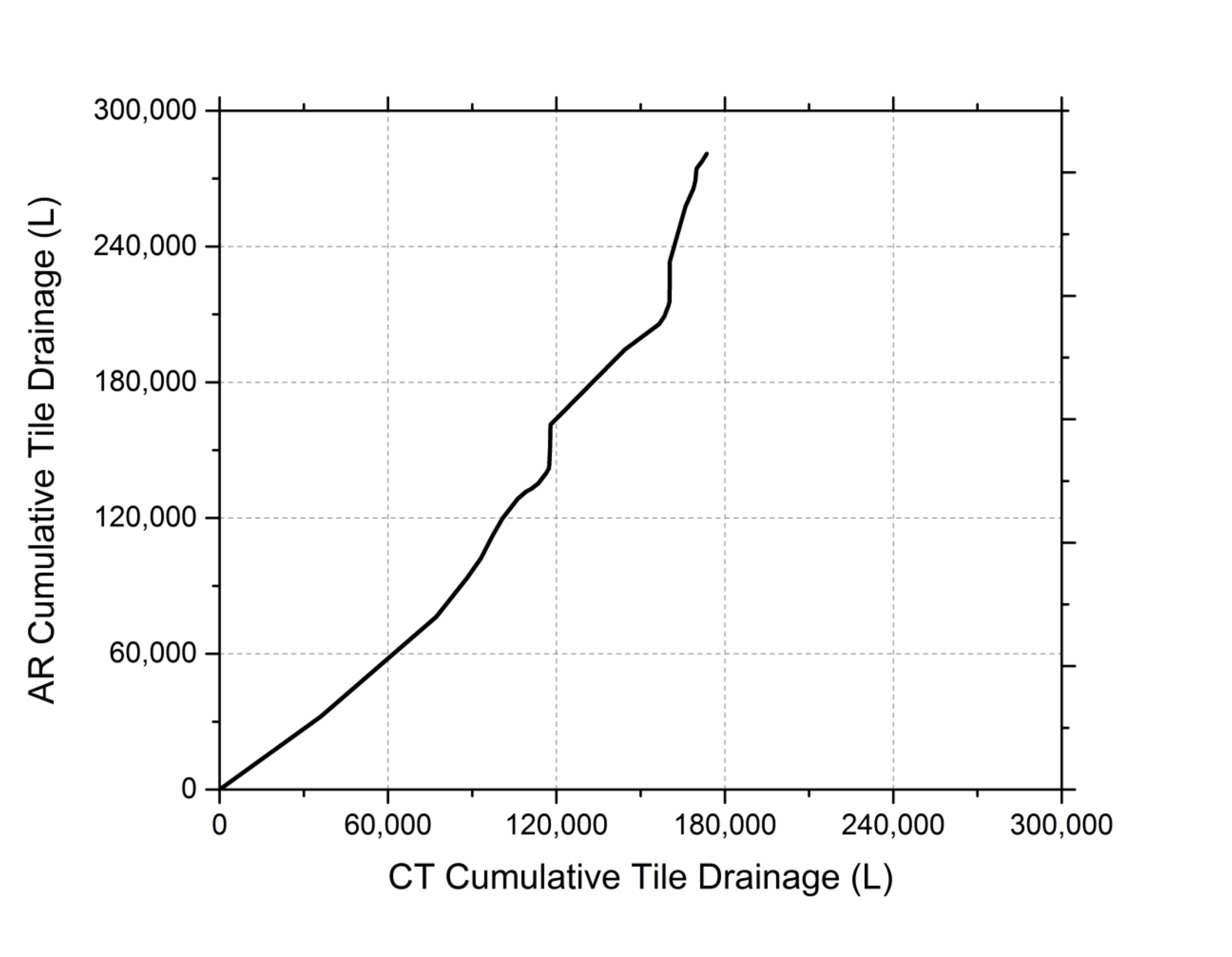


Figure 12. Double mass flow curve for April 19 – June 28, 2015 comparing conventional tillage (CT) to annual rye (AR).

Data from Table 4 confirms the daily flow means for AR were much greater than CT for the period immediately following cover-crop termination through canopy cover. This difference can be attributed to lower evaporation values, less resistance through more intact macropore flow channels, a greater soil moisture value for the annual rye treatment or some combination of previously suggested reasoning. Conventional tillage creates more air space in the surface soil, but this reduces soil water content. Soil moisture samples, taken the same date of side-dress nitrogen application, showed higher moisture content for annual rye than conventional tillage and conversely a lower bulk density measurement for conventional tillage than annual rye.

Table 4. Daily flow data values for April 19 – June 28, 2015.

Descriptive Statistics						
	N	Mean	SE Mean	Standard Deviation	Minimum	Maximum
AR Daily Flow [L]	61	4606	1089	4606	50	44050
CT Daily Flow [L]	61	2844	995	7771	0	41145

5.2.5 Late Vegetative and Reproductive Growth

The late season vegetative growth period was the only period of water collection in which the evapotranspiration coefficient would no longer be affected by the residue or growth of the cover crop. This period was June 19 – September 30, 2015. Figure 13 shows conventional tillage plot had a slightly higher cumulative flow, however much of the period had a very similar drainage pattern.

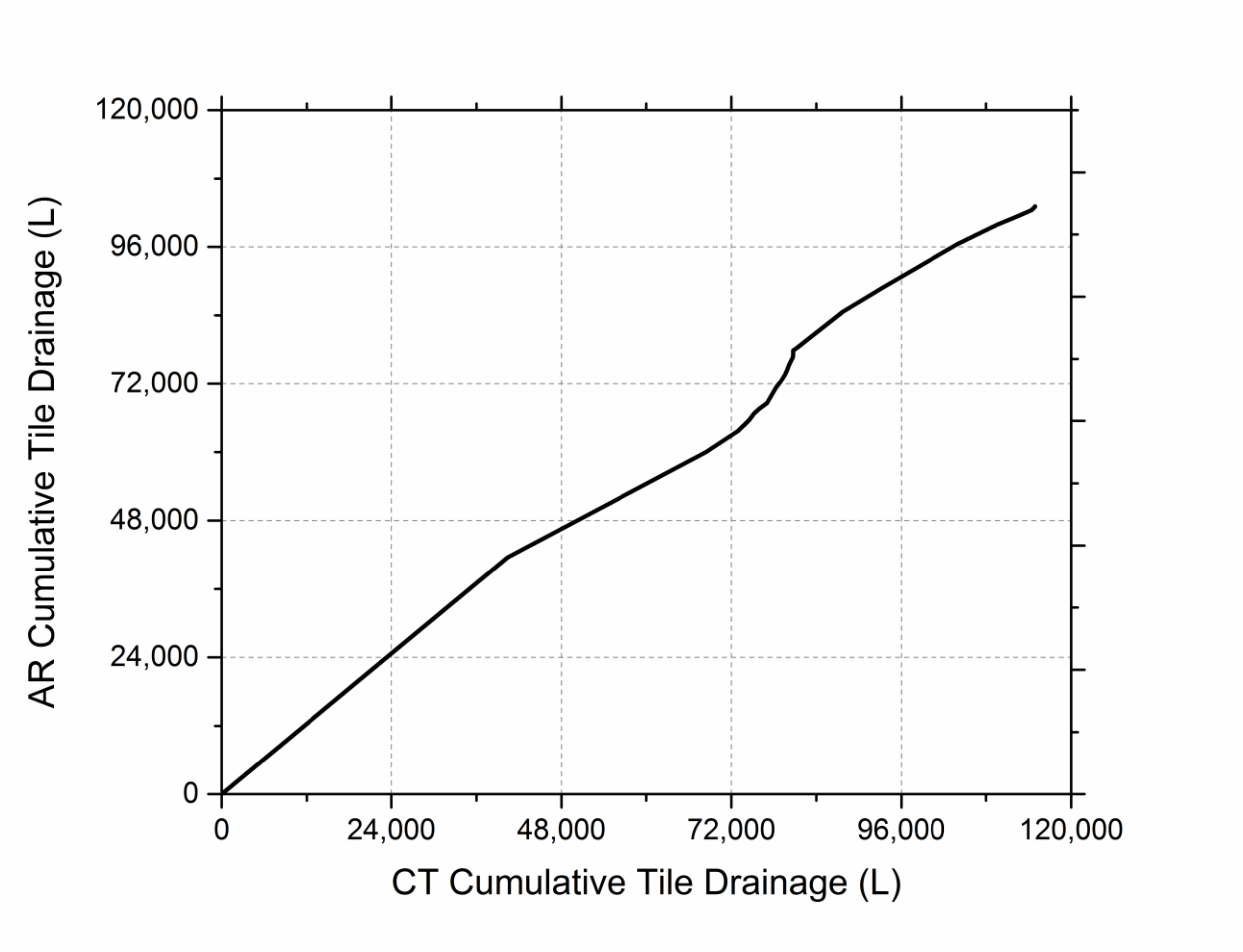


Figure 13. Double mass flow curve for June 19 – September 30, 2015 comparing conventional tillage (CT) to annual rye (AR).

Table 5 daily flow also represent similar drainage values for the AR and CT treatments for late vegetative period through the end of the season. The annual rye no longer reduced evaporation from the soil surface and the depth of the corn roots likely equalized the deeper infiltration of the two treatments. The result is the treatments drainages are at more of an equilibrium than they were at any other time in the season analysis.

Table 5. Analysis data of daily flow between AR and CT treatments for period following full crop canopy of both treatments.

Descriptive Statistics						
	N	Mean	SE Mean	Standard Deviation	Minimum	Maximum
AR Daily Flow [L]	43	2398	1048	6869	0	41576
CT Daily Flow [L]	43	2672	1144	7504	0	40412

5.3 Subsurface Drainage Nutrient Analysis

Using 15-minute tile flow measurements and daily composite samples, it was possible to analyze nutrient concentrations and flux for the two tillage treatments at a subfield scale. Collecting tile water and analyzing it for nutrient concentrations provides supplementary information to nutrient management practices. Combining flow values with concentrations to calculate total nutrient mass load can provide a land manager with the nutrient losses and allow for more informed fertility management decisions.

5.3.1 Analysis Periods

Nutrient analysis was performed for the entire 2015 study period and also periods of cover crop growth, April 12 – April 18, 2015; post cover crop termination when soil evaporation values are affected by surface residue cover, April 19 – June 18, 2015; and the late vegetative and reproductive stages where equal evapotranspiration ratings (full crop canopy) were assumed, June 19 – September 30, 2015.

5.3.2 Full Season Nutrient Analysis

The full season analysis of subsurface tile water provides a seasonal scope for comparisons of the conventional and cover cropped treatments. During this period, April 12 – September 28, 2015, subsurface water analyzed for nitrate concentrations were generally greater for the conventional treatment than the winter cover crop. The weighted mean of the conventional tillage treatment was 6.1 ppm NO_3-N and the annual rye treatment was 4.41 ppm NO_3-N. This is likely a combination of two factors: 1) conventional tillage resulted in greater soil mineralization from exposing soil organic matter to microbial breakdown, and 2) annual rye treatment had greater water flow which acted as a source of dilution. The individual sample values of NO_3-N are expressed in Figure 14. The upstream annual rye NO_3-N values are generally higher in concentration than downstream annual rye NO_3-N. This should be expected because the upstream portion had plots that were fertilized preseason (plots 4, 5, 6, 7 on May 2, 2015) and would expel nitrates at an earlier time than a side-dressed plot. Upstream conventional tillage NO_3-N values are generally lower in concentration than downstream conventional tillage. This is expected because the upstream portion of the conventional tillage plots is a larger portion of annual rye than conventional tillage (approximately 85% AR and 15% CT). Although the upstream drainage region had a preseason application of anhydrous ammonia on some plots (plots 4, 5, 6, 7), the nitrogen mineralized from conventional tillage practices still resulted in greater downstream concentrations in the drainage tile.

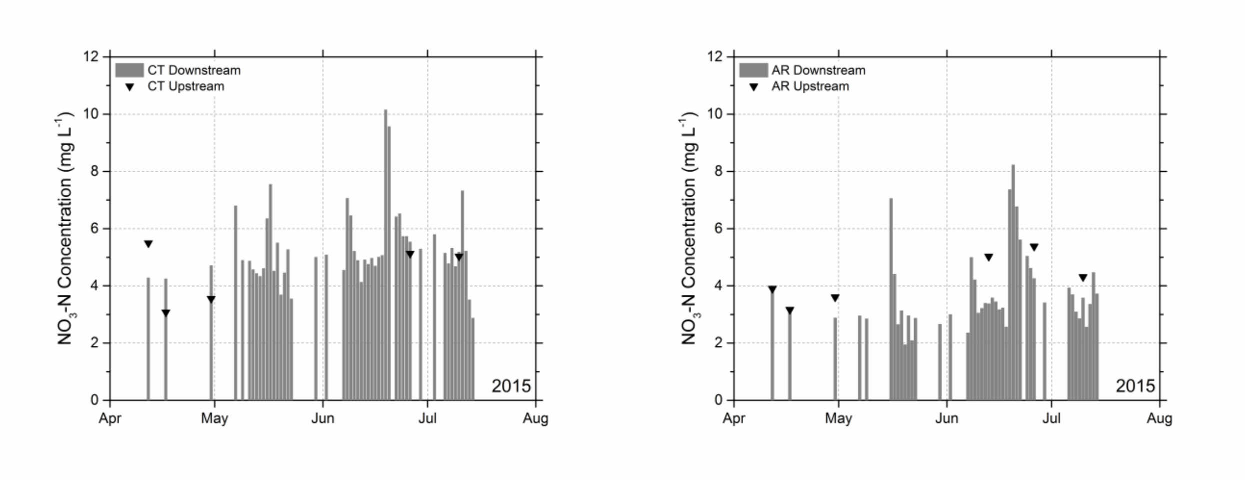


Figure 14. Sample concentrations for each treatment including upstream values.

Numerical observations of the nitrate concentrations (Table 6) showed AR treatment had lower NO_3-N concentrations than the CT treatment and confirm the visual observations from

Figure 14. The mean concentrations for both treatments are very low for a field supporting row crop corn. Given the conventional tillage was not completed until ground conditions were frozen in the fall of 2014, and that the majority of nitrogen fertilizer applications were made as side-dress application, the concentrations of the water could have been reduced. To put in perspective, a concentration of 3.77 mg L^{-1} (AR treatment) could be interpreted as the concentration of a native grassland and a concentration of 5.31 mg L^{-1} (CT treatment) could be interpreted as row crop production with a successful winter crop to "trap" N (Brouder et al., 2005).

Table 6. Season long values for nitrate concentrations descriptive statistics.

Descriptive Statistics						
	N	Mean	SE Mean	Standard Deviation	Minimum	Maximum
AR NO_3-N [mg/L]	44	3.77	0.21	1.39	1.94	8.22
CT NO_3-N [mg/L]	50	5.31	0.19	1.34	2.88	10.16

Utilizing analyzed and extrapolated water sample concentrations from linear interpolation, a cumulative nitrate flux curve which compared annual rye to conventional tillage could be drawn (Figure 15). The conventional tillage treatment had two periods in which the nitrate flux was greater than the annual rye treatment, the beginning of the season in which the cover crop was growing and also the period in which the maize crop was at maximum canopy. The cumulative losses of nitrate nitrogen were calculated at 11.69 and 10.61 kg ha^{-1} NO_3-N for the conventional treatment and annual rye treatment, respectively, with the annual rye winter cover crop slightly decreasing losses.

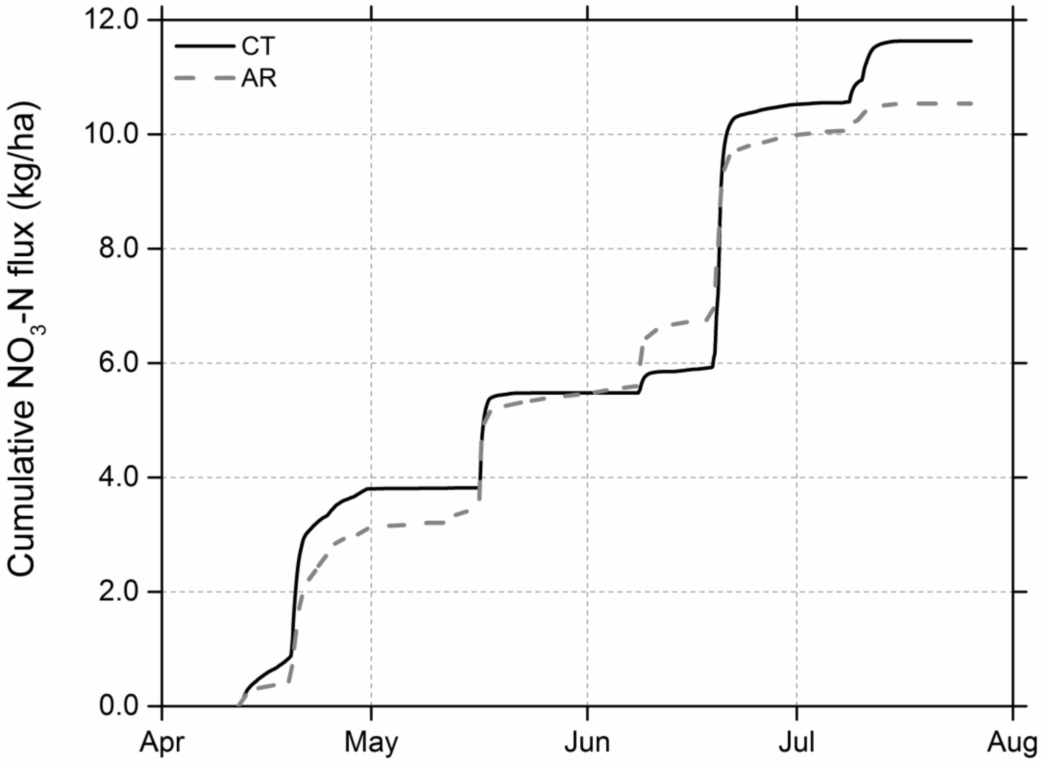


Figure 15. Comparing 2015 growing season cumulative NO_3-N flux for conventional tillage (CT) to annual rye (AR).

The numerical values for daily NO_3-N flux are expressed in Table 7. Greater flow from the annual rye treatment impacted the nitrate flux comparison. Because flow was greater in the annual rye for a majority of the season, the lower nitrate concentrations of most annual rye samples were offset by a larger volume of flow. Most daily nitrate flux values, in kg ha^{-1}, were greater for the annual rye treatment than the conventional treatment due to longer flow durations and a greater total flow volume. However, nitrate lost during rain events were large enough from the conventional treatment to offset the difference and result in greater cumulative nitrate losses (flux).

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Table 7. Season long daily NO_3-N flux values for annual rye and conventional tillage treatments.

Descriptive Statistics [NO_3-N Flux]						
	N	Mean	SE Mean	Standard Deviation	Minimum	Maximum
AR Daily Flux [kg ha^{-1}]	44	0.1584	0.0555	0.3682	0.0009	1.8338
CT Daily Flux [kg ha^{-1}]	50	0.1567	0.0609	0.4307	0.0000	2.4575

Water samples were analyzed for orthophosphate, total-nitrogen, and total-phosphorus, in addition to nitrate-nitrogen. These values are in Table 8. It is suggested that samples analyzed for orthophosphate be filtered and immediately analyzed upon collection. Given that the methodology of the study included autosamplers collecting daily samples and storing samples until collection, it was not possible to analyze samples for orthophosphate in this manner. Leaving samples unfiltered in the autosampler likely resulted in orthophosphate sorbed on sediment in the tile water desorbing during the storage period. This likely led to inconsistencies in sample orthophosphate concentrations. These inconsistencies were further supported by the values of total-P with respect to orthophosphate and values can be seen in the maximum columns where the ratio is greater than 1, a ratio that is not possible. The number of samples analyzed for total-N and total-P was less than the number of samples analyzed for nitrate or phosphate, the reasoning is discussed in section 4.9.1.

Table 8. Additional analysis of samples, full season values.

Descriptive Statistics						
	N	Mean	SE Mean	Standard Deviation	Minimum	Maximum
AR PO_4-P [mg L^{-1}]	42	0.0743	0.0081	0.0528	0.0060	0.3100
CT PO_4-P [mg L^{-1}]	45	0.0567	0.0045	0.0304	0.0040	0.1085
AR NO_3-N / TN	17	0.8000	0.0285	0.1175	0.5327	0.9669
CT NO_3-N / TN	17	0.8141	0.0305	0.1259	0.5858	1.0586
AR PO_4-P / TP	19	0.7550	0.1060	0.4620	0.1420	1.7580
CT PO_4-P / TP	19	0.948	0.1690	0.7370	0.0880	3.354

5.3.3 Living Cover Crop

The nitrate flux was greater for the conventional tillage treatment than the annual rye treatment during the period of active growth of the annual rye cover crop. This can be seen in Figure 16 and Table 9. An actively growing grass crop reduced the flux in two ways: 1) uptake of available nitrogen from the soil profile thereby reducing nitrate leaching losses, and 2) the uptake of soil water and a greater net transpiration resulting in significantly less tile water flow.

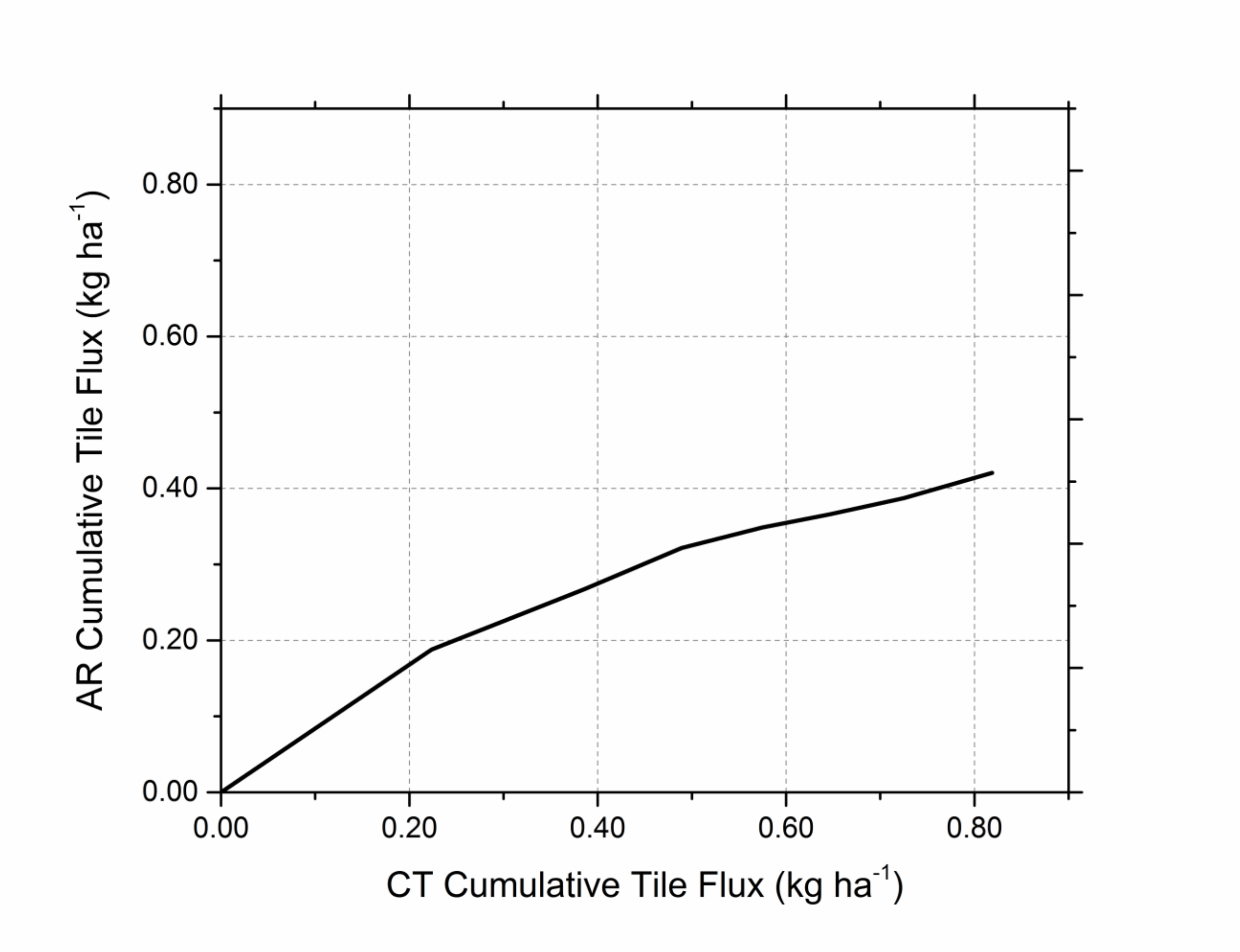

Figure 16. Double mass curve of cumulative NO_3-N flux for period April 12 – 18, 2015 comparing conventional tillage (CT) to annual rye (AR).

Table 9 returns NO^3-N flux values for April 12 – 18, 2015. These lower nitrate levels in the cover crop plots can be attributable to the combination of nitrogen uptake from the annual rye cover and increased soil mineralization in the conventional tillage plots. Soil mineralization begins as soon as soil temperature and moisture levels are adequate to stimulate microbial activity. Even with a late tillage event and a cooler than average spring, subsurface nitrate values were still elevated in the conventional tillage plot. Table 10 shows the majority of the nitrogen lost from tile water was in the nitrate form and most phosphate was lost in the orthophosphate form. Further analysis of other nutrients, also in Table 10, shows phosphate losses were very low for both treatments.

Table 9. Comparing NO_3-N flux for cover crop growth period of April 12 – April 18, 2015.

Descriptive Statistics [NO_3-N]						
	N	Mean	SE Mean	Standard Deviation	Minimum	Maximum
AR Daily Flux [kg ha^{-1}]	2	0.10	0.08	0.12	0.02	0.19
CT Daily Flux [kg ha^{-1}]	2	0.15	0.07	0.10	0.08	0.22

Table 10. Additional analysis of select nutrients during cover crop growth.

Descriptive Statistics						
	N	Mean	SE Mean	Standard Deviation	Minimum	Maximum
AR NO_3-N [mg L^{-1}]	2	3.55	0.37	0.52	3.19	3.92
CT NO_3-N [mg L^{-1}]	2	4.27	0.02	0.02	4.25	4.28
AR PO_4-P [mg L^{-1}]	2	0.02	0.01	0.01	0.02	0.03
CT PO_4-P [mg L^{-1}]	2	0.03	0.01	0.01	0.02	0.04
AR NO_3-N / TN	2	0.86	0.02	0.03	0.84	0.88
CT NO_3-N / TN	2	0.89	0.06	0.09	0.83	0.96
AR PO_4-P / TP	2	1.00	0.76	1.07	0.24	1.76
CT PO_4-P / TP	2	0.67	0.58	0.82	0.09	1.24

5.3.4 Following Cover Crop Termination, Early Vegetative Maize Growth

The cumulative NO_3-N flux losses following cover crop termination was greater for the annual rye treatment than the conventional tillage treatment (Figure 17). This was likely due to the greater rate of flow from the annual rye treatment which led to a greater volume of flow for each rain event and a longer period of flow following rain events. The annual rye treatment would provide a less resistant flow path for water and nutrients to the subsurface drainage tiles by way of root channels created by the rye grass and undisturbed macropore channels. At this time there were also greater evaporation losses from the conventional tillage plot due to reduced residue cover. Nitrate-N flux values can be seen in Table 11.

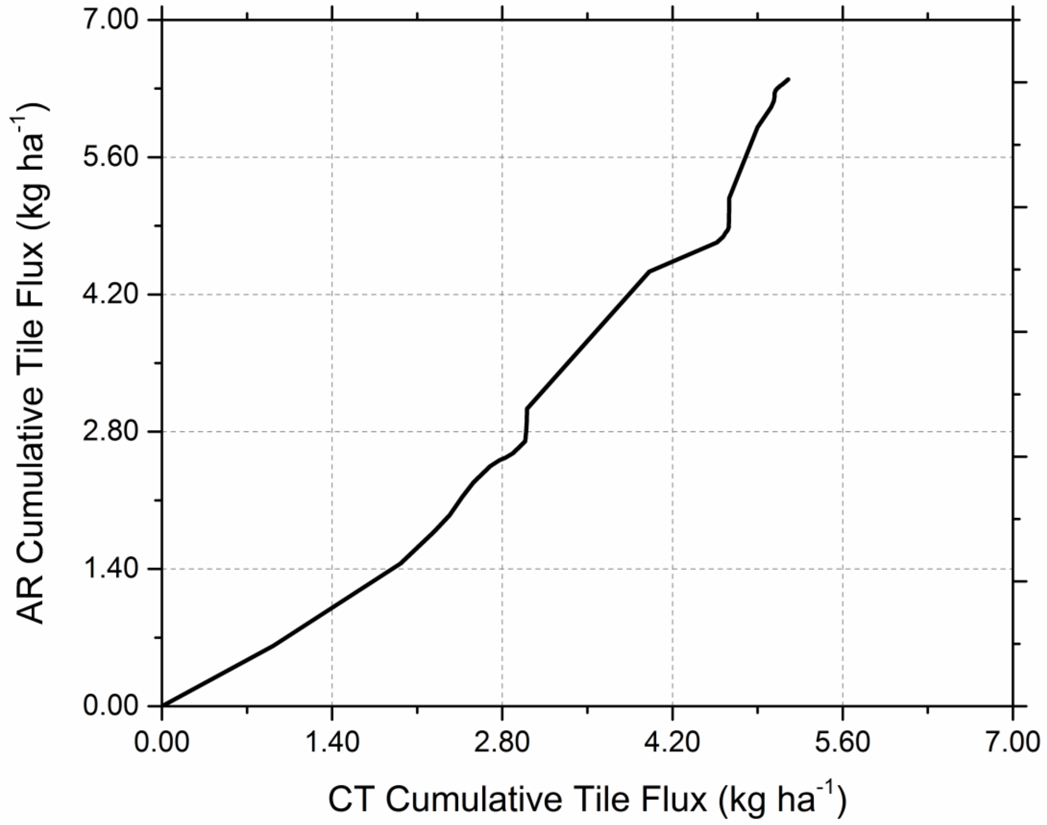

Figure 17. Double mass curve of cumulative NO_3-N flux for period April 19 – June 18, 2015 comparing conventional tillage (CT) to annual rye (AR).

The annual rye treatment had a significantly lower NO_3-N concentration than the conventional tillage treatment during the period immediately following cover crop termination to full canopy of the following maize crop. Larger NO_3-N concentrations from the conventional tillage treatment are likely due to a combination of stimulated mineralization caused by conventional tillage and the lower flow rates observed for this period of study. The lower nitrate values from the annual rye treatment were likely a combination of greater dilution from more water storage in the soil and also the immobilizing effect annual rye residue breakdown would have had on available soil nitrogen. Table 12 compares cover crop and conventional treatment NO_3-N for April 19 – June 18, 2015.

Other select nutrient analysis were performed for the period April 19 – June 18, 2015 (Table 12). The annual rye treatment had a higher mean concentration of PO_4-P. Given these sites have similar fertility management histories, the best viable conclusion for the annual rye treatment having a higher PO_4-P concentration is its losses through macropore channels, which had been left uncompromised due to no tillage practices. The nitrate/total nitrogen ratios were very similar between the two treatments for this period of the study. The phosphorus/total phosphorus ratios are lower for the annual rye treatment than the conventional treatment; however, the ratios in the maximum column again returned impossible ratios greater than 1. Given that PO_4-P is supposed to be filtered immediately and analyzed soon after collection, it is possible that the methodology of storying samples in the autosampler for periods of up to a week or more exacerbated the lab analysis.

Table 11. Comparing NO_3-N flux for period April 19 – June 18, 2015.

Descriptive Statistics [NO_3-N]						
	N	Mean	SE Mean	Standard Deviation	Minimum	Maximum
AR Daily Flux [kg ha^{-1}]	25	0.1285	0.0608	0.3042	0.0009	1.3986
CT Daily Flux [kg ha^{-1}]	30	0.0729	0.0377	0.2063	0.0000	1.0044

Table 12. Select nutrient analysis for period April 19 – June 18, 2015.

Descriptive Statistics						
	N	Mean	SE Mean	Standard Deviation	Minimum	Maximum
AR NO_3-N [mg L^{-1}]	25	3.28	0.21	1.04	1.94	7.06
CT NO_3-N [mg L^{-1}]	30	5.07	0.17	0.93	3.55	7.55
AR PO_4-P [mg/L]	24	0.07	0.01	0.07	<MDL	0.31
CT PO_4-P [mg/L]	27	0.05	0.01	0.03	<MDL	0.11
AR NO_3-N / TN	8	0.79	0.05	0.14	0.53	0.95
CT NO_3-N / TN	8	0.79	0.04	0.12	0.62	0.96
AR PO_4-P / TP	8	0.454	0.138	0.39	0.142	1.30
CT PO_4-P / TP	10	0.71	0.131	0.413	0.35	1.75

5.3.5 Late Vegetative and Reproductive Maize Growth Stages

The analysis of the late vegetative and early reproductive stages, from June 19 – July 21, 2015, of the maize crop represented a period in which soil evaporation values could be assumed to have negligible differences between the two treatments. The maize of both treatments had grown to a stage that, by visual confirmation, would have provided equal shading of the soil surface and a more similar evapotranspiration coefficient. For this stage the cumulative NO_3-N flux losses were greater for the conventional tillage treatment than the annual rye treatment (Figure 18).

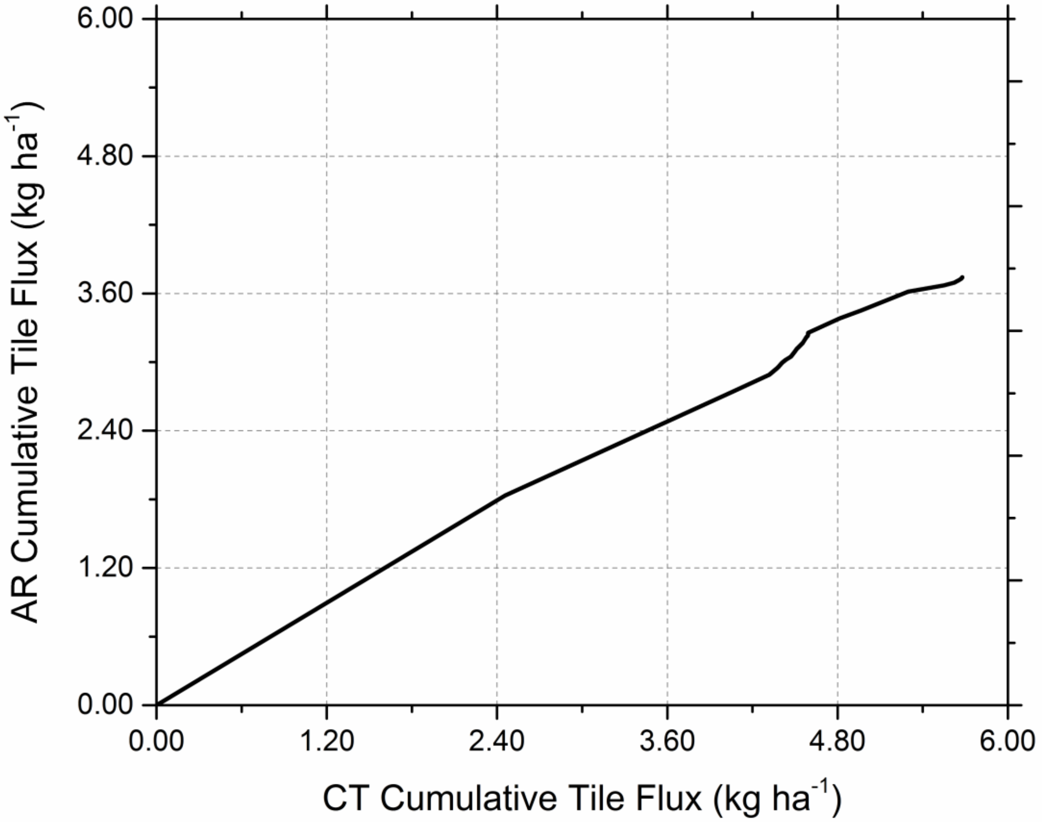

Figure 18. Double mass curve of cumulative NO_3-N flux for June 19 – July 21, 2015 comparing conventional tillage (CT) to annual rye (AR).

In the late stages of the season, the conventional tillage treatment had higher NO_3-N flux losses than the cover crop treatment (Table 13). During this period, similar to pre cover crop termination, the conventional tillage treatment had a higher NO_3-N concentration (Table 14) and also a slightly higher water volume lost (Figure 13). The combination of the two resulted in a greater nitrate flux for the conventional tillage treatment.

The conventional tillage treatment had higher mean concentration of NO_3-N during late season vegetative and reproductive growth stages. Additional nitrogen from mineralization that is caused by tillage in combination with the immobilization of nitrogen during breakdown of annual rye residues are the most likely contributors to larger NO_3-N concentrations in the conventional treatment. It is most likely that nitrates had slowly been leaching down the profile from tillage practices in the early spring, and the nitrates lost later in the season were from early season losses below the root zone. This period also marked the highest concentrations of NO_3-N, likely as a result of soil warming and mineralization, nitrogen fertilizer applications, and adequate rainfall to move nitrogen from the surface layers of soil to the subsurface layer where the drainage tile rests.

Although the mean nitrate concentrations were greater for the conventional tillage treatment, the last samples collected for the study were of values 3.72 and 2.88 mg/L NO_3-N for the annual rye and conventional tillage treatment, respectively. Not only had the concentrations fallen back to more equal levels for the two treatments, but the conventional tillage treatment had a lower concentration than the annual rye treatment and marked one of only three days throughout the study in which a lower nitrate concentration was obtained for the conventional tillage treatment. The other two occurrences were on the second to last day of water collection, and a rainfall measuring greater than 2.54 cm followed starter fertilization and cover crop termination.

The treatments again showed values of equal PO_4-P concentrations (Table 14), but the values have increased as the season has progressed. Given the plots received a lower phosphorus application than what is taken up by the plant during a growing season (15 lbs applied compared to 101 lbs P_2O_5 uptake), it is hard to reason why the phosphorus values would be increasing.

Table 13. Nitrate-N flux for June 19 – July 21, 2015.

Descriptive Statistics [NO_3-N]						
	N	Mean	SE Mean	Standard Deviation	Minimum	Maximum
AR Daily Flux [kg/ha]	17	0.2090	0.1140	0.4690	0.0060	1.8340
CT Daily Flux [kg/ha]	18	0.2970	0.1540	0.6540	0.0000	2.4570
Difference [kg/ha]	16	-0.1191	0.0552	0.2210	-0.6971	0.0154

Table 14. Select nutrient analysis for period June 19- July 21, 2015.

Descriptive Statistics						
	N	Mean	SE Mean	Standard Deviation	Minimum	Maximum
AR NO_3-N [mg/L]	17	4.50	0.39	1.62	2.56	8.23
CT NO_3-N [mg/L]	18	5.82	0.42	1.79	2.88	10.16
AR PO_4-P [mg/L]	16	0.08	0.01	0.03	0.03	0.12
CT PO_4-P [mg/L]	16	0.07	0.01	0.03	0.02	0.11
AR NO_3-N / TN	7	0.86	0.04	0.10	0.73	0.97
CT NO_3-N / TN	7	0.82	0.05	0.14	0.59	1.06
AR PO_4-P / TP	9	0.97	0.07	0.21	0.61	1.43
CT PO_4-P / TP	7	1.37	0.37	0.97	0.59	3.35

5.4 Crop Nutrient Uptake

Crop nutrient uptake can be determined by proper plant sample collection and analysis. It can be used to determine nutrient use efficiency of soil supplied nutrients and applied fertilizers under specific weather and crop rotations.

5.4.1 Annual Rye

The cover crops in this study were used as a resource to scavenge available soil nitrogen. This process would be used as a measure to reduce leaching and denitrification losses. This plant nitrogen would then be utilized in the following maize crop. Table 15 shows certain characteristics of the growing cover crop prior to termination and the expected plant available nitrogen (PAN) to be released to the maize crop.

An important characteristic of plant material is the carbon to nitrogen ratio. A commonly accepted value of less than 20 is expected to mineralize nitrogen. The annual rye was slightly less than the 20 ratio, thus it would be expected to mineralize nitrogen. Most of the nitrogen that was absorbed by the actively growing cover crop is not considered PAN, and the amount of nitrogen considered PAN is minimal. However, small amounts of fertilizer nitrogen had significant impacts on final yields.

Table 15. Annual Rye Nutrient Uptake.

Annual Rye							
Plot ID	Soil	Above Ground BM	C:N ratio	Total-N	Total-P	Total-N	PAN*
		kg ha^{-1}		kg ha^{-1}	kg ha^{-1}	%	kg ha^{-1}
1	453A	1004	19.7	21.8	3.5	2.17	5.6
4	453A	1100	19.7	23.9	3.8	2.17	6.1
5	453A	794	19.7	17.2	2.8	2.17	4.4
6	453A	1084	19.7	23.5	3.8	2.17	6.0
7	50A	1345	17.4	32.7	5.1	2.43	9.9
8	50A	1078	17.4	26.2	4.1	2.43	7.9
9	50A	1091	17.4	26.5	4.1	2.43	8.0
10	50A	1072	17.4	26.0	4.1	2.43	7.9
12	453A	846	19.7	18.4	3.0	2.17	4.7
13	453A	923	19.7	20.0	3.2	2.17	5.1
14	453A	930	19.7	20.2	3.3	2.17	5.2
11	50A	1055	17.4	25.6	4.0	2.43	7.8

*Plant available Nitrogen (PAN) is calculated using formula [1] (Sullivan et al., 2011).

5.4.2 Maize at Relative Maturity

The analysis performed from the aboveground portion of maize show the potential variability of a hybrid when the growing conditions are varied by tillage and soil nitrogen fertility (Table 16). For every conventional tillage treatment, plant uptake of nitrogen exceeded the fertilizer application rate of nitrogen. These results are consistent with the stimulated mineralization and elevated leaching losses observed in the drainage water analysis. The value for sample MC20 of 425 kg ha^{-1} is much greater than the applied amount. This higher uptake is likely due to greater N supply and uptake from soil mineralization, but could be attributed to improved plant and root vigor from an application rate sufficient to meet crop demands throughout the season whereas the other plants were nitrogen limited. The lower leaves in the other test plots had more visible senescence whereas there was very little observed in the high nitrogen rate conventional plot, likely a response of remobilizing nutrients to support grain fill. Although there was a much greater value of nitrogen in the MC20, the yield was only slightly higher than MC76 and VR20. Therefore, yield potential was not limited by nitrogen, but some other variable. Conventional tillage treatments also resulted in a greater plant biomass and phosphorus uptake when compared to annual rye treatments. However, there was an exception of the Virden soil at the 177 kg ha^{-1} nitrogen rate, VR76, took up more phosphorus than the conventional treatment but this is most likely due to the lower stand count of the conventional plot at the 177 kg ha^{-1} rate, MC76. Yields are discussed more thoroughly in Yield Analysis. Harvest index (HI) for most of these samples was greater than recorded values in one recent study (Bender et al., 2012). The high HI reflects the remobilization of nutrients from the stalk and leaves to support ear development and grain fill, a variable that is likely dependent upon the specific hybrid.

The highest yield of 16,842 kg ha^{-1}, accumulated 425 kg ha^{-1} and 47.1 kg ha^{-1} of nitrogen and phosphorus. However, a yield of 16,653 kg ha $^{-1}$ was observed with nitrogen values of 219.7 and 31.6 kg ha^{-1} of N and P respectively and is a reminder of the variability in nutrient uptake and ability of modern hybrids to repartition limited nutrients and still achieve high yield levels. There should be a word of caution when trying to reach high yield levels on minimal nutrients as the remobilizing of nutrients leaves the stalk of the maize plant more vulnerable to stalk lodging, although excessive N also promotes stock lodging.

Table 16. Nutrient uptake of maize crop at relative maturity.

Sample ID	MC20	MR20	MC76	MR76	VR76	MC46	MR46	VR46	PMR20	PVR20	VR20	MC00	MR00	VR00
Soil	453A	453A	453A	453A	50A	453A	453A	50A	453A	50A	50A	453A	453A	50A
Management	CT	AR	CT	AR	AR	CT	AR	AR	AR	AR	AR	CT	AR	AR
NH3 Timing	Side	Side	Side	Side	Side	Side	Side	Side	Pre	Pre	Side	Side	Side	Side
N Rate (kg ha^{-1})	198	198	177	177	177	151	151	151	206	206	206	22.4	22.4	22.4
Biomass (g plant^{-1})	364.9	264.6	322.1	280.4	279.3	299.1	240.7	211.5	286.5	300.3	258.3	128.7	161.4	143.7
Harvest Stand (plant ha^{-1})	83194	79899	75780	79899	83194	81546	78252	81546	77428	78252	78252	72486	79075	63425
Biomass (Mg ha^{-1})	30.36	21.14	24.41	22.41	23.24	24.39	18.84	17.25	22.19	23.50	20.21	9.33	12.76	9.11
Plant Moisture (%)	46.2	49.3	48.4	53.0	53.7	52.1	49.7	48.3	50.2	40.6	52.2	49.6	52.6	56.5
Total N (%)	1.4	0.9	0.9	0.9	0.8	0.9	0.7	0.8	0.9	0.9	0.8	0.6	0.5	0.5
Total P (%)	0.28	0.25	0.19	0.2	0.25	0.23	0.21	0.19	0.22	0.22	0.21	0.21	0.25	0.23
Carbon (%)	44.58	45.01	44.7	44.22	44.46	44.15	44.86	44.51	44.62	44.72	44.37	44.21	43.83	43.84
Yield (kg ha^{-1})	16842	15379	16653	14444	14732	16026	13703	13866	15323	15417	16390	5756	3452	3346
Biomass-N (kg ha^{-1})	425.0	190.3	219.7	201.7	185.9	219.5	131.9	138.0	199.7	211.5	161.7	56.0	63.8	45.6
Biomass-P (kg ha^{-1})	47.1	38.4	31.6	28.9	36.8	36.9	28.8	28.3	33.7	33.9	34.4	12.1	8.6	7.69
Harvest Index	0.47	0.61	0.58	0.54	0.54	0.56	0.61	0.68	0.58	0.55	0.69	0.52	0.23	0.31

5.5 Yield Analysis

A producer will likely make management decisions such as hybrid selection, fungicide and pesticide applications, and/or a tillage practice based on the historical yields. For dryland row crop production, yield returns will fluctuate year by year with weather, but management is likely decided from long term average returns. However, it is necessary with the accelerated improvements of hybrids and technologies to compare standard practices every year.

5.5.1 Comparing Tillage Treatments

Figure 19 represents yield results comparing conventional tillage to annual rye treatments at four side dress nitrogen rates. These yields only reflect 453A soil, Muren silt loam. Conventional tillage had higher yields than annual rye at all nitrogen rate when looking at the trials in plots 11-14 (Figure 2). In a year where nitrogen rate had a significant impact on final yields, the extra available nitrogen caused by stimulated mineralization from tillage generated greater yields. When comparing the 151 kg ha^{-1} (135 lb ac^{-1}) N side dressed treatments to the control of 22.4 kg ha^{-1} (20 lb ac^{-1}) N, the initial increase in yield was 77.8 and 79.3 kg ha^{-1} per kg ha nitrogen (1.38 and 1.4 bu ac^{-1} lb N^{-1}) for the annual rye and conventional tillage treatments, respectively. The conventional tillage treatment had a higher control yield and here was still more benefit for the first 128 kg ha^{-1}. However, there was a yield plateau reached for conventional tillage at the nitrogen rate of 198 kg ha^{-1} (177 lb ac^{-1}) signifying there was a limited benefit from additional nitrogen for this trial beyond 177 kg ha^{-1} (158 lb ac $^{-1}$).

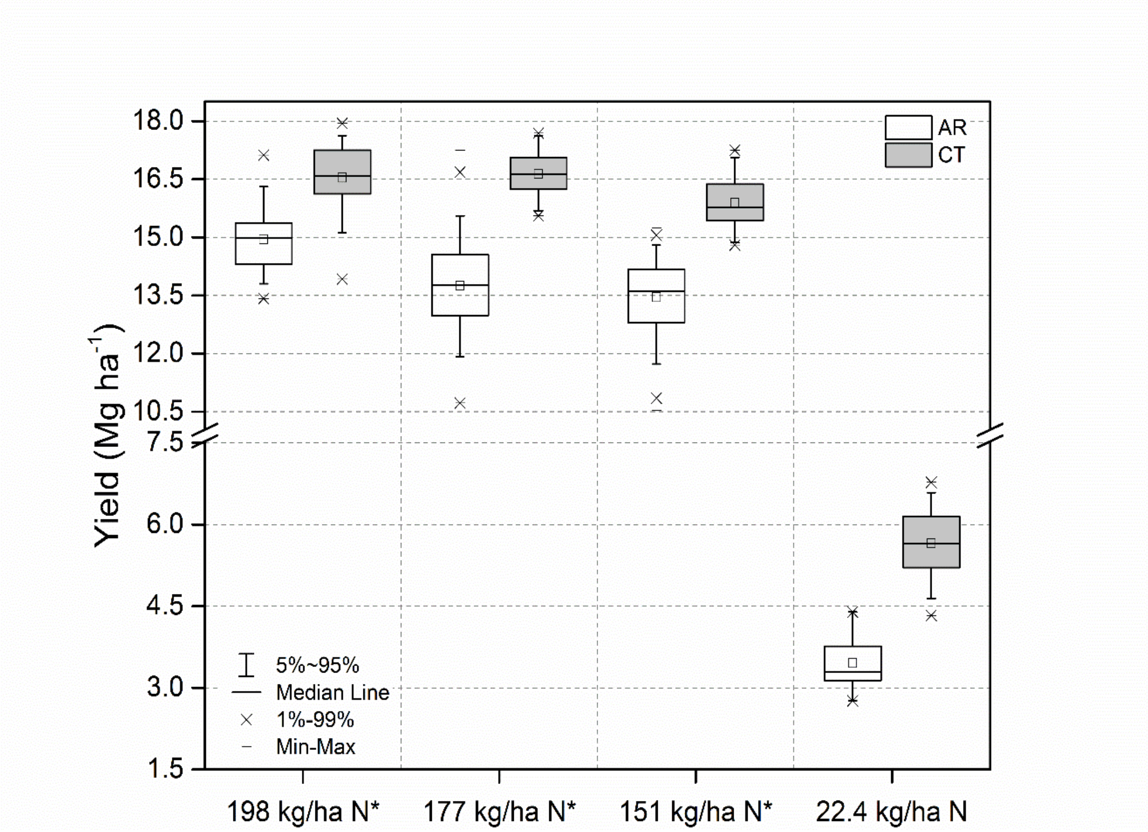

Figure 19. Yield results comparing conventional (CT) and annual rye (AR) treatments at multiple nitrogen fertilizer rates. *Anhydrous ammonia applied as side-dress

5.5.2 Comparing Soil Types

The 50A and 453A soil types are different at many levels, but most notably in organic matter content and soil fertility levels. The comparison of each nitrogen rate was one method of determining whether soil fertility had an effect on yield response. It was very fortunate to have the maize planted and emerged uniformly at the close interval between preseason nitrogen applications and planting. This growing maize likely took up much of the nitrified nitrogen and minimized losses of nitrogen from leaching, but also allowed a good comparison for nitrogen rates and yield trials.

Figure 20 represents annual rye treatments at 2 timings, 4 rates, and compares the soil types (see Figure 2, annual rye only). For both soils, greater nitrogen rates resulted in greater yields. There are little differences between yields the Virden (50A) to Muren (453A) soil types. Preseason nitrogen applications (totals of 206 kg ha^{-1}) had the highest yields with this comparison. It is possible that applying fertilizer more than a month earlier resulted in greater losses than sidedress nitrogen, but the yields did not reflect significant nitrogen losses. Not only did the preseason nitrogen application result in the highest grain yield, there was an increase in yield per unit of nitrogen applied.

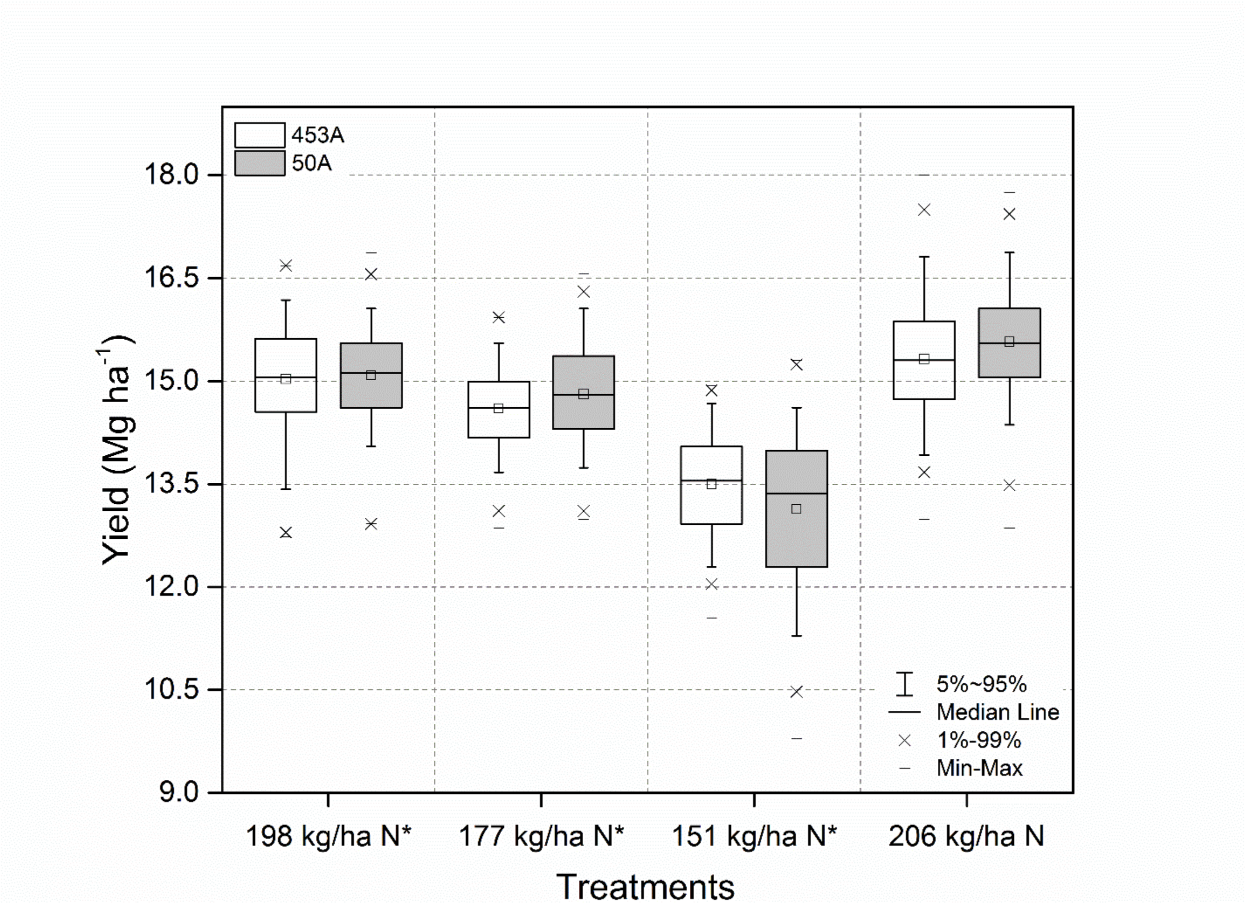

Figure 20. Yield comparisons for two soil types, both cover-cropped soils.
*Anhydrous ammonia applied at side-dress.

5.5.3 Comparing All Treatments

With the pairing of geospatial technologies in the combine with a program such as ArcMAP™ it was possible to break up the original 14 plots and two tillage treatments into many more divisible plot IDs and compare yield differences at a more detailed level.

Table 17. Subplot yield analysis, yield table 1 of 2.

Yield										
Plot ID	**N Rate**	**Soil ID**	**Tillage**	**Mean**	**SE Mean**	**St Dev**	**Q1**	**Median**	**Q3**	**N**
	kg/ha			**kg/ha**	**kg/ha**	**kg/ha**	**kg/ha**	**kg/ha**	**kg/ha**	
9_East*	177	453A	CT	16992	169	565	16572	16823	17450	11
12_East*	198	453A	CT	16842	107	590	16383	16823	17325	31
14_West*	177	453A	CT	16653	100	559	16258	16634	17074	31
9_East*	177	50A	CT	16609	188	603	16195	16603	17074	10
8_West*	206	50A	AR	16390	69	647	16007	16446	16823	89
12_West*	198	453A	CT	16258	163	916	15630	16258	17199	31
13_East*	151	453A	CT	16026	119	684	15505	15818	16603	32
10_West*	151	453A	CT	15994	113	502	15756	16007	16258	19
7_East	206	50A	AR	15969	69	722	15505	16007	16415	109
6_East	206	453A	AR	15881	264	596	15348	15756	16478	5
6_East	206	50A	AR	15850	94	816	15191	15881	16509	77
8_West*	206	453A	AR	15818	201	496	15272	15944	16245	6
13_West*	151	453A	CT	15774	107	590	15335	15756	16258	32
9_West*	177	50A	CT	15737	151	596	15429	15944	16164	16
5_West	206	50A	AR	15712	119	847	15065	15944	16245	48
5_West	206	453A	AR	15636	144	986	15097	15567	16446	45
5_East	206	50A	AR	15473	163	1036	14814	15505	16069	41
4_West	206	50A	AR	15423	100	766	14940	15316	15881	61
6_West	206	50A	AR	15423	107	734	14877	15379	15787	49
7_West	206	50A	AR	15417	63	621	15021	15379	15881	108
4_West	206	453A	AR	15398	119	785	14845	15253	15850	41
3_East*	198	453A	AR	15379	82	577	14971	15316	15787	49
9_West*	177	453A	CT	15354	132	352	15065	15253	15630	7
4_East	206	453A	AR	15323	107	640	14927	15285	15881	38
5_East	206	453A	AR	15297	157	1092	14375	15379	16182	50
3_East*	198	50A	AR	15297	107	665	14783	15285	15630	40
10_East*	151	453A	CT	15272	126	697	14751	15442	15712	30
8_East*	198	50A	AR	15260	75	615	14720	15316	15818	69
12_East*	198	453A	AR	15184	100	747	14689	15191	15693	55
9_East*	177	50A	AR	15153	82	684	14657	15191	15661	69
4_East	206	50A	AR	15134	94	722	14689	15191	15567	57
6_West	206	453A	AR	14902	132	716	14437	14751	15536	29
3_West*	198	453A	AR	14852	100	879	14249	14877	15505	77
2_West*	177	453A	AR	14802	69	621	14437	14814	15191	82
7_East	206	453A	AR	14783	31	44	NA	14783	NA	2

Table 17 (cont.). Subplot yield analysis, yield table 2 of 2.

Plot ID	**N Rate**	**Soil ID**	**Tillage**	**Mean**	**SE Mean**	**St Dev**	**Q1**	**Median**	**Q3**	**N**
	kg/ha			**kg/ha**	**kg/ha**	**kg/ha**	**kg/ha**	**kg/ha**	**kg/ha**	
9_West*	177	50A	AR	14732	69	590	14281	14751	15128	70
14_West*	177	453A	AR	14632	100	847	14174	14563	15210	70
12_West*	198	453A	AR	14619	107	647	14048	14532	15128	36
3_West*	198	50A	AR	14601	126	728	14124	14626	15191	35
2_West*	177	50A	AR	14569	138	716	14124	14469	15159	28
12_West*	198	50A	AR	14557	195	722	14343	14657	14958	14
2_East*	177	50A	AR	14550	144	791	14092	14500	15034	29
2_East*	177	453A	AR	14444	56	527	14061	14437	14783	81
10_West*	151	50A	AR	13866	75	621	13496	13872	14312	73
1_East*	151	50A	AR	13803	138	722	13276	13810	14343	28
13_East*	151	453A	AR	13803	94	778	13389	13935	14362	72
1_East*	151	453A	AR	13703	82	690	13138	13872	14186	76
1_West*	151	50A	AR	13351	144	734	12805	13433	13810	27
1_West*	151	453A	AR	13333	88	734	12868	13370	13747	72
13_West*	151	453A	AR	13113	132	1092	12178	13056	14029	70
14_East*	177	453A	AR	12918	94	816	12448	12994	13496	72
10_East*	151	50A	AR	12115	94	822	11632	12021	12711	72
11_West*	22	453A	CT	5756	113	653	5367	5712	6277	32
11_East*	22	453A	CT	5555	100	571	5053	5587	5932	33
11_East*	22	453A	AR	3452	132	534	3139	3296	3766	16
11_West*	22	50A	AR	3346	82	508	2950	3327	3735	41
11_East*	22	50A	AR	2856	113	552	2636	2762	3264	23

*Anhydrous ammonia applied at side-dress.

When the yield data were broken into all appropriate trials, it is worth noting that conventional tillage was an attribute of seven out of the top ten yield averages. If the yield is divided by the nitrogen rate, the average weight return per kg of nitrogen applied (excluding the control plots of 22 kg N (20 lb N acre^{-1})) were 94 and 78 kg ha $^{-1}$ grain per kg ha^{-1} nitrogen, respectively (1.7 and 1.4 bu lb^{-1} N) for the conventional tillage and the annual rye treatment. For this experiment, under the weather conditions of 2015, it is possible to conclude that growing an annual rye winter cover crop required a larger amount of applied nitrogen per unit of grain. For the nitrogen rates, the conventional tillage plot was close to its yield plateau at the 198 kg/ha nitrogen rate, but without a greater nitrogen rate it cannot be determined if the yield could have increased. The annual rye was still continuing to increase in yield at the side-dress nitrogen application rate (206 kg/ha), therefore it remains uncertain what nitrogen rate was needed for the crop to reach its plateau.

5.6 Soil Analysis

In order to maintain high levels of production, it is necessary to analyze soils for certain soil fertility levels. Most commonly analyzed are the macronutrients phosphorus, potassium, and quality measures such as organic matter, pH, and CEC. However, it is becoming more common to measure the soil nitrogen levels for reasons such as return on input, yield goals, and concerns of losses into the environment. Not only are soils being tested for their current status of nitrogen, but there are tests available to estimate what will be available throughout the season due to mineralization. The following sections describe the organic matter, soil nitrate, soil phosphate, and the Illinois Soil Nitrogen Tests (ISNT) levels of the plots. It is worth noting that the sample date of the 0-76 cm samples, September 20, 2015 or the end of the maize nutrient uptake, was different than the March 20-21, 2015 sample date of the other sample depths.

5.6.1 Organic Matter Analysis by Depth

A measurement of soil quality can be determined by measuring the soil organic matter. Table 18 compares organic matter values by soil, management, and depth. The soil analysis for the 0-15, 15-46, and 0-76 cm depths returned greater organic matter values for the annual rye treatment. This could be from the annual rye creating enough organic carbon to raise organic matter content, it could be the conventional tillage losing organic matter, or a combination of both. No measurable differences were observed for the 46-76 cm depth. The cool fall, winter, and spring, could have limited the root growth of the annual rye and limited its root depth. The 0-76 cm samples were taken at relative maturity of the maize crop and show that even after the termination and breakdown of the annual rye crop, there could potentially be greater organic matter retained in the soil.

The Virden soil type has a greater organic matter percentage at every depth than the Muren soil. Virden was formed under prairie grass and is expected to have a higher organic matter content than the Muren soil type which was formed under forest.

Table 18. Organic matter analysis by depth.

Organic Matter							
Soil	**Management**	**Depth**	**N**	**Mean**	**StDev**	**Min**	**Max**
		cm		**%**	**%**	**%**	**%**
453A	AR	0_15	8	1.06	0.14	0.87	1.32
453A	AR	15_46	8	0.57	0.21	0.30	1.02
453A	AR	46_76	8	0.38	0.12	0.19	0.52
453A	CT	0_15	8	0.97	0.20	0.62	1.20
453A	CT	15_46	8	0.63	0.15	0.39	0.80
453A	CT	46_76	8	0.42	0.11	0.25	0.55
50A	AR	0_15	6	1.31	0.18	1.14	1.58
50A	AR	15_46	6	0.87	0.18	0.61	1.12
50A	AR	46_76	6	0.58	0.14	0.36	0.70
50A	CT	0_15	3	1.18	0.12	1.08	1.31
50A	CT	15_46	3	0.65	0.26	0.47	0.94
50A	CT	46_76	3	0.44	0.07	0.39	0.52
453A	AR	0_76*	5	0.57	0.04	0.53	0.62
453A	CT	0_76*	4	0.51	0.08	0.42	0.58
50A	AR	0_76*	5	0.74	0.10	0.57	0.84

*Represents end of season sampling analysis

5.6.2 Soil Nitrate Analysis by Depth

Nitrogen is the most common yield limiting nutrient in maize production. The levels of nitrate in the soil can be used to predict nitrogen fertilizer response and can be a precursor of leaching losses. See Table 19 for soil nitrate values.

At all depths and both timings, soil nitrate levels for the annual rye treatment were lower than the conventional tillage treatment. This could be due to annual rye taking up available soil nitrogen and immobilizing it, the conventional tillage stimulating mineralization and nitrification, or a combination of both. This is significant because the lower levels in the annual rye treatment likely contributed to the lower nitrate leaching losses. The conventional tillage treatment having more available nitrate in the early stages of crop growth likely impacted the early vigor of the maize plants and improved final yield results. Nitrate values were greater in the Virden than the Muren soil for all depths, presumable reflecting increased organic matter that led to greater mineralization and nitrification.

Table 19. Soil nitrate values.

Soil Nitrate							
Soil	**Management**	**Depth**	**N**	**Mean**	**StDev**	**Min**	**Max**
		cm		**ppm**	**ppm**	**ppm**	**ppm**
453A	AR	0_15	8	1.80	0.42	1.20	2.40
453A	AR	15_46	8	1.11	0.41	0.70	1.90
453A	AR	46_76	8	0.98	0.23	0.70	1.40
453A	CT	0_15	7	2.20	1.07	1.30	4.40
453A	CT	15_46	6	1.67	0.38	1.20	2.30
453A	CT	46_76	7	1.36	0.22	1.10	1.70
50A	AR	0_15	5	3.12	1.29	1.90	5.10
50A	AR	15_46	5	1.18	0.08	1.10	1.30
50A	AR	46_76	5	1.44	0.80	0.60	2.30
50A	CT	0_15	3	2.73	0.45	2.30	3.20
50A	CT	15_46	2	1.15	0.07	1.10	1.20
50A	CT	46_76	3	0.97	0.06	0.90	1.00
453A	AR	0_76*	5	0.90	0.21	0.60	1.10
453A	CT	0_76*	4	0.95	0.17	0.80	1.20
50A	AR	0_76*	5	1.14	0.29	0.90	1.50

*Represents end of season sampling analysis

5.6.3 Soil Phosphate Analysis by Depth

The routine analysis of soil phosphorus levels and maintenance by fertilization is an important management practice in row crop agriculture in the Midwest United States. Phosphorus is also the limiting factor for algae growth in fresh water systems, thus over applying can result in losses and environmental consequences.

There was only one sample in the annual rye treatment group which had a soil phosphorus analysis return a value similar to the conventional tillage treatment samples. This was the 15-46 cm depth for the Virden soil. All other annual rye soil sample analysis averages were lower than conventional tillage. The annual rye took up very little phosphorus as determined by plant analysis (Table 15), therefore the phosphorus could have been made available by the physical processes of tillage. Lab results were inconclusive on phosphorus losses, but the additional phosphorus made available by tillage could have resulted in improved early season plant vigor and could have helped improved final yields.

The Virden soil type had a more soil P_1-P than did the Muren at all depths except the 46_76 cm depths. Given Virden is a higher organic matter soil, it would have a higher level of mineralizable phosphorus and return greater PO_4-P values over time; however, the lower levels at the deeper depth are contradictory to this suggestion. It is possible the deeper depths of the Virden soil type hold excess water and prevent mineralization or the greater clay percentage ties up phosphorus before it can leach to lower depths.

Table 20. Soil P_1 results.

Bray P_1							
Soil	**Management**	**Depth**	**N**	**Mean**	**StDev**	**Min**	**Max**
		cm		ppm	ppm	ppm	ppm
453A	AR	0_15	8	20.46	17.10	11.30	61.80
453A	AR	15_46	6	3.05	3.43	0.60	9.90
453A	AR	46_76	7	2.43	2.04	0.50	5.40
453A	CT	0_15	7	24.94	6.64	15.80	35.00
453A	CT	15_46	7	4.81	2.62	1.40	9.00
453A	CT	46_76	5	2.36	2.09	0.30	5.40
50A	AR	0_15	5	29.38	14.29	9.90	44.80
50A	AR	15_46	5	4.90	5.94	1.30	15.40
50A	AR	46_76	4	1.13	0.62	0.30	1.80
50A	CT	0_15	3	35.50	12.57	21.90	46.70
50A	CT	15_46	2	3.05	0.35	2.80	3.30
50A	CT	46_76	1	1.20	*	1.20	1.20
453A	AR	0_76*	5	3.96	3.37	1.80	9.80
453A	CT	0_76*	4	4.05	2.27	2.40	7.30
50A	AR	0_76*	5	4.06	2.27	1.80	7.60

*Represents end of season sampling analysis

5.6.4 Illinois Soil Nitrogen Test Analysis by Depth

The fundamental value of the ISNT is that it is an outlook of the potential mineralization capacities of the soil done with a simple analysis. It can be at least 2 – 3 year sampling interval much like all the other routine sampling measures or longer intervals up to 4 – 8 years.

Soil ISNT levels were greater in the surface 0-15 cm (0-6 inch) samples of the annual rye treatment than the conventional treatment. This could be due to the greater organic matter present in the surface of the annual rye treatments. Further evidence that supports organic matter affecting the ISNT test values is the analysis of the Virden soil type having a greater ISNT level at all depths when comparing results to the Muren soil.

The Virden soil type was not consistently higher yielding than the Muren soil type. This is not reflective of having a higher soil fertility or a greater ISNT test. It is possible that the wet growing season was not the best growing environment for Virden, and that it lost more nitrogen from denitrification than the Muren soil type. See soil drainage factor in Figure 1. It is commonly accepted organic matter results in a greater mineralization, but a greater loss due to denitrification would have negated these added nutrients. Overall, yields were similar between the soil types and soil ISNT values had no apparent effect on final yields.

Table 21. Soil ISNT test levels.

Illinois Soil Nitrogen Test							
Soil	**Management**	**Depth**	**N**	**Mean**	**StDev**	**Min**	**Max**
		Inches		ppm	ppm	ppm	ppm
453A	AR	0_15	8	163	25	123	197
453A	AR	15_46	8	81	27	43	131
453A	AR	46_76	8	81	60	24	208
453A	CT	0_15	7	152	60	69	252
453A	CT	15_46	6	83	20	64	107
453A	CT	46_76	6	87	61	33	175
50A	AR	0_15	5	208	64	158	320
50A	AR	15_46	5	141	42	97	211
50A	AR	46_76	5	73	21	49	102
50A	CT	0_15	3	160	9	151	169
50A	CT	15_46	2	117	13	107	126
50A	CT	46_76	1	176	*	176	176
453A	AR	0_76*	5	97	12	77	109
453A	CT	0_76*	4	88	13	72	103
50A	AR	0_76*	5	111	18	84	132

*Represents end of season sampling analysis

Chapter 6. Conclusions

The purpose of this research was to develop a field experiment that would provide scientific data either supportive or contradictive of claims that wide-spread adoption of winter cover cropping practices would improve land and water resources. The research also serves as a fundamental level of management guidance and practical applications for producers who are asked to successfully grow a cash crop following winter cover. It was made possible through the support of the local farm's land and equipment resources and also the blessing of cooperative weather. Given that the objectives of the study were to compare yield responses for multiple nitrogen rates and analyze the water through tile drainage, the weather could not have been better. Excess rainfall created tile flow through mid-July but also provided the maize crop with adequate moisture to reach a yield potential that was restricted by nitrogen rates tested in the experiment. The greatest challenges of this field study were to quickly provide a plan of action for unexpected rain events and transform a large amount of data into understandable and practical results for a broad audience.

6.1 Comparing Tillage Treatments and Nitrogen Rates

At all nitrogen application rates, conventional tillage out yielded the annual rye treatment when the soil type was isolated to the 453A Muren Soil. The yield return for each pound of nitrogen applied decreased as nitrogen rates increased, following the law of diminishing returns. The reductions were more apparent for the conventional tillage than the cover-cropped treatments, likely due to a more adequate supply made available through increased levels of soil organic matter mineralization by mechanical tillage in the conventional treatment. Possible immobilization of nitrogen by the carbon supplied by the cover crop residue likely reduced the availability of nitrogen for the maize crop following the annual rye, which reduced yields.

6.2 Comparing Soil Fertility, Nitrogen Rates, and Yield Response

The soil types reflected the baseline soil fertility. The 50A, Virden, was more fertile than the 453A, Muren Soil especially with respect to ISNT results. There were, however, very negligible correlations with yield and soil fertility. An unusually wet June could have resulted in prolonged periods of saturation and ultimately increased denitrification rates in the slower draining Virden. The losses would have been offset by the greater mineralization and yields were similar as a result. Weather and especially rainfall plays such a large role in the success or failure of soil tests.

6.3 Drainage Water Comparison

The cumulative values of nitrogen flux and average nitrate concentration between the two treatments of conventional tillage and annual rye cover crop duration of the season resulted in a greater nitrogen flux and higher nitrate concentration for the conventional tillage treatment. When comparing the total flow, the annual rye treatment had a greater cumulative flow than the conventional tillage. It is questionable whether the phosphorus samples returned accurate lab analysis given the duration of time they sat idle in the autosamples before being analyzed.

When the season was segregated into different periods based on evapotranspiration coefficients, the nitrogen flux values were less for the cover crop while the annual rye was actively growing, greater for cover crop for the period following annual rye termination through maximum crop canopy, and lower in the late stages of vegetative growth through relative maturity. Nitrate concentrations were greater for the conventional tillage treatment than the annual rye treatment until the final two dates of water analysis, meaning that conventional tillage increased nitrate leaching for a period up to eight months following first tillage practice.

Chapter 7. Recommendations for Future Work

7.1 Long-Term Analysis

Given the fluctuation of weather on a year-to-year basis, it would be best to conduct a long term analysis of the land and water resources that are affected by a cover crop study. A long term study would provide better feedback to growers regarding managing cropping practices more appropriately relating to weather events and seasonal fluctuations.

7.2 Multidisciplinary Handling of Data

It was quite challenging to handle data from soil, water, and crops. To provide data back to farmers in a timely manner, it must be quickly analyzed, summarized and communicated among the many specialized areas of research involved. This is especially important given the rapid improvements to modern crops.

7.3 Utilize Growers

The most cost-efficient manner of conducting a field study is to utilize growers. This will provide a broadened and dynamic source of weather and soil variability necessary in providing scientifically supported guidelines for a greater number of farmers utilizing different management practices. This will be important in developing guidelines for the ISNT or other new soil tests.

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Appendix A

Table A. 1. Subplot yield analysis in English units, yield table 1 of 2.

Yield										
Plot ID	**N Rate**	**Soil ID**	**Tillage**	**Mean**	**SE Mean**	**St Dev**	**Q1**	**Median**	**Q3**	**N**
	lb/ac			**Bu/ac**	**Bu/ac**	**Bu/ac**	**Bu/ac**	**Bu/ac**	**Bu/ac**	
9_East*	158	453A	CT	270.7	2.7	9.0	264.0	268.0	278.0	11
12_East*	177	453A	CT	268.3	1.7	9.4	261.0	268.0	276.0	31
14_West*	158	453A	CT	265.3	1.6	8.9	259.0	265.0	272.0	31
9_East*	158	50A	CT	264.6	3.0	9.6	258.0	264.5	272.0	10
8_West*	184	50A	AR	261.1	1.1	10.3	255.0	262.0	268.0	89
12_West*	177	453A	CT	259.0	2.6	14.6	249.0	259.0	274.0	31
13_East*	135	453A	CT	255.3	1.9	10.9	247.0	252.0	264.5	32
10_West*	135	453A	CT	254.8	1.8	8.0	251.0	255.0	259.0	19
7_East	184	50A	AR	254.4	1.1	11.5	247.0	255.0	261.5	109
6_East	184	453A	AR	253.0	4.2	9.5	244.5	251.0	262.5	5
6_East	184	50A	AR	252.5	1.5	13.0	242.0	253.0	263.0	77
8_West*	184	453A	AR	252.0	3.2	7.9	243.3	254.0	258.8	6
13_West*	135	453A	CT	251.3	1.7	9.4	244.3	251.0	259.0	32
9_West*	158	50A	CT	250.7	2.4	9.5	245.8	254.0	257.5	16
5_West	184	50A	AR	250.3	1.9	13.5	240.0	254.0	258.8	48
5_West	184	453A	AR	249.1	2.3	15.7	240.5	248.0	262.0	45
5_East	184	50A	AR	246.5	2.6	16.5	236.0	247.0	256.0	41
4_West	184	50A	AR	245.7	1.6	12.2	238.0	244.0	253.0	61
6_West	184	50A	AR	245.7	1.7	11.7	237.0	245.0	251.5	49
7_West	184	50A	AR	245.6	1.0	9.9	239.3	245.0	253.0	108
4_West	184	453A	AR	245.3	1.9	12.5	236.5	243.0	252.5	41
3_East*	177	453A	AR	245.0	1.3	9.2	238.5	244.0	251.5	49
9_West*	158	453A	CT	244.6	2.1	5.6	240.0	243.0	249.0	7
4_East	184	453A	AR	244.1	1.7	10.2	237.8	243.5	253.0	38
5_East	184	453A	AR	243.7	2.5	17.4	229.0	245.0	257.8	50
3_East*	177	50A	AR	243.7	1.7	10.6	235.5	243.5	249.0	40
10_East*	135	453A	CT	243.3	2.0	11.1	235.0	246.0	250.3	30
8_East*	177	50A	AR	243.1	1.2	9.8	234.5	244.0	252.0	69
12_East*	177	453A	AR	241.9	1.6	11.9	234.0	242.0	250.0	55
9_East*	158	50A	AR	241.4	1.3	10.9	233.5	242.0	249.5	69
4_East	184	50A	AR	241.1	1.5	11.5	234.0	242.0	248.0	57
6_West	184	453A	AR	237.4	2.1	11.4	230.0	235.0	247.5	29

Table A. 1 (cont.). Subplot yield analysis in English units, yield table 2 of 2.

Plot ID	**N Rate**	**Soil ID**	**Tillage**	**Mean**	**SE Mean**	**St Dev**	**Q1**	**Median**	**Q3**	**N**
	lb/ac			**Bu/ac**	**Bu/ac**	**Bu/ac**	**Bu/ac**	**Bu/ac**	**Bu/ac**	
3_West*	177	453A	AR	236.6	1.6	14.0	227.0	237.0	247.0	77
2_West*	158	453A	AR	235.8	1.1	9.9	230.0	236.0	242.0	82
7_East	184	453A	AR	235.5	0.5	0.7		235.5		2
9_West*	158	50A	AR	234.7	1.1	9.4	227.5	235.0	241.0	70
14_West*	158	453A	AR	233.1	1.6	13.5	225.8	232.0	242.3	70
12_West*	177	453A	AR	232.9	1.7	10.3	223.8	231.5	241.0	36
3_West*	177	50A	AR	232.6	2.0	11.6	225.0	233.0	242.0	35
2_West*	158	50A	AR	232.1	2.2	11.4	225.0	230.5	241.5	28
12_West*	177	50A	AR	231.9	3.1	11.5	228.5	233.5	238.3	14
2_East*	158	50A	AR	231.8	2.3	12.6	224.5	231.0	239.5	29
2_East*	158	453A	AR	230.1	0.9	8.4	224.0	230.0	235.5	81
10_West*	135	50A	AR	220.9	1.2	9.9	215.0	221.0	228.0	73
1_East*	135	50A	AR	219.9	2.2	11.5	211.5	220.0	228.5	28
13_East*	135	453A	AR	219.9	1.5	12.4	213.3	222.0	228.8	72
1_East*	135	453A	AR	218.3	1.3	11.0	209.3	221.0	226.0	76
1_West*	135	50A	AR	212.7	2.3	11.7	204.0	214.0	220.0	27
1_West*	135	453A	AR	212.4	1.4	11.7	205.0	213.0	219.0	72
13_West*	135	453A	AR	208.9	2.1	17.4	194.0	208.0	223.5	70
14_East*	158	453A	AR	205.8	1.5	13.0	198.3	207.0	215.0	72
10_East*	135	50A	AR	193.0	1.5	13.1	185.3	191.5	202.5	72
11_West*	20	453A	CT	91.7	1.8	10.4	85.5	91.0	100.0	32
11_East*	20	453A	CT	88.5	1.6	9.1	80.5	89.0	94.5	33
11_East*	20	453A	AR	55.0	2.1	8.5	50.0	52.5	60.0	16
11_West*	20	50A	AR	53.3	1.3	8.1	47.0	53.0	59.5	41
11_East*	20	50A	AR	45.5	1.8	8.8	42.0	44.0	52.0	23