THE USE OF NITROGEN TIMING AND NITRIFICATION INHIBITORS AS TOOLS IN CORN AND WHEAT PRODUCTION IN KANSAS

by

TIMOTHY J. FOSTER

B.S., Kansas State University, 2012

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Agronomy
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2014

Approved by:

Major Professor
David B. Mengel

Copyright

Abstract

World population, together with the cost of crop production inputs, is increasing rapidly. The current seven billion people on earth are expected to reach nine billion by 2050 with resulting demands on world food production. In addition, the quality of our environment is being impacted by human activities, including agricultural production and crop fertilization. Nitrogen (N) management is the process of applying N fertilizers in a way to maximize use of N by crops, while minimizing loss to the environment. It is becoming imperative, as a means of increasing crop yields and food supplies, while reducing input usage, and minimizing the impact of N fertilization on the quality of our environment, that improved N application practices be identified and utilized. The objectives for this study were to compare the timing of anhydrous ammonia (AA) fertilizer N applications, fall and spring, with and without two different nitrification inhibitors (NI) as possible tools to enhance yield and Nitrogen Use Efficiency (NUE) in corn (*Zea mays*) and winter wheat (*Triticum aestivum L.)* in Kansas. Two different nitrification inhibitors were tested as alternatives, N-Serve (nitrapyrin) produced and marketed by Dow AgroSciences, and an experimental product under development by Koch Agronomic Services LLC. Three differing rates of the experimental product were used to assist in determining the optimal rate for this product. The study was conducted over two growing seasons, 2012 and 2013, which differed significantly in rainfall, rainfall distribution, and resulting NUE. Experiments were established at three sites for both crops in both years, on sites/soils selected for differing potentials for N loss, and mechanisms of N loss. One site was established at the Kansas State University Agronomy North Farm (N Farm), where yield potential was high, and N loss potential was low. A second site was established under irrigation at the Kansas River Valley Experiment Field near Topeka, KS (KRV), on a coarse silt loam soil with high potential for N loss through leaching. The third site was established at the East Central Kansas Experiment Field near Ottawa KS (ECK), on a clay pan soil with a high potential for denitrification loss. Weather conditions together with soil characteristics played a major role in the performance of N timing applications and impacted the response to the use of the inhibitors. In low N loss environments such as the N Farm, fall applications of AA to increase spring time-availability for producers showed minimal negative effects on yield or NUE. When combined with a nitrification inhibitor in the fall, performance was similar to spring application for both

corn and wheat. At the KRV site leaching loss or potential loss from fall application was high for corn and wheat in both years, however little impact on NUE with NI use was observed. At the high ECK denitrification site, there was only one N loss potential event leading to inhibitor performance at Ottawa in corn in 2013.

Table of Contents

List of Figures

List of Tables

Acknowledgements

I would like to acknowledge and thank those who have assisted me in my college career, in pushing me to further myself and my education. I would like to thank Koch Industries for their financial contributions to my education and the research conducted. Also, I would like to thank my major professor Dr. Dave Mengel for his support, advice, and mentoring to help mold and shape me into the professional agronomist I have grown to become. Another key player in my Master's career has been my good friend and colleague Ray Asebedo who I would like to thank for providing encouragement, assistance, and bit of good humor during the thick of it. Furthermore, I would like to acknowledge the members of my committee, Dorivar Ruiz Diaz and Eric Adee, and thank them for their guidance and assistance in the success of my research. Additionally, those who provided field support, assisting in ways that made the operation smooth and successful, include our assistant scientist Garry Harter, fellow graduate student Robert Florence, and student workers Tasha Foster, Jacob Havercamp, Tyler Gardner, Kelsey Girvin, Sarah Tatarko, and Travis Denison. Likewise, research stations that provided an immense level of assistance include the Kansas River Valley Research Station and the East Central Research Station. From these research stations, I would especially like to thank Bill Riley, Charlie Clarke, and Jim Kimball for their dedicated assistance in the daily tasks and maintenance of the studies. Each individual played a key role in the overall completion of my education, and without them, it would not have been possible.

Dedication

First and foremost, I would like to dedicate my work to the One who made all things possible, my Heavenly Father. He instilled within me the abilities, desires, and experiences to complete the task set before me. Also, He provided the loving support of family. Tasha, my wife, has been an inspiration and encouragement ever since I have known her. My parents have provided a lifelong experience of teaching and guidance for daily life. Without their commitment toward my success, I would not be at the place I am today. My father, George Foster, instilled the concept of strong work ethic and enjoyment of work for which I am truly grateful. My mother, Debbie Foster, was my teacher from K-12, guiding me toward diligence and attention to detail in my work. Lastly (but not least), my grandfather, Walter McGrath, has been ever so supportive of my education, providing wisdom and direction in the path in which to take. All of which I am exceedingly appreciative for, resulting in my desire to dedicate my thesis work to each one of them.

Chapter 1 - Factors Involved in Nitrogen Management: A Review of Literature

Introduction

Nitrogen (N)…what is it? Where is it found? What benefits does it provide? How is the environment impacted by its usage? These questions are very challenging to answer due to the nature in which N resides in our planet. Seventy-nine percent of the earth's atmosphere consists of N_2 gas. Nitrogen is also found in plant available forms, as well as, forms unavailable to plants. Nitrogen is one of the three primary macronutrients essential for plant growth. When present as nitrate, it is the most mobile macronutrient of the three, N, P, and K. But when present as ammonium, it is retained on the soil's cation exchange capacity and can be stored in soils. It, also, is needed in one of the largest quantities among the essential elements in many plants. As a result, N is indeed a crucial element for plant and animal growth, and deserving of extensive research to understand the transformations which can occur, and its movement through soil to air, plants, and water.

How does one manage such a diverse element in nature? In agriculture, the key portion of the ecosystem is at the soil level; the area plants exploit to extract N for growth, where fertilizer is placed, and where key transformations in N forms occur. So many interactions occur within the soil-plant interface. Microbial populations of many differing degrees thrive in the soil and network with both plants and soil, changing the forms of available N, as well as, moving available forms of N into unavailable forms. With the constant transformation of N in mind, nitrogen management is the practice of implementing strategies with the goals in mind of increasing optimal production potential, input efficiency and environmental protection. (Griffith and Murphy, 1991) Each of these goals is very important and they work hand in hand. The goal of agriculture is to provide food for the ever-increasing human population with the limited resources as its disposal, keeping in mind the effects on the environment.

Environmental Impacts

Lost N from the soil system can be found in different chemical forms in the atmosphere, groundwater, and large bodies of surface water. Nitrogen in the wrong place, wrong form, or wrong concentrations can have detrimental effects on our environment and the organisms that inhabit it. Nitrogen in the form of N_2O, a gaseous form of N released from the surface of soils, contributes to stratospheric ozone depletion. It is an intermediate product of denitrification produced when low O_2 levels do not allow for the complete transformation of NO_3^- to N_2 (Firestone and Davidson, 1989). N_2O emission is just one example of harmful effects to the environment that can result from too much N in the wrong area or wrong form at the wrong time.

Another example where N in the wrong place can have a negative impact on our environment is the leaching of N as nitrate in groundwater, lakes, or rivers. Movement of high levels of NO_3^- into a water system can have a negative effect on the fish habitat, as well as, reduce the quality of drinking water for humans. Death is a possibility from high concentrations of nitrate in the water found in these habitats. Eutrophication is the "*condition in an aquatic ecosystem where excessive nutrient concentrations result in high biological productivity, typically associated with algae blooms, that cause sufficient oxygen depletion to be detrimental to other organisms"* (Glossary of Soil Science Terms, 2013). Also, human infants have the possibility of dying from consuming high concentrations of nitrate in the drinking water by a disease termed methaemoglobinemia. This disease, given the common name "blue baby syndrome", is a result of the decreased ability of blood to move oxygen through the body (World Health Organization). These are only a few examples of detrimental effects of an overabundance of N under the misplaced circumstances. Thus, the environmental impacts of N in the wrong place, wrong concentration, and wrong form can be extremely detrimental to our planet. As a result, N management strategies to reduce the loss of N from soils and resulting environmental impacts are and should be a priority for the agricultural community.

Nitrogen Use Efficiency

The world population is growing rapidly, and is expected to reach 9 billion people by 2050. At the same time, tillable land to produce food is decreasing due to urbanization, salinization, erosion, and other issues. Thus, yields produced per hectare must nearly double by 2050 to meet the food demands of our growing world. Nitrogen fertilizers will play an important role in that increased production. However, concerns with excessive usage of N in the production of food throughout the world, and subsequent environmental problems are an issue of great apprehension. Nitrogen management, as a result, has become an issue of great importance. The concept of nitrogen use efficiency (NUE) measures how efficiently both N fertilizers and naturally occurring N additions to the soil are utilized. It is a means of measuring the portion of applied or naturally available N supplied is used by a target crop. Also, NUE is a means to define the impact of N fertilization on productivity in crop production as kilograms of crop produced per kilogram of N applied or available. Thus managing N to maximize NUE means N is being taken up and utilized in the most effective way possible.

NUE levels worldwide were assessed to be around 33% using the following NUE calculation: NUE = [(total N removed) – (Soil N + Rainfall N)]/(Applied Fertilizer N) (Raun and Johnson, 1999). This quantity is very concerning, as it implies that 67% of the available N to a crop is either lost from the soil or remains in the soil and could be potentially lost. Nitrogen Use Efficiency in some areas of the world are substantially better. In Kansas, for example, an NUE value of 50% is routinely used in making N rate recommendations for corn (Mengel, Personal Communication). Work in wheat in Kansas has shown that NUE is also commonly in the 50% range, with an additional 30% of the applied N being incorporated into the soil organic fraction (Swallow and Olson, 1985). Thus actual N loss from the soil system was less than 20%. By utilizing appropriate N management techniques to decrease losses and increase NUE, crop yields can be enhanced and N losses reduced, for the improvement of our planet and the survival of mankind.

4R Concept

One tool or system developed to focus on decreasing N loss, environmental impact, and increasing NUE is called the 4R's. The components of the 4R's are the following: right product, right rate, right time, and right place (Roberts, 2007). This is a site–specific management concept that matches together fertilizer source, crop need, soil properties, N rate, application timing, and placement of N to maximize utilization by the crop and minimize N loss. A number of tools at our disposal have been shown to work at specific times and places to enhance NUE. However, research has proven them not to work in all situations, but have a site-specific value. These include N fertilizer placement, application timing, slow or controlled release fertilizers, urease inhibitors, nitrification inhibitors, and different N sources. As a result, it is crucial to keep location in mind when making management decisions.

N Cycle: Loss Mechanisms

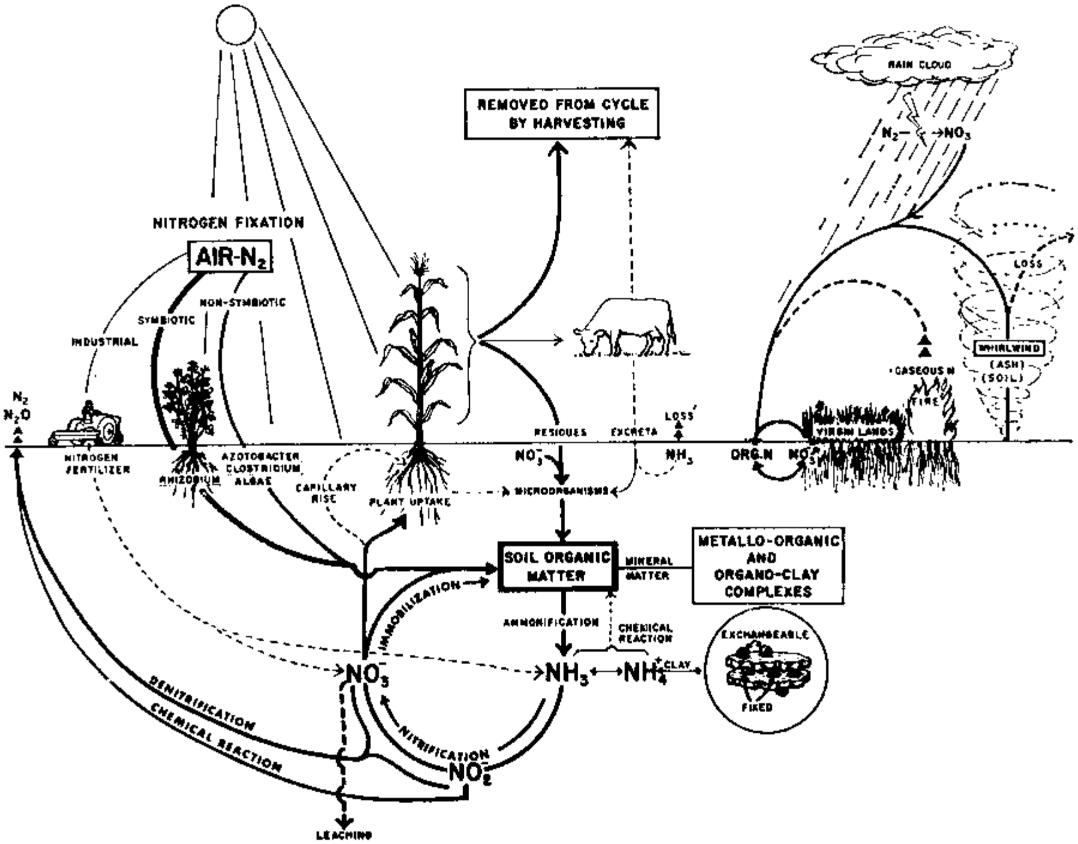

Figure 1.1 N Cycle (Stevenson, et. al, 1965)

The complexity of N in the environment is shown in Figure 1.1 above. This schematic illustrates the main factors involved in the additions of N to the soil system, some of the transformations and sites of retained N in the soil, and movement or loss of N from the soil to the atmosphere or water. Losses of N from the crop root zone are the main dynamic reducing the efficiency of nitrogen fertilizer applications. The major factors involved in truncated levels of NUE and reduced availability of nitrogen to the plant by movement from the root zone include volatilization, denitrification, leaching, and immobilization.

Volatilization: How It Works

According the Soil Science Society of America Glossary, the definition of ammonia volatilization is "*the mass transfer of nitrogen as ammonia gas from soil, plant, or liquid systems to the atmosphere*". Right placement and right source play a role in the loss of N through volatilization. Ammonia volatilization is primarily a problem associated with surface applied urea or urea-containing fertilizers. Past research with urea fertilizers found losses of N as NH_3 to exceed 40% in surface applied applications with no incorporation (Fowler and Brydon, 1989). Soil, environment, and management factors influence the level of volatilization that occurs in a system.

Soil factors that affect the level of ammonia loss include soil pH and buffering capacity. With increasing pH levels, more volatilization occurs due to the increase in NH_3 concentration present in the soil solution at high pH. However, with the increase in buffering capacity of a soil, volatilization decreases (Ferguson, et.al, 1984). With the variation of buffering capacity between soil types, the level of volatilization between locations will vary. Soils with high buffering capacity have the ability to preserve reduced volatilization levels, while pH levels are high. As a result, buffering capacity is the major soil factor affecting the amount of volatilization.

Environmental factors that influence NH_3 loss include temperature, soil-water content, precipitation, and air exchange. Temperatures greater than 4°C, wet soil conditions with a drying period, precipitation events less than 0.63 cm of rain, and increasing wind speed under moist soil conditions all contribute to an increase in volatilization (Hargrove, 1988). All of these environmental factors work hand in hand. With cold, dry weather conditions and little evaporation of soil water, there is low potential for N loss. Surface evaporation is a major carrier of NH_3 volatilization so factors that enhance water evaporation will also enhance volatilization.

Lastly, management factors that affect volatilization include nitrogen source, rate, application method, and residues. Urea-containing fertilizers and anhydrous ammonia both have high potentials for volatilization losses. Increasing rates of N of these sources, broadcasting on the surface, and applying under high residue systems will increase the potential for N loss through volatilization (Ernst and Massey, 1960). Shallow application of ammonia and inadequate sealing of the ammonia application slot will also lead to volatilization. With proper N management strategies that target the high loss mechanisms of volatilization, a reduction in N loss is possible. Incorporation (right place) of the fertilizer will decrease the losses from volatilization substantially. While soil, environmental, and management factors affect how much N is lost via mass transfer of NH_3 gas from the soil to the atmosphere, proper incorporation or subsurface application will significantly decrease volatilization loss. In reference to source of the 4R concept, usage of products that have a decreased concentration of N in the urea form will reduce volatilization losses. In a study conducted in Indiana, granular urea was compared to a very acid forming co-granulated urea-urea phosphate, urea-ammonium nitrate (UAN) solution, and prilled ammonium nitrate. Reduced N losses from volatilization were found with the urea-urea phosphate and no loss was found from ammonium nitrate. Volatilization loss per unit of urea was similar from liquid UAN and granular urea (Keller and Mengel, 1986). Proper management of volatilization losses can foster increased NUE levels in the agricultural sector which, in turn, will benefit mankind.

Denitrification

According to the Soil Science Society of America Glossary (2013), the definition of denitrification is the "*reduction of nitrogen oxides (usually nitrate and nitrite) to molecular nitrogen or nitrogen oxides with a lower oxidation state of nitrogen by bacterial activity (denitrification) or by chemical reactions involving nitrite (chemodenitrification). Nitrogen oxides are used by bacteria as terminal electron acceptors in place of oxygen in anaerobic or microaerophilic respiratory metabolism.*" As a result of this reduction, there is a loss of plant available N. Losses vary with environment; research has measured losses from 0 to 70% of the total applied N (Firestone, 1982). Three major factors that affect the amount of denitrification that occurs in the soil are carbon levels, oxygen levels, and temperature. There are many other factors that affect the growth and activity of the bacteria populations linked to reducing nitrate in soil, however, carbon, oxygen, and temperature are the key elements.

Organic matter is the food source for microbial populations. Increasing its levels will increase the level of microbial populations in the soil. Research has shown there is a positive relationship between soil organic matter and denitrification (Bremner and Shaw, 1958). The presence of soil amendments such as manure or plant residue also greatly increases denitrification in the soil (Guenzi, et al., 1978).

Parallel to SOM as a major contributor to denitrification, oxygen levels in the soil also play a role in the extent as to how much N is utilized by bacteria populations. Denitrification is amplified under reduced oxygen concentrations. Studies have shown O_2 levels lower than 0.2 *u*g cm^{-2} min^{-1} to have a substantial increase in denitrification (Brandt, et. al, 1964). Moisture content and soil texture are two major factors influencing how much oxygen is found in soil. The soil is composed of particles with differing sizes and pores of differing sizes. Pores are the open spaces between soil particles which are able to hold either air or moisture. As soils decrease in particle size, porosity size decreases, while the number of pores increase. With the decrease in soil particle size, water percolation rate decreases, resulting in extended periods of waterlogged soils under wet conditions. As oxygen levels decrease with increasing moisture levels, higher potential for denitrification occurs. Water fills the pore spaces, pushing oxygen out of the system, and making suitable anaerobic conditions for the denitrifying bacteria populations to thrive (Craswell and Martin, 1974). As a result, higher potential for denitrification is seen in waterlogged, fine textured soils.

Temperature is another major factor involved in denitrification rates. Because denitrification occurs as the result of the breakdown of nitrate by bacteria populations, factors that influence the activity of the bacteria will influence the level at which denitrification occurs. Denitrification slows down to undetectable levels at temperatures below 10°C (Craswell, 1978). However, as temperature increases, biological activity increases exponentially (Nommik, 1956). Maximum temperatures in which denitrification occurs has been observed at around 75°C, while optimum temperatures occur in the range of 49–66°C (Bremner and Shaw, 1958). From the research conducted on the effect of temperature on denitrification, applications of N in temperatures below 10°C will potentially reduce major losses through the denitrification process due to the reduced activity of the bacteria in the soil. Denitrification occurs in the nitrate form, not the ammonium form. Most fertilizer N sources currently on the market are in the ammonium form when applied. As a result, there is a lag window of reduced N loss from denitrification from the applied fertilizer after initial application. The fertilizer must be transformed in soil by the nitrification process prior to the possible occurrence of denitrification.

Denitrification rates are linked to the viability and activity of the anaerobic bacteria populations in the soil. High OM, waterlogged, poorly drained soils with temperatures greater than 10°C are optimal conditions for loss of N through denitrification.

Timing and source are two critical management components involved in reducing the denitrification loss mechanism. Making timely applications targeting periods when the conditions for denitrification as discussed above are not optimal, will lower loss potential. When one of the factors like high temperatures or low O_2 levels are removed from the system via timing of the year or weather conditions, denitrification will be drastically reduced. The practice of side-dressing N during the growing season is one example of this concept. Making N available for plant uptake with reduced probability of wet periods is the idea behind side-dressing.

Leaching

Leaching is defined as the "*removal of soluble material from one zone in soil to another via water movement in the profile*" (Glossary of Soil Science Terms, 2013). In the N cycle as discussed earlier, the main N form lost by leaching in soils is NO_3^-. The amount of nitrate that is moved out of the profile is affected mainly by soil type and climate. High rainfall events increase the potential for leaching. However the rate of loss varies with soil structure/texture. Soils with coarse textures and large pore sizes will increase the potential for leaching (Mulla and Strock, 2008). As the infiltration and percolation rate increases in the soil, the movement of water increases the movement of soluble nitrate with it. There are many management strategies available to reduce the risk of high potential losses from this loss mechanism.

In order to reduce losses of N from leaching, application of fertilizer should be moved closer to the time of crop uptake. Research is moving toward multiple 'spoon-fed' applications of N to help reduce losses. This is included in the 4R concept of timing.

Immobilization

"*The conversion of an element from the inorganic to the organic form in microbial or plant tissues*" is the description for immobilization transcribed by the Soil Science Society of America Glossary (2013). Immobilization removes N from the plant-available pool for a time period. N is not lost forever; it will mineralize out in the future and be once again available to the plant (Bartholomew, 1965). However, it makes management more interesting because one must account for the loss of this available N, while expect the mineralization of available N in the future. Organic matter and mineral material binds most of the N normally located in the soil (Stevenson, et. al, 1965).

Factors that affect the level of immobilization include the amount of residue, the C:N ratio of the residue, and factors affecting microbial activity such soil temperature and moisture. High amounts of high carbon residue increase immobilization of N and removal from the plant available pool. Microbial populations utilize the N provided, to reproduce and take advantage of the energy source provided by the residue, breaking down the residue and tying up the N. By moving the N away from these microbial populations and residue, removal from the inorganic stage will be reduced. The C:N ratio of the residue plays an important part in managing how much N is moved out of the available form. C:N ratios of 25:1 or less found in such plant residues as legume crops do not require additional N from the soil profile for the microbial breakdown process (Brady and Weil, 2009). However, under higher C:N ratios, microbes demand additional N, resulting in immobilization of plant available N. As a result, an understanding of differing crop residues is a key aspect involved in management of immobilization. No-till systems with high levels of wide C:N residue are systems potetntially leading to increased immobilization, making it an issue of great concern.

The 4R concept critical in controlling immobilization is right placement. As much as 21% of surface applied N has been tied up through immobilization in a no-till system, which was double that compared to a tilled system (Rice and Smith, 1984). Subsurface application of N also is beneficial for reducing immobilization. In no-till systems, reduced immobilization can be achieved by knifing or banding fertilizer to minimize contact with residue (Mengel, et. al, 1982).

Anhydrous Ammonia as a Fertilizer Source

With N deficiency being a major limiting factor in the growth of plants across the world, commercial fertilizers have been used and are greatly needed to assist in maximizing yield potential of a crop. In the Midwest, a cheap commercial fertilizer that has been used as a major source of N is Anhydrous Ammonia (AA). AA has been desired for its limited mobility in the soil in comparison with other N products. The conversion of AA into the plant available form NH_4^+ produces a very stable N form in the soil. AA (NH_3) is a compound containing one nitrogen atom and three hydrogen atoms. It has a molecular weight of 17, very similar to water

(H_2O) which has a molecular weight of 18 (Sharp, 1966). As a result, these molecules work similar to each other as solvents and ionizing agents. These similarities also cause the molecules to compete in the soil for the cation exchange sites (CEC). CEC is a cation holding reservoir in the soil composed of permanent or variable negative charge. The permanent negative charge results from differing levels of positive charge from cations present in the structure of clay minerals, developing a force called isomorphic substitution which is unaffected by pH (Evangelou and Phillips, 2005). The negative charge developed from these forces is the core of the CEC, allowing cations such as NH_4^+, a form of ammonia, to be held in the soil with limited mobility until the plant requires it. As a result, ammonia is one of the preferred forms of commercial fertilizer in a system where high levels of N are applied to the soil at an extended period before the plant requires the resource. However, water affects the retention of NH_4^+ to the soil particle. Anhydrous ammonia still has potential to move in the soil which can be limiting to the efficiency of the product, as well as, a detriment to the environment if high levels move into the water supply. One factor that affects the movement of AA in soil is water content in the profile.

Ammonia is first applied in a band in the soil underneath the soil surface at a depth greater than 10 cm to limit the escape of the ammonia into the atmosphere and maximize sorption in the soil. Sorption is the process where ammonia transfers from a gaseous phase into a liquid phase (Brown and Bartholomew, 1962). Moisture is a major factor in keeping the ammonia in the soil by providing lubrication for the soil to close over the slot, which the equipment used to inject the ammonia into the soil made. Soils with a high level of clay are able to sorb ammonia effectively without the need for an extensive source of water (Brown and Bartholomew, 1962). One study showed that increasing moisture increased the initial capacity of soil to retain ammonia (Parr Jr. and Papendick, 1966). Keeping ammonia from escaping the slot is the main requirement for moisture at the time of application. If the slot is not properly sealed, higher ammonia volatilization losses will occur. The main emphasis of moisture is at the time of application when a high concentration of ammonia is applied. The soil system is thrown out of equilibrium and must quickly adapt and move back to equilibrium. Moisture assists in the movement back to the equilibrium.

After the NH_3 is applied to the soil, the possibility of four different reactions occurs to change NH_3 into NH_4^+. Reacting with exchangeable H^+, reacting with surface hydroxyls of clay lattices, reacting with dry exchangeable ions forming ammonates, or reacting with H_2O to form NH_4^+ which has limited mobility and is available to the plant (Brown and Bartholomew, 1962). With water being only one of the reactions converting ammonia to ammonium, there are three other reactions that are able to occur as well which allow ammonia to be applied in dry environments as long as the slot is closed at the surface after the fertilizer is applied.

Anhydrous Ammonia is an N source with many benefits. Proper care must be taken with the product to reduce initial loss, as well as, maximize future potential. AA has a reduced mobility in the soil until it is converted into the mobile nitrate form. Under dry environments, applications can still be made because the soil system will react with the ammonia and bind it to itself, in turn, reducing loss.

Nitrification

The nitrification process is an autotrophic oxidation process, carried out by chemolithotrophic bacteria, converting NH_4^+ to NO_2^- to NO_3^- (Frye, 2005). Nitrosomonas are the main type of bacteria affecting the nitrification process of conversion from NH_4^+ to NO_2^-. Nitrite is a mobile anion with potential to be very lethal in soil under conditions when linked with amines (Schmidt, 1982). However, in most system, nitrite is available only in very limited supply. Nitrite is transformed into nitrate by bacteria, mostly Nitrobacter. Nitrate is a highly mobile form of N that can lead to loss pathways of denitrification and leaching as discussed previously.

Nitrification can occur at a very rapid rate under proper conditions for microbial activity. Factors affecting nitrifying bacteria include the following: NH_4^+ levels, O_2 levels, H_2O levels, pH, and temperature. Ammonium is a necessity to the nitrification process. Nitrifying bacteria require O_2 for survival, unlike denitrifying bacteria, so situations that reduce the O_2 supply such as water-logged soils will inhibit the nitrification process. Also periods of very dry soil conditions reduce the level at which nitrification occurs (Alexander, 1960). Soil pH plays a role in the nitrification process. Optimal pH for nitrification occurs between 7-9 (Alexander, 1960). Also, temperatures below 4°C greatly limit the nitrification process (Anderson and Boswell, 1964). Peak nitrification occurs at temperatures in the range of 20-40°C, depending upon climate and soil type (Schmidt, 1982). Nitrification occurs in high levels only under warm, moist conditions with available ammonium in slightly acid to alkaline soils.

The importance of nitrification has been discussed above in the respect of N loss mechanisms. Nitrogen in the ammonium form is fairly immobile in the soil, while the product of nitrification, nitrate, is very mobile in the soil. Thus, keeping N in the ammonium form is important from the standpoint of reducing potential denitrification or leaching losses.

Nitrification Inhibitors

One method to retain N in the NH_4^+ form is the use of nitrification inhibitors. The concept behind the usage of nitrification inhibitors is to slow down the nitrification process by which NH_4 is converted to NO_3, allowing time for the plant to take up the N before major losses occur. By reducing the amount of N present in the mobile NO_3^- form for a longer period, the potential for increased nitrogen use efficiency is possible. There are only a few nitrification inhibitors on the market presently. N-Serve (nitrapyrin), Dwell (etradiazol), Entec (DMPP), and Guardian (DCD) are four nitrification inhibitors with different active ingredients that are being used or have been used. N-Serve is the only nitrification inhibitor registered for use with AA in the United States. Dwell was registered as a nitrification inhibitor in 1982, but since has been taken off the market (Nelson and Huber, 1992). DCD has been registered in the U.S. for usage with granular and liquid N products. It is not currently used with AA. DMPP is currently used in Europe and the manufacturer is considering the U.S. market. All of these products have potential, displaying different levels of success under differing conditions.

DCD

DCD is registered in the U.S., and is marketed by the Conklin Company for use with UAN or urea, and has been used with the urease inhibitor, NBPT, and marketed as the products, Agrotain Plus and Super U, by Koch Industries. Results of success are variable, as should be expected, based on soil, weather, and management factors dependent on conditions favorable for denitrification. In a study completed on wheat, mixed results occurred with the use of DCD applied with UAN (Scharf and Alley, 1995). One of the reasons for variable results by DCD is its phytotoxic effect. When taken up by the plant, DCD can reduce chlorophyll concentrations and plant growth. DCD inhibits the cytochrome oxidase system, which is a critical piece in the ammonia oxidation process by the Nitrosomonas bacteria. This process has potential effects on the structural integrity of the chloroplasts, potentially reducing plant growth (Reeves and Touchton, 1986). Potential for DCD phytotoxicity is reduced under lower rates. While effective as a nitrification inhibitor, the potential for expanded use of DCD is somewhat hindered due to its possible phytotoxic effect under certain conditions.

DMPP

DMPP has been synthesized and produced by BASF, but is not currently registered for use in the U.S. It is applied at rates 0.5-1.5 kg ha^{-1} on granular fertilizer products in Europe and marketed under the name Entec. Studies have been completed, comparing DCD to DMPP, and performance has been higher as measured by yields, with DMPP (Zerulla, et. al., 2001). Also, DMPP performed better under lighter soils and higher levels of precipitation. When there are higher levels of N loss, this product increased in performance. (Pasda, et.al , 2001) A study on wheat where Entec was applied with N prior to planting and then added again with top-dress N around Feekes 4-5 improved yield and grain uptake in a two year study (Villar and Guillaumes, 2010). DMPP shows promise for being a useful nitrification inhibitor product in the U.S.

N-Serve (Nitrapyrin)

Nitrapyrin (trade name N-Serve) is a nitrification inhibitor synthesized by Dow Agro-Sciences LLC. It has been proven to work under many conditions. Years of research have been completed on this product. A large amount of the research was summarized in a combined analysis by Jeffrey Wolt in 2004. Thirty-nine of the 50 research studies completed throughout different locations in the Midwest displayed a higher utilization of N with the addition of nitrapyrin (Wolt, 2004). Nitrapyrin is suspected to affect the nitrification process at the initial step where NH_4^+ is converted to NO_2^-. Nitrosomonas bacteria are the main component of the first step in the nitrification process, in which nitrapyrin focuses on controlling (Wolt, 2000). Nitrapyrin does not kill the bacteria; instead it inhibits their growth (Rodgers and Ashworth, 1982). By slowing their growth rate, they are unable to utilize as much NH_4^+ and as a result reduce the amount of NH_4^+ converted into NO_2^-. The level of bacteriostatic effect is variable due to environmental factors causing inconsistent results from usage of the nitrapyrin.

From the meta-analysis completed by Wolt, mixed results are shown under different environments. Factors that affect the success of nitrapyrin are pH, OM, temperature, and clay content (Touchton, et. al, 1979). The longevity of nitrapyrin in the soil is affected by these factors. Soils incubated at 20°C showed a half-life range for nitrapyrin of 9 to 16 days, while soils incubated at 10°C displayed a half-life range of 43 to 77 days (Herlihy and Quirke, 1975). Lower temperatures when Nitrosomonas bacteria are operating at a reduced rate allows nitrapyrin to provide a longer period of resistance. Work completed by Touchton in 1979 showed that nitrapyrin applied when soil temperatures were above 13°C reduced the effectiveness of Nitrosomonas control to an unsatisfactory level. Low OM levels also decrease the longevity of nitrapyrin in the soil (Touchton, et.al, 1979). Nitrapyrin is adsorbed to OM, holding it in the system for a longer period of time, and as a result, increasing its effectiveness. Similar to OM, clay content acts in a similar manner with similar results. pH is also a factor in nitrapyrin longevity; the higher the pH the higher the loss of nitrapyrin (Touchton, et. al, 1979). This result is partially due to the rapid increase in nitrification at the optimal pH between 7-9. As discussed above in the nitrification section, the optimal pH range for nitrification to occur is between pH 7 and pH 9. However, some soils are not affected as extensively, most likely correlated to the amount adsorbed. Adsorption sites decrease and bonds become weaker as pH increases resulting in greater loss and degradation of nitrapyrin (Touchton, et. al, 1979). Many different interactions occur in the soil affecting the longevity and performance of nitrapyrin.

Nitrapyrin has many pathways of loss if it is not sorbed by the soil clay particles or organic matter. Some potential avenues of loss are leaching through the profile, plant uptake, runoff, or volatilization (Wolt, 2000). It is critical that nitrapyrin be incorporated into the soil or it will rapidly volatilize given its physicochemical composition (Briggs, 1975). Moisture is a major factor affecting the runoff and leaching pathways. As moisture movement across and through the soil system increases, there is a higher loss potential. Also, the plant takes up small portions of nitrapyrin. If excessive rates of nitrapyrin are applied, plant growth may be reduced due to phytotoxicity. As a result, a negative effect can result if nitrapyrin is applied under the wrong conditions. However, plant uptake, runoff, leaching, and volatilization are all pathways of loss that minimize the effectiveness of nitrapyrin. These are all pathways of loss that increase the susceptibility to degradation when nitrapyrin is not sorbed to the soil (Touchton, et.al, 1978).

Variable results from the usage of nitrapyrin are effects of the wide array of loss pathways, the sensitivity to environmental factors like OM and temperature, as well as possibly a phytotoxic effect on the plant. If nitrapyrin is not sorbed quickly to the soil, it will be degraded quickly and have a reduced probability of success. Nitrapyrin has been shown to work, but not under all conditions.

Summary

Nitrogen is a complicated element to understand. It is found in many different forms, both available and unavailable to the plant. While extremely important for crop production as a fertilizer, if found in the wrong place at the wrong time or in the wrong concentration or form, its effect on the environment can be detrimental. It can be very mobile in the soil system when present as nitrate, yet can accumulate in organic forms. Losses from soils can be substantial in warm climates with high levels of moisture.

There are many available management strategies to help to reduce N losses. Two potential management strategies are time of N application and the usage of a nitrification inhibitor. Both hinge on the idea of higher levels of N in the NH_4^+ less mobile form. Fine-tuning N management systems to reduce N loss is critical for increased crop yield, profitability by the producers, as well as, preservation of environmental quality.

References

Alexander, Martin. 1960. “Nitrification.” In *Soil Nitrogen*. 307–343.

Anderson, O. E. and F. C. Boswell. 1964. The influence of low temperature and various concentrations of ammonium nitrate on nitrification in acid soils. Soil Sci. Soc. Am. Proc. 28:525-532

Bartholomew, W. V. (1965). Mineralization and Immobilization of Nitrogen in the Decomposition of Plant and Animal Residues. *Journal of Soil Nitrogen* , 285-306.

Brady, N. C., & Weil, R. R. (2009). *Elements of the Nature and Properties of Soils* (Third Edition ed.). Pearson.

Brandt, G. H., Wolcott, A. R., & Erickson, A. E. (1964). Nitrogen Transformations in Soil as Related to Structure, Moisture, and Oxygen Diffusion Rate. *Soil Science Society of America , 28*, 71-75.

Bremner, J. M., & Shaw, K. (1958). Denitrification in Soil. *Journal of Agricultural Sciences* , 22-59.

Briggs, G. G. (1975). The Behavior of the nitrification inhibitor "N-Serve" in broadcast and incorporated applications to soil. *J. Sci. Food Agric. , 26*, 1083-1092.

Brown, J. M., & Bartholomew, W. V. (1962). Sorption of Anhydrous Ammonia by Dry Clay Systems. *Soil Sci. Soc. Am. J. , 26* (3), 258-262.

Cramer, M., & Lewis, O. (1993, 10 1). The Influence of Nitrate and Ammonium Nutrition on the Growth of Wheat (Triticum aestivum) and Maize (Zea mays) Plants. *Annals of Botany , 72* , 359-365.

Craswell, E. T. (1978). Some factors influencing denitrification and nitrogen immobilization in a clay soil. *Soil Biol. biochem. , 10*, 241-245.

Craswell, E. T., & Martin, A. E. (1974). Effect of Moisture Content on Denitrification in a Clay Soil. *Soil Biol. Biochem. , 6*, 127-129.

Deignan, M. T., & Lewis, O. A. (1988). The Inhibition of Ammonium Uptake by Nitrate in Wheat. *New Phytologist , 110* , 1-3. Wiley on behalf of the New Phytologist Trust.

Ernst, J. W., & Massey, H. F. (1960). The Effects of Several Factors on Volatilization of Ammonia Formed from Urea in the Soil. *Soil Science Society of America* , 87-90.

Evangelou, V. P., & Phillips, R. E. (2005). Cation Exchange in Soils. *Chemical Processes in Soils , sssabookseries* (chemicalprocess), 343-410.

Ferguson, R. B., Kissel, D. E., Koelliker, J. K., & Basel, W. (1984). Ammonia Volatilization from Surface-Applied Urea: Effect of Hydrogen Ion Buffering. *Soil Science Society of America , 48* (3), 578-582.

Firestone, M. K. (1982). Biological Denitrification. *Nitrogen in Agricultural Soils* , 289-326.

Firestone, M. K., & Davidson, E. A. (1989). Microbiological basis of NO and N2O production and consumption in soils. *Exchange of trace gases between terrestrial ecosystems and the atmosphere* , 7-21.

Fowler, D. B., & Brydon, J. (1989). No-till winter wheat production on the Canadian prairies: Placement of urea and ammonium nutrate fertilizers. *Agronomy Journal , 81*, 518-524.

Frye, W. (2005). Nitrification Inhibition for NItrogen Efficiency and Environment Protection. *IFA International Workshop on Enhanced-Efficiency Fertilizers*, (pp. 1-7).

Glossary of Soil Science Terms. (2013). Retrieved 11 13, 2013, from Soil Science Society of America: https://www.soils.org/publications/soils-glossary#

Griffith, W. K., & Murphy, L. S. (1991). The development of crop production systems using best management practices.

Guenzi, W. D., Beard, W. E., Watanabe, F. S., Olsen, S. R., & Porter, L. K. (1978). Nitrification and denitrification in cattle manure-amended soil. *Journal of Environmental Quality , 7*, 196-202.

Hageman, R. H. (1984). *Ammonium Versus Nitrate Nutrition of Higher Plants.* Retrieved 4 23, 2013, from Acsess Digital Library: https://dl.sciencesocieties.org/publications/books/abstracts/acsesspublicati/nitrogenincropp/67

Hargrove, W. L. (1988). Evaluation of Ammonia Volatilization in the Field. *Production Agriculture , 1* (2), 104-111.

Herlihy, M., & Quirke, W. (1975). The persistence of 2-chloro-6-(trichloromethyl) pyridine. *Commun. Soil Sci. Plant Anal. , 6*, 513-520.

Keller, G. D., & Mengel, D. B. (1986). Ammonia Volatilization from Nitrogen Fertilizers Surface Applied to No-till Corn. *Soil Science Society of America Journal , 50*.

Mengel, D. B., Nelson, D. W., & Huber, D. M. (1982). Placement of N fertilizers for no-till and conventional till corn. *Agronomoy Journal , 74*, 515-518.

Mulla, D. J., & Strock, J. S. (2008). Nitrogen Transport Processes in Soil. *Nitrogen in Agricultural Soils* , 361-400.

NCR-13. (1998). Recommended Chemical Soil Test Procedures for the North Central Region. *North Central Regional Research Publication , 221*.

Nelson, D. W., & Huber, D. (1992). *Nitrification Inhibitors for Corn Production.* Iowa State University, Extension.

Nommik, H. (1956). Investigations on denitrification in soils. *Acta Agric. Scand. , 6*, 195-228.

Nommik, H., & Vahtras, K. (1982). Retention and Fixation of Ammonium and Ammonia in Soils. *Nitrogen in Agricultural Soils , agronomymonogra* (nitrogeninagrics), 123-171.

Orsel, M., Filleur, S., Fraisier, V., & Daniel-Vedele, F. (2002, 4 15). Nitrate transport in plants: which gene and which control? *Journal of Experimental Botany , 53* , 825-833.

Papendick, R. I., & Engibous, J. C. (1980). Performance of Nitrification Inhibitors in the Northwest. *Nitrification Inhibitors-Potentials and Limitations* , 107-117.

Parr Jr., J. F., & Papendick, R. I. (1966). Retention of Ammonia in Soils. *Agricultural Anhydrous Ammonia Technology and Use , acsesspublicati* (agriculturalanh), 213-236.

Pasda , G., Hahndel, R., & Zerulla, W. (2001). Effects of Fertilizers with the New Nitrification Inhibitor DMPP (3,4-dimethylpyrazole phosphate) on Yield And Quality of Agricultural and Horticultural Crops. *Biol Fertil Soils* .

Raun, W. R., & Johnson, G. V. (1999). Improving Nitrogen Use Efficiency for Cereal Production. *Agronomy Journal , 91*, 357-363.

Reeves, D. W., & Touchton, J. T. (1986). Relative Phytotoxicity of Dicyandiamide and Availability of its Nitrogen to Cotton, Corn, and Grain Sorghum. *Soi Science Society of America* , 1353-1357.

Rice, C. W., & Smith, M. S. (1984). Short-term immobilization of fertilizer nitrogen at the surface of no-till and plowed soils. *Soil Science Society of Americal Journal , 48*, 295-297.

Roberts, T. L. (2007). *Right product, right rate, right time and right place...the foundation of best management practices for fertilizer.* Retrieved from IPNI: http://www.ipni.net/ipniweb/portal.nsf/0/55C6FA392D96B89885257A8C0057EDAA/$FILE/Roberts_2007_4Rs.pdf

Roberts, T. L. (2007). Right products, right rate, right time and right place...the foundation of best management practices for fertilizer. *Fertilizer Best Management Practices* (1), 29-32.

Rodgers, G. A., & Ashworth, J. (1982). Bacteriostatic action of nitrification inhibitors. *Canada Journal of Microbiology , 28*, 1093-1100.

Scharf, P. C., & Alley, M. M. (1995). NItrogen Loss Inhibitors Evaluated for Humic-Region Wheat Production. *J. Prod. Agric. , 8* (2), 269-275.

Sharp, J. C. (1966). Properties of Ammonia. *Agricultural Anhydrous Ammonia Technology and Use , acsesspublicati* (agriculturalanh), 21-31.

Stevenson, F. J., Bartholomew, W. V., & Clark, F. E. (1965). Origin and Distribution of Nitrogen in Soil. *Soil Nitrogen* , 1-42.

Touchton, J. T., Hoeft, R. G., & Welch, L. F. (1978). Effect of Nitrapyrin on Nitrification of Fall and Spring-Applied Anhydrous Ammonia. *Agronomy Journal , 70*.

Touchton, J. T., Hoeft, R. G., & Welch, L. F. (1978). Effect of Nitrapyrin on Nitrification of Fall and Spring-Applied Anhydrous Ammonia. *Agronomy Journal , 70*, 805-810.

Touchton, J. T., Hoeft, R. G., & Welch, L. F. (1978). Nitrapyrin Degradation and Movement in Soil.

Touchton, J. T., Hoeft, R. G., Welch, L. F., & Argyilan, W. L. (1979, Jan. 22). Loss of Nitrapyrin from Soils as Affected by pH and Temperature.

Touchton, J. T., Hoeft, R. G., Welch, L. F., & Argyilan, W. L. (1979). Loss of Nitrapyrin from Soils as Affected by pH and Temperature. *Agronomy Journal , 71*.

Touchton, J. T., Hoeft, R. G., Welch, L. F., Mulvaney, D. L., Oldham, M. G., & Zajicek, F. E. (1979). N Uptake and Corn Yield as Affected by Applications of Nitrapyrin with Anhydrous Ammonia. *Agronomy Journal , 71*, 238-242.

Tremblay, N., Bouroubi, Y. M., Belec, C., Mullen, R. W., Kitchen, N. R., Thomason, W. E., et al. (2012). Corn Response to Nitrogen is Influenced by Soil Texture and Weather. *Agronomy J. , 104*, 1658-1671.

Villar, J. M., & Guillaumes, E. (2010). Use of Nitrification Inhibitor DMPP to Improve Nitrogen Recovery in Irrigated Wheat on a Calcareous Soil. *Spanish Journal of Agricultural Research , 8* (4), 1218-1230.

Wang, X., & Below, F. E. (1998). Accumulation and Partitioning of Mineral Nutrients in Wheat as Influenced by Nitrogen Form. *Journal of Plant Nutrition , 21* (1), 49-61.

Wolt, J. D. (2004). A meta-evaluation of nitrapyrin agronomic and environmental effectiveness with emphasis on corn production in the Midwestern USA. *Nutrient Cycling in Agroecosystems , 69*, 23-41.

Wolt, J. D. (2004). A meta-evaluation of nitrapyrin agronomic and environmental efffectiveness with emphasis on corn production in the Midwestern USA. *Nutrient Cycling in Agroecosystems , 69*, 23-41.

Wolt, J. D. (2000). Nitrapyrin Behavior in Soil and Environmental Considerations. *Journal of Environmental Quality , 29*, 367-369.

World Health Organization. (n.d.). *Water Sanitation Health*. Retrieved 12 9, 2013, from World Health Organization: http://www.who.int/water_sanitation_health/diseases/methaemoglob/en/

Zerulla, W., Barth, T., Dressel, J., Erhardt, K., Locquenghien, K. H., Pasda, G., et al. (2001). 3,4 Dimethylpyrazole phosphate (DMPP) - a new nitrification inhibitor for agriculture and horticulture. *Biol Fertil Soils , 34*, 79-84.

Chapter 2 - Timing of Nitrogen Application and Nitrification Inhibitors as Management Tools to Enhance Nitrogen Use Efficiency in Winter Wheat (*Triticum aestivum L.)*

Abstract

Several tools are available to wheat producers in Kansas to reduce Nitrogen (N) losses from leaching and denitrification. Applying N as close as possible to the time of N uptake by the plant is one commonly used tool to avoid N loss. Another strategy is the use of nitrification inhibitors (NI) with ammonium-N sources such as anhydrous ammonia (AA). Maintaining N in the ammonium form by reducing nitrification can help reduce leaching and denitrification. This project was conducted during the 2011-2012 and 2012-2013 winter wheat growing seasons, at three locations in Kansas on soils differing in both denitrification and leaching potential. The objective for this study was to compare the timing of fertilizer N applications, anhydrous ammonia (AA) with and without two different nitrification inhibitors (NI) in the fall and traditional spring topdressing with urea, as possible tools to enhance yield and Nitrogen Use Efficiency (NUE) in winter wheat (*Triticum aestivum L.)* in Kansas. The two nitrification inhibitors used were N-Serve (nitrapyrin) as well as a new experimental product, named G77. Fall and winter precipitation varied widely between the locations, resulting in variable N use and yield. Minimal losses from fall ammonia were seen at Manhattan and Ottawa in both site years, as indicated by high N recovery. At the sandier Kansas River Valley site, yield and N uptake were severely impacted by disease in 2011-2012. In the following growing season, at KRV, high levels of N loss from both fall AA and spring urea were noted.

Introduction

As the main fertilizer input, N management is always a hot topic. Furthermore, concerns over environmental impacts of crop fertilization on water quality and the release of potential greenhouse gases are high. Improved methods of N management for crops such as wheat are critical for the profitability of the producer, as well as, benefit to the environment. These are fundamental goals agreed upon by both the environmental community and producers. As input costs and environmental awareness keep rising, the agricultural industry is forced to discover and implement improved N management strategies. The 4R system of N management (right product, right rate, right time, right place) adopted by the fertilizer industry discusses four basic concepts to manage N to minimize loss. These are broad generalizations that need site-specific research conducted under each concept to maximize efficiency (Roberts, 2007). Finding appropriate N management strategies for wheat to reduce overall fertilizer cost of application, as well as, increase Nitrogen Use Efficiency (NUE), and reduce N losses is an important focus of current N management research.

Currently in wheat production, the most common method of N application is the practice of top-dressing urea or UAN solutions in the spring, at or before spring green-up (Feekes 3-4 growth stage). There are positive and negative effects to this application system. In high residue, no-till situations, urea or UAN fertilizers applied on the surface of soils have high potential of being immobilized or volatilized. As much as 21% of surface applied urea can been immobilized in a no-till system (Rice and Smith, 1984). Also, urea displays a high potential for volatilization in comparison with other products that are surface applied such as UAN or AN (Keller and Mengel, 1986). In terms of application method and source, this practice has a high potential for loss. However, the timing of application is close to plant uptake, which is a potential benefit for reducing the opportunity of loss in this system, once the N has entered the soil. But on many production operations, spring applications are difficult to make when work on other crops is required or weather conditions make field operations difficult. As a result, management tools that increase the window of opportunity, decrease N loss, increase NUE, and decrease environmental impacts are rare, but desired tactics.

One concept in N management is to increase the window of opportunity for producers to make applications, yet limit N loss by keeping N in the NH_4^+ form for a longer period after application, which will decrease losses of N by reducing its time in the very mobile NO_3^- form. There are both potential benefits and problems with this concept. One method to apply this concept and maximize cost effectiveness of N fertilizer application in wheat is to apply N as anhydrous ammonia (AA) in the fall before planting. Anhydrous ammonia is normally the cheapest N fertilizer source on the market, also a 100% NH_4^+ source, and must be incorporated into the soil. This reduces the potential for volatilization or immobilization with surface residue. As a result, its price and chemical form make it an excellent candidate for achieving the goals of minimal loss, at least from these mechanisms and reasonable cost. However, applying in the fall lengthens the time N will be in the soil before plant uptake, increasing the potential for loss from leaching or denitrification.

Ammonia is a toxic substance, presenting a human risk of injury from accidents to the person making the application. However, that toxicity is an advantage in the immediate ammonia band of killing or suppressing, for a short period of time, the soil bacteria involved in the nitrification process. By employing a second management strategy, the usage of a nitrification inhibitor added to the applied N, N is potentially preserved in the NH_4^+ form for a longer period of time. Currently in the U.S., only one nitrification inhibitor, N-Serve or nitrapyrin, is cleared for application with AA. This product is marketed by Dow Agro-Sciences. A significant body of research has been conducted with this product. Work by Touchton (1978) has shown that in certain soils, N-Serve does decrease nitrification and NO_3^- accumulation, consequently, keeping N in the NH_4^+ form. However, maintaining N in the NH_4^+ form longer does not always lead to reduced N loss or higher yield. These results are quite variable based on soil characteristics and weather conditions. In a study conducted by Papendick and Engibous (1980) in the Northwest U.S., the addition of N-Serve to AA applications in wheat did not significantly increase yields. However, the N taken up into the plant was increased with the N-Serve treatment in comparison with AA alone, and the NO_3^- concentrations found in the wheat plant were much lower with the addition of N-Serve in comparison with AA alone (Papendick and Engibous, 1980). A meta-analysis completed by Wolt (2004) indicated that 39 of 50 sites studied showed a benefit to the use of N-Serve (nitrapyrin). This indicates the high level of variability as to the success achieved from using N-Serve.

N-Serve appears to be less effective and provides very poor performance in soils with high pH and low OM (Touchton, et. al, 1979). With N-Serve being the only nitrification inhibitor in the U.S. cleared for application with AA, there is potential for new and improved nitrification inhibitors on the market.

This research has three objectives: first, compare the impact of two N application systems, applying all the N in the fall prior to planting wheat as ammonia vs. spring topdressing with urea on wheat yield, and the relative effectiveness of those systems as measured by nitrogen uptake and NUE recovery; second, determine the effectiveness of a nitrification inhibitor with fall applications; third, compare the usage of a new potential nitrification inhibitor being examined by Koch Agronomic Services LLC, G77, to N-Serve.

Materials and Methods

The study was initiated in the fall of 2011 and was conducted for two crop years. The locations of the study were the KSU Agronomy North Farm (NF) in Manhattan, KS, in 2012 and 2013; the Kansas River Valley Experiment Field (KRV), Rossville unit in 2012, and Silver Lake unit in 2013; and the East Central Experiment Field (ECK) near Ottawa, KS, in 2012 and 2013. Plots were arranged in the field using a randomized complete block design with four replications. The blocks at each location were set up to maximize uniformity and minimize soil variability within the block. All locations were set up using 3 m by 15 m plots with 7.6 m alleys between blocks. Alleys were used for equipment maneuvering between treatments and applicator calibration.

The treatments, summarized in Table 2.1, applied at each location consisted of an N response curve with rates of 0, 34, 67, 101, and 134 kg N ha^{-1} applied at green-up, approximately Feekes 3-4 as granular urea. In addition, fall applications of N as AA at a rate of 67 kg N ha^{-1} with and without NI were also applied. The 67 kg N rate was used because it was considered to be slightly suboptimal, providing the best expression of management system and inhibitor performance. Nitrification inhibitor products used were N-Serve (nitrapyrin) at a 2.3 L ha^{-1} rate, and G77, and an experimental material being evaluated for Koch Agronomic Services. The G77 product was applied at rates of 9.4, 18.7, and 28.4 L ha^{-1}. Since the G77 product at the highest rate contained 10 kg N ha^{-1}, N rates were equalized in all treatments by adding 10 kg N as UAN to treatments not receiving G77. The two lower rates of G77 received enough UAN to balance out the additional 10 kg N rate. In 2012-13, additional fall ammonia rates of 34, 101, and 134 kg N ha^{-1} were added to provide complete fall ammonia and spring urea N response curves.

Fall ammonia applications were applied using a John Deere 2510 High Speed, Low Draft applicator at a depth of about 13 cm. The 3 m coulter toolbar was set up at 0.5 m coulter spacing. The applicator was calibrated over a distance of 91 m to apply 67 kg N ha^{-1} at a speed of 11.2 km h^{-1} using onboard weigh scales. The nitrification inhibitors were applied using a Raven variable rate injection system mounted on the tool bar. N-Serve was applied directly into the AA stream prior to entering the manifold at the recommended rate of 2.3 L ha^{-1}. G77 was applied 1.3 cm behind the AA stream in the application furrow. Urea was broadcasted by hand.

Cultural Practices

Tables 2.2, 2.3, 2.4, and 2.5 include key information about the timing of activities, as well as, the cultural practices that were used to establish the study. Wheat at all locations was drilled in 19 cm rows. Starter fertilizer was applied with the drill at NF and KRV field in 2012 at a rate of 10 kg N ha^{-1} and 47 kg P ha^{-1} as MAP. In 2013, 11 kg N ha^{-1} and 52 kg P ha^{-1} as DAP were applied via the drill at the North Farm and KRV sites. At the KRV Rossville site in 2012, an additional 25 kg Cl ha^{-1} as KCl was applied via a 3 m drop spreader over the entire site. In 2013 at the NF site, a fertilizer application of 36 kg K ha^{-1}, 29 kg Cl ha^{-1}, and 9 kg S ha^{-1} were applied in a blend of KCl and Gypsum at Feekes 4 via a 3 m drop spreader. At the KRV Silver Lake unit in 2013, 18 kg S ha^{-1} as Gypsum was broadcast over the entire location at Feekes 6 because signs of possible sulfur deficiency were observed though no potential S deficiency was indicated by soil tests. At the ECK site in 2012, 19 kg N ha^{-1}, 48 kg P ha^{-1}, 22 kg K ha^{-1}, and 18 kg Cl ha^{-1} as a DAP/KCl blend was broadcast as starter prior to planting over the entire site. In 2013 at the ECK site, a starter application of 24 kg N ha^{-1}, 19 kg P ha^{-1}, 51 kg K ha^{-1}, and 34 kg Cl ha^{-1} as a DAP/ KCl blend was applied with the drill. An additional blend of 16 kg N ha^{-1} as urea, 50 kg K ha^{-1} and 32 kg Cl ha^{-1} as KCl was broadcast about three weeks after planting. As a result of these applications, no signs of deficiency other than N were noted during the growing season.

Table 2.1 Treatments Utilized in the Experiment

Year	Treatment	Nitrogen Rate		N Source	Inhibitor	
		Fall	Spring		Source	Rate
		kg ha^{-1}				L ha^{-1}
2012-13	1	67		NH_3		
2012-13	2	67		NH_3	G77	9.4
2012-13	3	67		NH_3	G77	18.7
2012-13	4	67		NH_3	G77	28.1
2012-13	5	67		NH_3	N-Serve	2.3
2012-13	6		0	Control		
2012-13	7		34	Urea		
2012-13	8		67	Urea		
2012-13	9		101	Urea		
2012-13	10		134	Urea		
2013 only	11	34		NH_3		
2013 only	12	101		NH_3		
2013 only	13	134		NH_3		

Table 2.2 Key Dates of Field Activities, 2012

	Location		
Activities	Manhattan	Rossville	Ottawa
Fall AA Treatments Applied	October 20, 2011	October 25, 2011	October 27, 2011
Planting Date	November 3, 2011	November 5, 2011	October 31, 2011
Spring Urea Treatments Applied	March 17, 2012	March 17, 2012	March 17, 2012
Flag Leaf Sampling Date	April 18, 2012	April 19, 2012	April 19, 2012
Whole Plant Sampling Date	April 30, 2012	April 30, 2012	May 4, 2012
Harvest Date	June 6, 2012	June 7, 2012	June 5, 2012

Table 2.3 Key Dates of Field Activities, 2013

	Location		
Activities	Manhattan	Silver Lake	Ottawa
Fall AA Treatments Applied	October 10, 2012	October 4, 2012	October 9, 2012
Planting Date	October 19, 2012	October 11, 2012	October 19, 2012
Spring Urea Treatments Applied	March 29, 2013	March 20, 2013	March 20, 2013
Flag Leaf Sampling Date	May 20, 2013	May 20, 2013	May 18, 2013
Whole Plant Sampling Date	June 3, 2013	June 3, 2013	June 6, 2013
Harvest Date	July 3, 2013	July 2, 2013	July 2, 2013

Table 2.4 Key Cultural Practices in 2012

	Location		
Cultural Practices	Manhattan	Rossville	Ottawa
GPS Coordinates	39N 12'44.67 96W 35'42.21	39N 07'07.78 95W 55'24.33	38N 32'28.15 95W 14'29.44
Previous Crop	Soybeans	Soybeans	Soybeans
Tillage	No-Till	No-Till	No-Till
Wheat Variety	Everest	Everest	Everest
Seeding rate	123 kg ha^{-1}	123 kg ha^{-1}	134 kg ha^{-1}

Table 2.5 Key Cultural Practices in 2013

	Location		
Cultural Practices	Manhattan	Silver Lake	Ottawa
GPS Coordinates	39N 12'44.86 96W 35'56.14	39N 04'35.69 95W 46'11.65	38N 32'18.07 95W 14'41.92
Previous Crop	Soybeans	Soybeans	Soybeans
Tillage	No-Till	No-Till	No-Till
Wheat Variety	Everest	Everest	Everest
Seeding rate	134 kg ha^{-1}	134 kg ha^{-1}	112 kg ha^{-1}

Soil Sampling and Analysis

In the fall at the beginning of each growing season, soil samples were collected using a Concord hydraulic soil probe, taking core samples to 91 cm, at each location. A plastic sleeve was placed inside the probe to collect the sample and save it for processing. If the samples were not processed directly after sampling, they were frozen at -6°C until a time was available to separate them into their specific segments. Twelve cores were taken per composite sample with one composite sample collected from each block. Each core was separated into 0-15 cm, 15-30 cm, 30-61 cm, 61-91 cm segments. Each segment of the cores was then carefully broken up and mixed and placed into a sample bag.

The samples were then submitted to the KSU Soil Testing Lab for analysis. The samples were dried at 50°C, then ground to pass through a 2 mm sieve. After the soil samples were prepared, the following analysis measurements were made: pH (1:1 soil:water) (Watson and Brown, 1998), OM (Modified Walkley-Black) (Combs and Nathan, 1998), NH_4-N (KCl extraction) (Gelderman and Beegle, 1998), NO_3-N (KCl Extraction) (Gelderman and Beegle, 1998), P (Mehlich-3) (Frank, Beegle, and Denning, 1998), K (NH_4OAc Extraction) (Warncke and Brown, 1998), Ca (NH_4OAc Extraction) (Warncke and Brown, 1998), Mg (NH_4OAc Extraction) (Warncke and Brown, 1998), S (Calcium Phosphate Extraction) (Combs, Denning, and Frank, 1998), and Cl (Calcium Nitrate Extraction) (Gelderman, Denning, and Goos, 1998). In Table 2.7, the available nutrients measured can be found. The values can be calculated into kg ha^{-1} by using the following equation: nutrient (ug g^{-1}) * 0.134 * depth (cm) = kg (nutrient) ha^{-1}.

Tables 2.6 and 2.7 include key information about the study site and soil test results from the study locations.

Table 2.6 Key Soil Information from Web Soil Survey

Site	Soil Series	Soil Description	Drainage Class	Flooding Class
Manhattan 2012-2013	Ivan and Kennebec Silt Loams	Fine-silty alluvium	Moderately, Well Drained	Occasional
Rossville 2012	Eudora Silt Loam	Coarse-silty alluvium	Well Drained	Very Rare
Silver Lake 2013	Eudora-Bismarckgrove Silt Loams	Coarse-silty alluvium	Well Drained	Occasional
Ottawa 2012-2013	Woodson Silt Loam	Silty and clayey alluvium	Somewhat, Poorly Drained	None

Table 2.7 Soil Analysis Results

Site	Block	pH	OM	P	K	NH_4-N	NO_3-N
Sampling Depth (cm)		15	15	15	15	91	91
			g kg^{-1}	*u*g g^{-1}			
Manhattan 2012	1	7.3	24.9	44.4	287	7.9	5.0
	2	7.1	24.0	38.4	250	8.5	4.9
	3	6.5	24.7	25.3	230	8.1	4.8
	4	6.3	23.0	10.6	214	8.1	3.5
	Average	6.8	24.1	29.7	245	8.1	4.5
Rossville 2012	1	6.9	9.6	27.6	110	4.8	2.7
	2	7.1	10.8	30.2	120	5.5	2.1
	3	6.8	9.1	21.1	110	5.4	2.6
	4	7.0	9.8	28.4	164	7.5	3.5
	Average	6.9	9.8	26.8	126	5.8	2.7
Ottawa 2012	1	6.0	25.8	17.9	173	6.7	2.3
	2	6.0	24.4	19.5	160	6.8	2.6
	3	6.1	21.1	18.5	152	6.4	2.2
	4	6.3	28.2	12.3	192	6.7	2.2
	Average	6.1	24.9	17.1	169	6.6	2.3
Manhattan 2013	1	7.1	24.6	20.6	421	5.0	1.7
	2	7.0	23.3	19.9	435	4.9	2.0
	3	6.8	24.4	20.3	435	4.5	2.1
	4	7.3	21.6	34.6	464	5.2	2.2
	Average	7.0	23.5	23.9	439	4.9	2.0
Silver Lake 2013	1	7.4	14.3	28.0	109	2.8	0.9
	2	7.0	10.3	26.2	92	3.7	4.2
	3	7.1	11.1	35.0	109	4.2	4.6
	4	6.9	12.8	29.5	146	5.2	3.8
	Average	7.1	12.1	29.7	114	4.0	3.4
Ottawa 2013	1	6.5	33.0	7.9	197	6.5	2.2
	2	6.6	27.0	5.3	227	6.1	1.9
	3	6.5	30.0	7.2	195	5.8	2.6
	4	6.3	27.0	6.8	195	6.2	2.1
	Average	6.5	29.3	6.8	204	6.1	2.2

Flag Leaf Sampling and Analysis

At Feekes 10.5 growth stage, flag leaf samples were collected from all locations in both years. A total of 50 flag leaves were selected from each plot by making two passes through the length of the plot randomly selecting leaves. The leaves were then put into brown paper bags and dried at 60°C and ground to pass through a 0.5 mm sieve. The samples were then submitted to the KSU Soil Testing Lab for analysis. There the concentrations of total N were analyzed using a sulfuric acid-hydrogen peroxide digest. The extract containing ammonia was analyzed with a colorimetric procedure (nitropruside-sodium hypochlorite) using RFA Methodology No. A303-S072, Total Kjeldahl Nitrogen.

Whole Plant Sampling and Analysis

At all locations in 2012-2013, whole plant samples were collected at Feekes 11.2. In 2012, only one whole plant sample was collected from each plot. In 2013, two whole plant subsamples were collected from each plot due to variability found with whole plant sampling in wheat. In 2012, two randomly selected 0.9 m sections of one row of biomass were sampled, harvesting all biomass down to 2.5 mm above the soil surface. These two sections of row were combined to make one sample and weighed at the site for measuring total biomass. The samples were then sent through a garden size plant chopper. A subsample was selected from the shredded sample and placed in a brown paper bag. The subsample was then weighed prior to the drying process as well as after the drying process. The samples were dried at 60°C and ground to pass through a 0.5 mm stainless steel sieve. In 2013, a similar procedure to 2012 occurred except that 2 randomly selected 1.5 m sections of row per plot were cut and processed separately.

After the samples were ground, they were submitted to the KSU Soil Testing Lab for analysis. There the concentrations of total N were analyzed using a sulfuric acid-hydrogen peroxide digest. The extract containing ammonia was analyzed with a colorimetric procedure (nitropruside-sodium hypochlorite) using RFA Methodology No. A303-S072, Total Kjeldahl Nitrogen.

Grain Sampling and Analysis

All locations were machine harvested, regardless of the yield levels. In 2012 at all locations, a 1.4 by 15.2 m area from the center of each plot was harvested with a Nursery Master Elite Wintersteiger plot combine. The yield from the entire harvested area was placed into a sack, weighed, and a subsample taken for analysis. The subsamples were then analyzed for moisture and test weight using a Dickey John 2100 GAC Moisture meter. All yields were then adjusted to the standard for wheat,120 g kg^{-1} moisture. All samples were placed in white cloth bags and dried at 60°C and ground to pass through a 0.5 mm stainless steel sieve. In 2013, similar procedures were followed, though different combines were used at each site, and the width of the harvested plot area varied from 1.4.-1.8 m. After grain samples were harvested, dried, and ground, they were submitted in vials to the KSU Soil Testing Lab for analysis. There the concentrations of N were analyzed using a sulfuric acid-hydrogen peroxide digest. The extract containing ammonia was analyzed with a colorimetric procedure (nitropruside-sodium hypochlorite) using RFA Methodology No. A303-S072, Total Kjeldahl Nitrogen.

The following calculations were used in completing the data analysis:

- Grain N Uptake = Yield (Mg ha^{-1}) * Grain N Content (g kg^{-1})
- Stover N Uptake = Stover Dry Matter (kg ha^{-1}) * Stover N Content (g kg^{-1})/ 10
- Total N Uptake (kg ha^{-1}) = Stover N Uptake + Grain N Uptake
- NUE Recovery (kg kg^{-1}) = Total N Uptake Fertilized Treatment (kg ha^{-1}) – Total N Uptake Unfertilized Treatment (kg ha^{-1})) / Applied N Fertilizer (kg ha^{-1})
- Grain Protein Content = Grain N Content (g kg^{-1}) * 6.25

Statistical Analysis

The data analysis was completed using the PROC MIXED procedure at an alpha level of 0.10 and 0.01 to show the extent of the significance between treatments. Blocks and treatments were both set as fixed effect in SAS 9.3 (SAS Institute, 2011). The reason the fixed effect was used for blocks with the PROC MIXED procedure was because the blocks were set up in a manner that captured the variability within the specific block. PROC MIXED was used to capture all the results, even with the deleted or missing data points. Outlier data points were analyzed when the CV for treatment exceeded 25% and the data point was removed if there was a reasonable explanation for the extreme diversity in the treatment. Soil textural variability extremes (clay lenses), goose damage, and poor stands in the specific plot were the most common reasons for data point deletions. The studies were monitored the entire season on a biweekly basis to assist with the explanations.

Results and Discussion

Combined Analysis

Table 2.8 Pooled Data Effects, Probability of a Greater F

Effect	Flag Leaf N	Protein Content	Total N Uptake	NUE Recovery	Yield
			P > F		
Treatment	<.0001	<.0001	<.0001	<.0001	<.0001
Block	0.022	0.991	0.001	0.331	<.0001
Year	0.035	0.090	0.647	0.778	<.0001
Location	<.0001	<.0001	<.0001	0.120	<.0001
Location*Year	0.001	0.001	<.0001	0.025	0.000
Treatment*Year	0.015	0.433	0.552	0.446	0.087
Treatment*Location	0.003	0.011	0.225	0.002	0.008
Treatment*Location*Year	0.653	0.025	0.497	0.634	0.002

A pooled analysis across locations and years was conducted. In the pooled data (Table 2.8) showing probabilities, most two-way interactions involving treatments, locations, and years were found to be significant. This is not totally unexpected with the wide variation in soils between these sites and with issues impacted by water and temperature. The primary analysis, which will be used to describe the results, was individual study comparisons for each site and year.

Overall Study Conditions

In 2012, very little moisture came during the early spring growing season. Conditions were very dry. As a result, yields were moderate to low, and N loss conditions were not extensive. Disease pressure was minimal under these growing conditions. The spring growing season started very early. The 2012 sites were about a month ahead of normal growing conditions. The sites were harvested in early June, a month early as a result.

In 2013, yields were much higher than they were in 2012. A few more rain events came at the proper times, even though total moisture was still moderate to low for the locations. In this study year, three more treatments were added to the study to the fall applications to allow direct comparisons of fall vs. spring applications at all N rates. The sites were harvested in early July, normal times for this area.

Manhattan, Agronomy North Farm Sites (NF)

Manhattan, 2012

In considering the results from this location, one must keep in mind the soil, a moderately, well-drained silt loam with a 24 g kg^{-1} OM and high productivity. In 2012, conditions were not favorable for high yields due to the low moisture. Total precipitation between fall and spring N applications was 266 mm (Figure 2.1) with only one major rainfall event a week after application in the fall. Precipitation between spring applications and May 31, approximate time N uptake would have finished, totaled 183 mm (Figure 2.1) with only one major rainfall event two days after spring N applications.

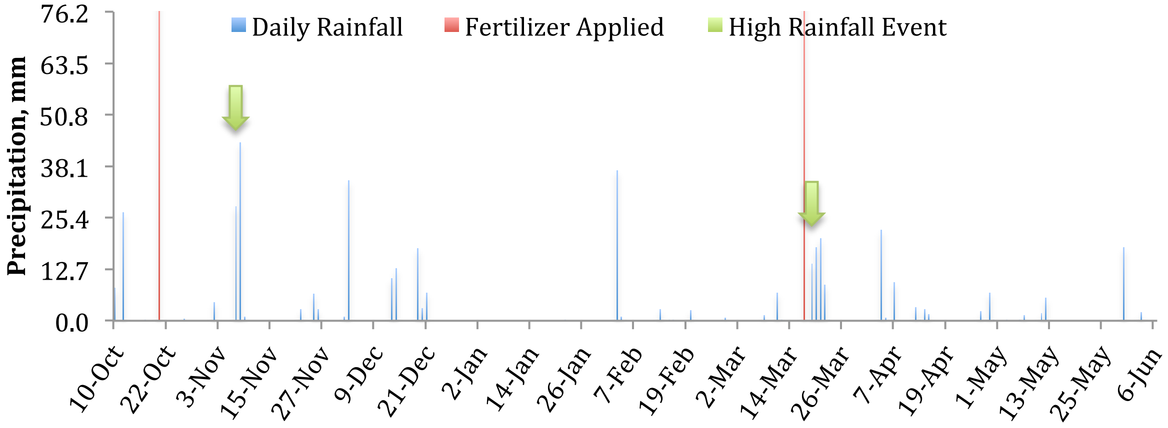

Figure 2.1 Precipitation Levels, Manhattan in 2011-2012

Fall and spring applications were both made when environmental conditions were optimal for minimal N loss. Seven days prior to fall AA application, 27 mm of moisture was recorded. Conditions were moist, allowing a strong sorption of AA without sealing problems. Even though the winter between applications had a fair amount of rain, the events were not extreme and soil temperatures (Figure 2.2) were low directly after fall application so minimal nitrification likely occurred. Hence there was minimal mobility from N because it was in the NH_4^+ form.

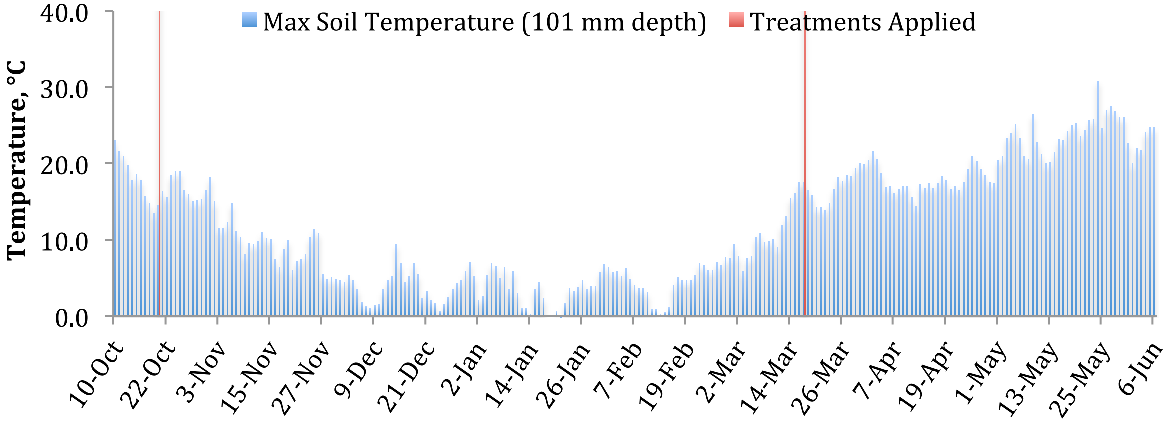

Figure 2.2 Soil Temperatures, Manhattan in 2011-2012

Volatilization from urea applications was also likely minimal because of the rain event one day after application. This would have been more than adequate to dissolve the urea granules, and move the N into the soil profile. Overall N loss mechanisms were quite minimal at this location.

Moderate yields (Figure 2.3) were harvested at this location. A strong response to N over the control was seen in all plant measurements taken at this location. However, no differences in yield between fall and spring application or advantage to the use of an inhibitor were found.

In terms of the N measured in the flag leaf (Table 2.9), a small significant increase was seen with the spring top-dress application, however, this trend was not carried on to the grain protein content and was not shown in the total plant uptake.

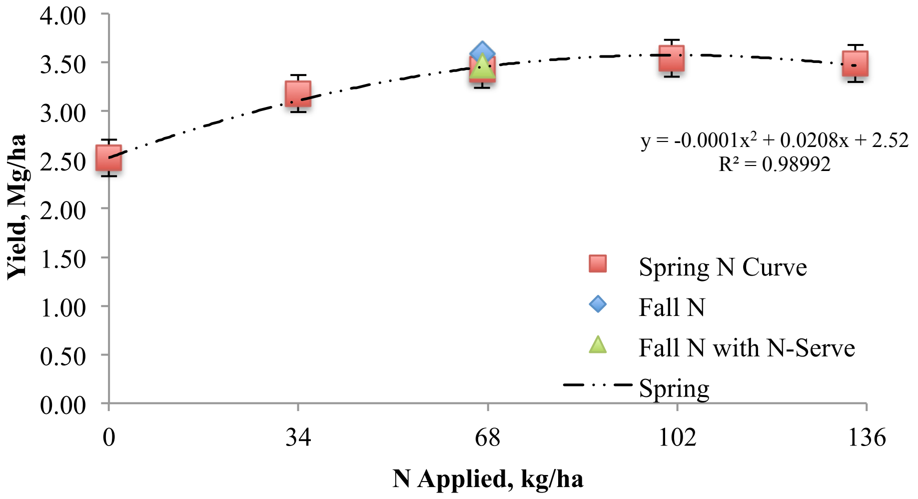

Figure 2.3 Spring N Curve, Manhattan in 2012

At this location, no benefit to using an inhibitor was seen (Table 2.9). Because yields were maximized at the 67 kg N rate where the inhibitor was compared, the response of the inhibitor would likely have been masked if there was an effect. As a result, N-Serve did not enhance performance of fall N applications in any measurement taken.

In terms of the comparison between N-Serve and the new inhibitor (Table 2.9), at all rates the G77 inhibitor did not increase yield, NUE, total N uptake, protein content, or flag leaf N for the same reason as N-Serve. Plots receiving N-Serve showed a slightly higher level of N in the flag leaf in comparison with G77 at the two lower rates, however, the higher rate was not statistically different from N-Serve. Performance of the new inhibitor at this site was understandable for the same reasons N-Serve did not perform at this location: low loss mechanisms and maxed yields.

From this site, we can conclude that fall applications with AA performed as well as spring applications with urea under these dry conditions. Also, an inhibitor did not seem to demonstrate an improved benefit under these dry conditions where yields were maximized at the 67 kg N rate. As a result, a proper assessment as to the effectiveness of an NI cannot be made.

Table 2.9 Results and Contrasts for Manhattan in 2012

Treatment	Treatment N	Inhibitor Rate	Flag Leaf N	Protein Content	Total N Uptake	NUE Recovery	Yield
	kg ha^{-1}	L ha^{-1}	g kg^{-1}	g kg^{-1}	kg ha^{-1}	kg kg^{-1}	Mg ha^{-1}
Fall NH3 only	67		31.3	108.6	165.1	1.00	3.59
Fall NH3 with G77	67	9.4	30.4	108.7	149.9	0.80	3.55
Fall NH3 with G77	67	18.7	30.3	107.7	130.2	0.56	3.38
Fall NH3 with G77	67	28.1	31.0	108.6	161.2	0.87	3.41
Fall NH3 with N-Serve	67	2.3	31.7	108.5	139.2	0.67	3.47
Control	0		25.8	104.7	86.8	NA[1]	2.52
Spring BC Urea	34		30.0	105.2	111.5	0.41	3.18
Spring BC Urea	67		32.6	112.6	158.3	0.90	3.43
Spring BC Urea	101		35.7	118.5	176.0	0.74	3.54
Spring BC Urea	134		36.0	124.4	177.6	0.62	3.49
SE			0.57	1	6.1	0.06	0.05
Treatments Pr > F			< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Contrasts							
Control vs. N Applied			(3.8)	(4.5)	(29.7)	NA	(0.46)
(6 vs. 1,7,8,9,10)			**	**	**		**
Fall N vs. Spring N			(0.7)	(2.0)	5.4	0.06	0.08
(1 vs. 8)			*				
Fall N with N-Serve vs. Fall N			0.2	(0.1)	(13.0)	(0.17)	(0.06)
(5 vs. 1)					*	*	
Fall N with N-Serve vs. Spring N			(0.5)	(2.1)	(7.6)	(0.10)	0.02
(5 vs. 8)							
N-Serve vs. G77 (1x)			0.6	(0.3)	(3.4)	(0.05)	(0.04)
(5 vs. 2)			*				
N-Serve vs. G77 (2x)			0.7	0.3	1.9	0.03	0.04
(5 vs. 3)			*				
N-Serve vs. G77 (3x)			0.3	(0.1)	(4.3)	(0.07)	0.03
(5 vs. 4)							
G77 (1x) vs. G77 (2x)			0.1	0.5	5.3	0.08	0.09
(2 vs. 3)							
G77 (2x) vs. G77 (3x)			(0.4)	(0.4)	(6.2)	(0.10)	(0.01)
(3 vs. 4)							

* indicates significance <0.10, ** indicates significance <0.01

---

[1] NA – Not Applicable because the Control treatment is used within the calculation for NUE

Manhattan, 2013

Conditions were still dry during the fall of 2012. Prior to fall AA application, no rain was received for 25 days prior to application. Potential for ammonia volatilization from poor sealing conditions was possible in the dry soil conditions. However, the soil was a fine-textured silt loam with an OM of 24 g kg^{-1} (Table 2.7) with a high water holding capacity, minimizing losses. Soils with higher clay and OM content are able to readily sorb AA to the soil system (Brown & Bartholomew, 1962). Soils conditions were not optimal, however, the wheat needed to be planted so the fertilizer was applied. These are the type of situations producers will face in farm operations with the diverse weather conditions in Kansas.

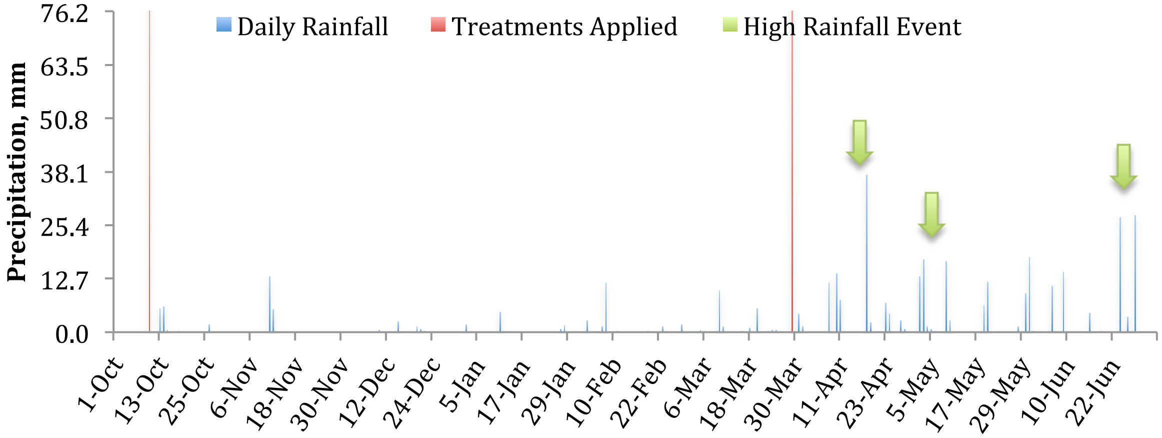

Figure 2.4 Precipitation Levels, Manhattan in 2012-2013

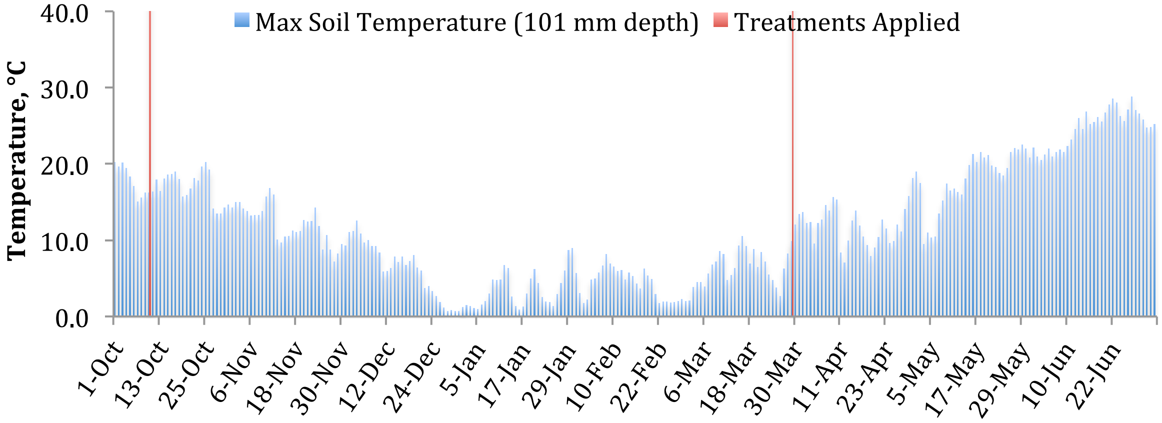

Figure 2.5 Soil Temperatures, Manhattan in 2012-2013

Over the winter months, there was a total precipitation of 87 mm (Figure 2.4) between fall and spring applications. The rain events were less than 38 mm in any event so the potential for leaching or denitrification was very minimal. Average high soil temperature at 101 mm soil depth between applications was 8°C making soil conditions warm for the winter months (Figure 2.5), but low enough with the minimal moisture to minimize any potential N loss by the reduction in the nitrification process.

Volatilization from the urea applications in the spring was quite possible. The average high air temperature between application and the first soaking rain (9 days after spring urea application) of 6.35 mm was 17.6°C. In the nine-day period between application and the first soaking rain, two small rain events less than 6.3 mm fell (Figure 2.4), possibly creating conditions for urea volatilization. That is a possible reason as to why the spring N curve is very similar to the fall N curve; both applications had some possible ammonia losses. The ammonia losses were not directly measured so speculation can only be made.

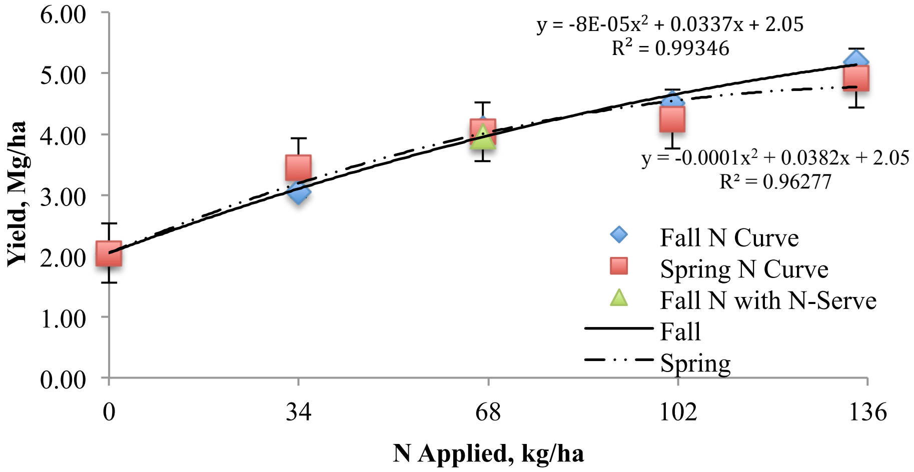

Figure 2.6 Impact of Fall vs. Spring N Application, Manhattan in 2013

At this location, yields up to 5.18 Mg ha^{-1} were obtained in 2013 (Figure 2.6), which is very respectable considering the low rainfall area at this site. In terms of the timing comparison between treatments, the fall and spring N response curves were very similar. Yields between the fall and spring treatments were not different, however a significant increase in flag leaf N content, total N uptake, and NUE favoring fall ammonia application was seen at this location (Table 2.10). We saw a yield response to N from 2 to 5.18 Mg ha^{-1} with the addition of N (Figure 2.6), and while the differences between fall and spring applications were slight, they did widen as rate increased. At this location, the wheat started spring regrowth late due to the dry conditions. Fall applications produced more fall biomass (Figure 2.7), likely due to the greater availability of N. Between the higher biomass and the potential for urea volatilization in the spring, we saw a decreasing increase in yield from spring applications in comparison with fall applications. Also, the higher biomass levels from fall application treatments led to increased uptake of N into the plant.

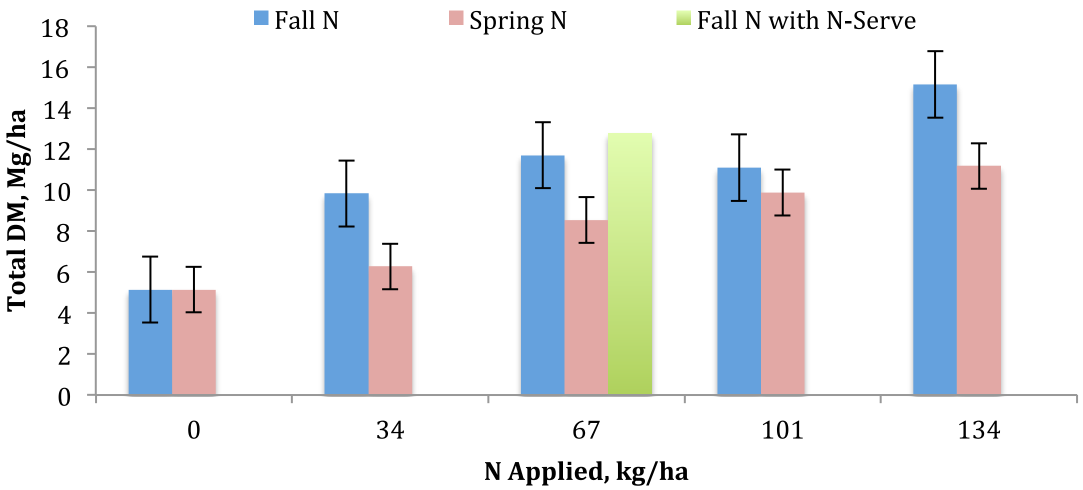

Figure 2.7 Total Dry Matter, Manhattan in 2013

N-Serve at this location again provided no benefit in terms of yield in 2013 (Table 2.10). The N-Serve treatment yielded similar to fall and spring N applications alone at the same N rate. However, flag leaf N and protein content increased slightly in comparison with fall N alone (Table 2.10). Protein content is important for grain quality. Currently, markets penalize for low protein contents.

In the comparison of N-Serve with the new nitrification inhibitor, there was no yield difference between the two types of inhibitors no matter the G77 inhibitor rate (Table 2.10). N-Serve showed improvements over the lower two rates of G77 in flag leaf N and protein content, however the highest rate of G77 was similar to N-Serve in flag leaf N, N uptake, and yield. At this location, the high G77 rate shows performance comparable to N-Serve as a nitrification inhibitor for use in increasing protein content.

Table 2.10 Results and Contrasts for Manhattan in 2013

Treatment	Treatment N	Inhibitor Rate	Flag Leaf N	Protein Content	Total N Uptake	NUE Recovery	Yield
	kg ha^{-1}	L ha^{-1}	g kg^{-1}	g kg^{-1}	kg ha^{-1}	kg kg^{-1}	Mg ha^{-1}
Fall NH3 only	67		29.5	101.0	134.7	0.92	4.09
Fall NH3 with G77	67	9.4	29.3	98.8	135.8	0.93	4.25
Fall NH3 with G77	67	18.7	27.8	101.8	124.7	0.79	3.86
Fall NH3 with G77	67	28.1	31.2	104.5	155.3	1.18	4.48
Fall NH3 with N-Serve	67	2.3	32.9	111.7	148.6	1.10	3.97
Control	0		24.4	110.5	63.8	NA[1]	2.05
Spring BC Urea	34		25.5	101.0	86.9	0.49	3.45
Spring BC Urea	67		29.1	111.0	117.6	0.70	4.04
Spring BC Urea	101		32.2	117.8	136.5	0.66	4.25
Spring BC Urea	134		33.8	128.8	184.6	0.84	4.92
Fall NH3 only	34		24.9	100.3	100.0	0.83	3.05
Fall NH3 only	101		35.1	118.5	155.0	0.82	4.51
Fall NH3 only	134		36.1	127.3	209.3	1.01	5.18
SE			0.59	1.6	6.5	0.06	0.12
Treatments Pr > F			< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Contrasts							
Control vs. N Applied (6 vs. 1,7,8,9,10)			(3.2) **	(1.3)	(38.5) **	NA	(1.07) **
All Fall N vs. All Spring N (1,11,12,13 vs. 7,8,9,10)			0.6 *	(1.4)	8.7 *	0.10 *	0.02
Fall 67 N vs. Spring 67 N (1 vs. 8)			0.2	(5.0) *	6.9	0.09	0.02
Fall N with N-Serve vs. Fall N (5 vs. 1)			1.7 *	5.4 *	9.1	0.11	(0.06)
Fall N with N-Serve vs. Spring N (5 vs. 8)			1.9 *	0.4	16.0 *	0.20 *	(0.04)
N-Serve vs. G77 (1x) (5 vs. 2)			1.8 *	6.5 **	6.9	0.09	(0.14)
N-Serve vs. G77 (2x) (5 vs. 3)			2.5 **	5.0 *	14.2 *	0.18 *	0.05
N-Serve vs. G77 (3x) (5 vs. 4)			0.8	3.7	(1.2)	(0.02)	(0.26)
G77 (1x) vs. G77 (2x) (2 vs. 3)			0.8	(1.5)	7.2	0.09	0.19
G77 (2x) vs. G77 (3x) (3 vs. 4)			(1.7) *	(1.4)	(15.3) *	(0.20) *	(0.31)
G77 (1x) vs. G77 (3x) (2 vs. 4)			(0.9)	(2.9)	(8.1)	(0.11)	(0.12)

* indicates significance <0.10, ** indicates significance <0.01 SAS 9.3 Proc Mixed

[1] NA – Not Applicable because the Control treatment is used within the calculation for NUE

From this location in this type of rainfall pattern, there was no difference between fall and spring applications at the main treatment rate. N-Serve only provided benefit in terms of increasing protein content for fall applications, making it comparable to spring applications. Also, G77 at the high rate displayed promise for effectiveness at this location.

Kansas River Valley Sites (KRV)

Rossville, 2012

The data from this location was collected, and is available in the appendix. However, it will not be discussed due to extremely low yields and high levels of variability within the study. Poor stand, hail damage, and bird damage all played a role in injuring the quality of the study.

Silver Lake, 2013

This location was a coarse-textured silt loam with a low OM of 10-14 g kg^{-1} (Table 2.7). As a result, the soil had a high potential for leaching. This study was blocked in a way that minimized variability within each block, but soil differences between blocks was extensive. Block one contained a very coarse texture continuing past 91 cm, while the other blocks had a finer textured horizon closer to the surface. The first block, as a result, was the lowest yielding, but similar trends in results were seen across the study.

The coarse texture led to N loss during fall AA application and over winter. The soil was dry when applications were made. The last noteworthy rain of 25.4 mm occurred 19 days prior to application (Table 2.8). The first rain of 15.2 mm did not occur till 9 days after application. Soil conditions at application were conducive for ammonia volatilization of AA, especially in a soil with low sorption capacity for N. Soil temperatures remained over 10°C (Table 2.9) most of the winter so temperature was not a limiting factor in the nitrification process as has been seen in other years. As a result, when moisture was available, nitrification most likely occurred, though at a lower rate. Over winter, there were two possible leaching events. Also, the total rainfall for the winter between fall and spring N applications totaled 169 mm (Figure 2.8) which possibly led to some movement of N down through the profile.

In terms of volatilization losses at the time of urea application in the spring, the prospective loss was minimal. The average air temperature was 2°C in the three-day period after application before a 9.6 mm rain was received. As a result, ammonia volatilization from spring urea was likely not an issue at this site.

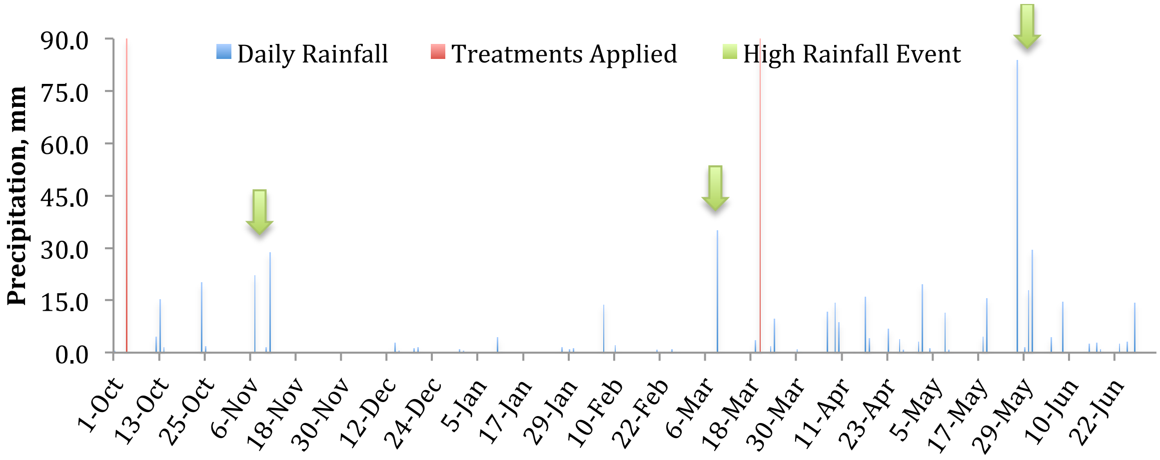

Figure 2.8 Precipitation Levels, Silver Lake in 2012-2013

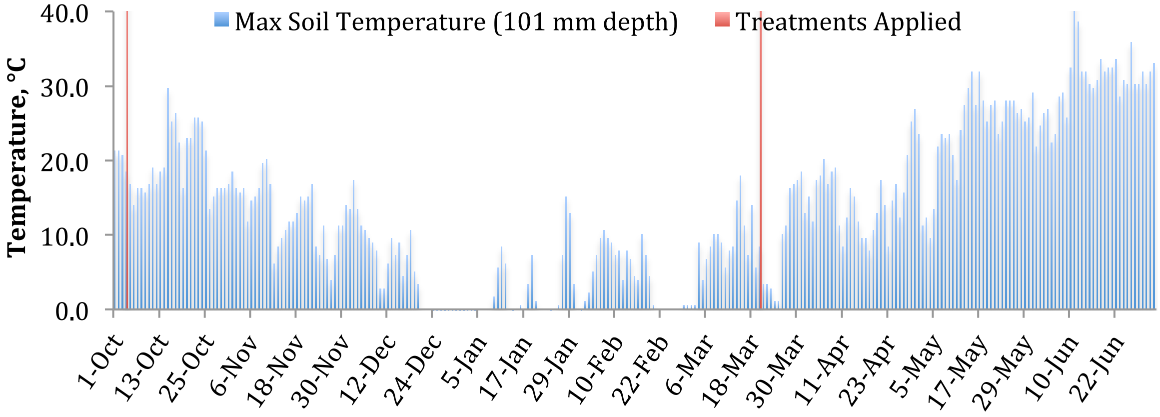

Figure 2.9 Soil Temperatures, Silver Lake in 2012-2013

Two hundred, sixty-nine millimeters of rainfall came between spring applications and May 31 with two possible major leaching events (Figure 2.8). Moisture was available in the fall growing season for a significant level of crop biomass developed in the fall-applied treatments (Figure 2.11). However, the stronger fall biomass did not translate to higher yields or improved NUE. The comparison of the fall and spring N curves display a different response than what was shown at Manhattan in 2013. Spring applications of urea closer to the period of higher uptake of the plant proved superior at this location. There was a strong response to N in both fall and spring applications (Figure 2.10). However, timing played a key role in significantly increasing yield, protein, and flag leaf N with spring application producing higher yields than fall application compared across all rates (Table 2.11). Yields also peaked at a rate of 102 kg N ha^{-1} from spring application, but the 136 kg ha^{-1} rate was required for fall application to receive equal yield.

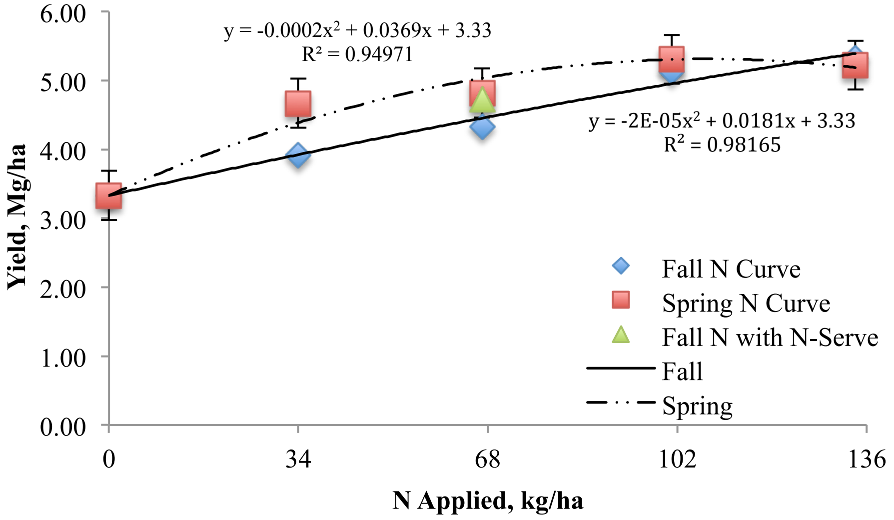

Figure 2.10 Impact of Fall vs. Spring N Application, Silver Lake in 2013

Total N uptake and NUE were similar (Table 2.11) between fall and spring raising the issue of biomass. Biomass levels too high too soon can lead to loss of yield at the end of season because too much leaf canopy can lead to an in canopy environment conducive for disease (Bockus, et. al, 2010). Also, weather, particularly moisture stress can play a role. Too much biomass toward the end of season without the moisture or nutrients required to support and maintain it can lead to a loss in yield. Since fall wheat conditions were very lush and N uptake was similar for both fall and spring applications, I would suspect the yield difference to be caused by some N leaching and high fall treatment biomass levels. As can be seen in Figure 2.11, biomass was higher from the fall applications than the spring applications. As a result, yields may have been reduced because the relatively dry spring was unable to support lush growth with fall applied N. Fall applications at this location under this type of soil texture and under these moisture conditions may not be advisable.

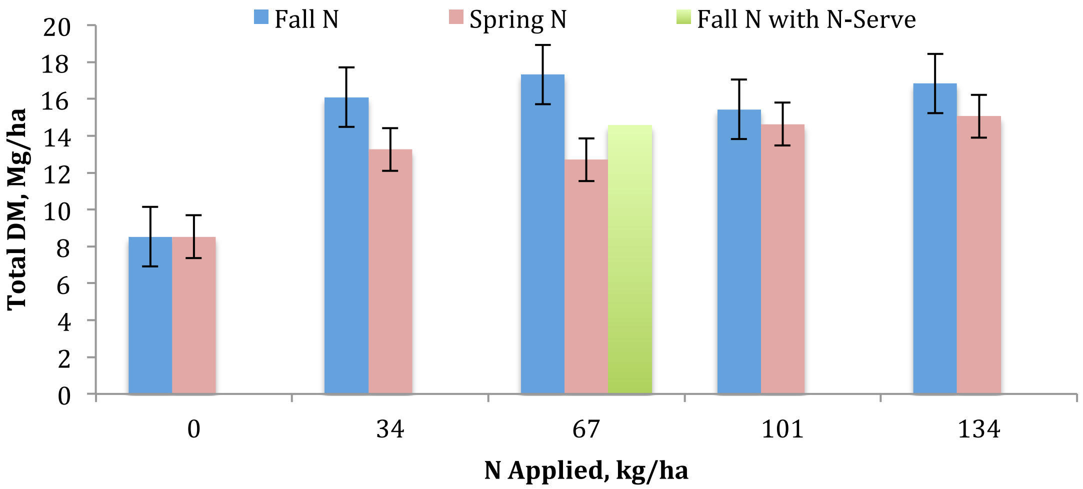

Figure 2.11 Total Dry Matter, Silver Lake in 2013

At this location, fall N with N-Serve did improve yield in comparison with fall AA alone (Figure 2.10). The reason for this yield increase was likely because there was some N loss due to the two irrigation applications that occurred three to five weeks after fall N application. The inhibition of the nitrification process, keeping the applied N in the less mobile NH_4^+ form for a longer period, kept more N in the profile for the winter period. Because soil temperatures were so high for the duration of the winter (Figure 2.9), nitrification was likely occurring throughout most of the winter under conditions when moisture was available. As a result, N was available in the NO_3^- form and highly susceptible to leaching. An inhibitor is especially useful for reducing N loss from high moisture events in the month or so after N application. N-Serve likely reduced N loss during the fall and winter at this site. As a result, N applied with N-Serve in the fall resulted in yields similar to those from spring applications. This is surprising because work done by Touchton (1979) showed that low OM soils have a lower tendency for positive results from N-Serve. The effectiveness of N-Serve is decreased under low OM and high pH soils, but as can be seen by this site it can still produce positive results.

Little difference was seen in the comparison of G77 with N-Serve (Table 2.11). At the lowest rate, G77 produced a significantly lower yield than N-Serve. At the middle rate, G77 had a significant decrease in protein content. However, at the highest rate of G77 no significant differences were seen in any of the parameters measured in comparison with N-Serve.

Table 2.11 Results and Contrasts for Silver Lake in 2013

Treatment	Treatment N	Inhibitor Rate	Flag Leaf N	Protein Content	Total N Uptake	NUE Recovery	Yield
	kg ha^{-1}	L ha^{-1}	g kg^{-1}	g kg^{-1}	kg ha^{-1}	kg kg^{-1}	Mg ha^{-1}
Fall NH3 only	67		31.4	108	184.4	0.78	4.33
Fall NH3 with G77	67	9.4	32.1	104.8	149.5	0.50	4.29
Fall NH3 with G77	67	18.7	35.1	112.8	163.7	0.68	4.60
Fall NH3 with G77	67	28.1	31.9	101.5	166.4	0.71	4.56
Fall NH3 with N-Serve	67	2.3	32.7	103.5	165.1	0.70	4.73
Control	0		31.7	111.5	102.0	NA[1]	3.33
Spring BC Urea	34		32.3	108.5	159.3	1.10	4.67
Spring BC Urea	67		33.3	106.3	171.9	0.79	4.82
Spring BC Urea	101		36.4	114.0	199.4	0.80	5.31
Spring BC Urea	134		39.0	123.5	208.0	0.67	5.22
Fall NH3 only	34		30.5	104.8	185.3	1.40	3.91
Fall NH3 only	101		33.4	109.8	193.7	0.74	5.13
Fall NH3 only	134		36.9	112.8	216.5	0.73	5.32
SE			0.56	1.4	6.1	0.05	0.12
Treatments Pr > F			< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Contrasts							
Control vs. N Applied			(1.2)	0.3	(37.2)	NA	(0.75)
(6 vs. 1,7,8,9,10)			*		**		**
All Fall N vs. All Spring N			(1.1)	(2.1)	1.5	0.03	(0.17)
(1,11,12,13 vs. 7,8,9,10)			*	*			**
Fall 67 N vs. Spring 67 N			(1.0)	0.9	(1.1)	(0.01)	(0.24)
(1 vs. 8)							**
Fall N with N-Serve vs. Fall N			0.7	(2.3)	(2.3)	(0.03)	0.20
(5 vs. 1)							*
Fall N with N-Serve vs. Spring N			(0.3)	(1.4)	(3.4)	(0.04)	(0.04)
(5 vs. 8)							
N-Serve vs. G77 (1x)			0.3	(0.6)	7.8	0.10	0.22
(5 vs. 2)							*
N-Serve vs. G77 (2x)			(1.2)	(4.6)	0.7	0.01	0.07
(5 vs. 3)				*			
N-Serve vs. G77 (3x)			0.4	1.0	(0.7)	(0.01)	0.09
(5 vs. 4)							
G77 (1x) vs. G77 (2x)			(1.5)	(4.0)	(7.1)	(0.09)	(0.15)
(2 vs. 3)							
G77 (2x) vs. G77 (3x)			1.6	5.6	(1.3)	(0.02)	0.02
(3 vs. 4)				*			
G77 (1x) vs. G77 (3x)			0.1	1.6	(8.5)	(0.11)	(0.14)
(2 vs. 4)							

* indicates significance <0.10, ** indicates significance <0.01 SAS 9.3 Proc Mixed

[1] NA – Not Applicable because the Control treatment is used within the calculation for NUE

No improvement was seen from the use of G77 over N-Serve at this location. According to the literature, this type of location with its coarse texture, low OM, and high pH is a soil that N-

Serve does not have as much success. G77 does not seem to show any improvement in this type of situation.

Ottawa, East Central Kansas Sites (ECK)

Ottawa, 2012

In 2012, conditions at Ottawa were similar to Manhattan. There were only two major rain events that occurred throughout the season greater than 38 mm received in a period of three days or less (Figure 2.12). The loss potential as a result was small. The primary loss mechanisms expected at this location would be denitrification due to the poorly drained, clay pan soils that the plot was set up on. Also, ammonia volatilization would be another possibility. In terms of AA application, if the slot is not sealed properly due to conditions being too dry or too wet, then volatilization loss is plausible.

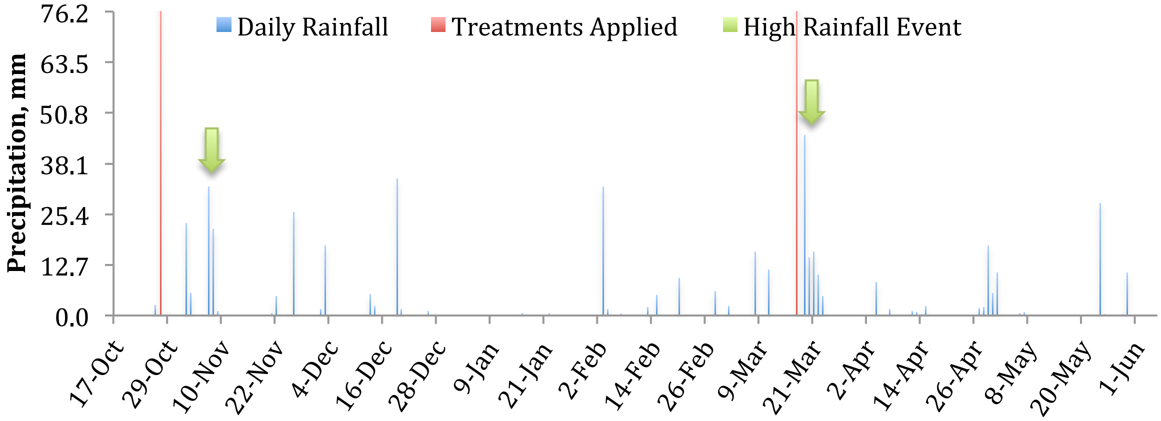

Figure 2.12 Precipitation Levels, Ottawa in 2011-2012

Also, in reference to urea applications, if conditions are dry with minuscule amounts of rain or dew on the surface interacting with the urea granules, then increased volatilization is possible. Immobilization is another possibility for urea in the high residue no-till conditions at this site. Soil temperatures were high after fall applications were made. Maximum daily soil temperatures to a depth of 101 mm moved from 18 C to 10°C over the month of November, but hovered around 10°C throughout the winter months dipping down to 0°C periodically, but then rising again (Figure 2.13). Periodic events of moisture came down during November and

December, then started again in February (Figure 2.12). As a result, nitrification most likely was possible during the months of December, February, and March. However, since the moisture events were not extensive, conducive for denitrification, N loss was likely not high over the winter months even though N was most likely available for loss in the NO_3^- form.

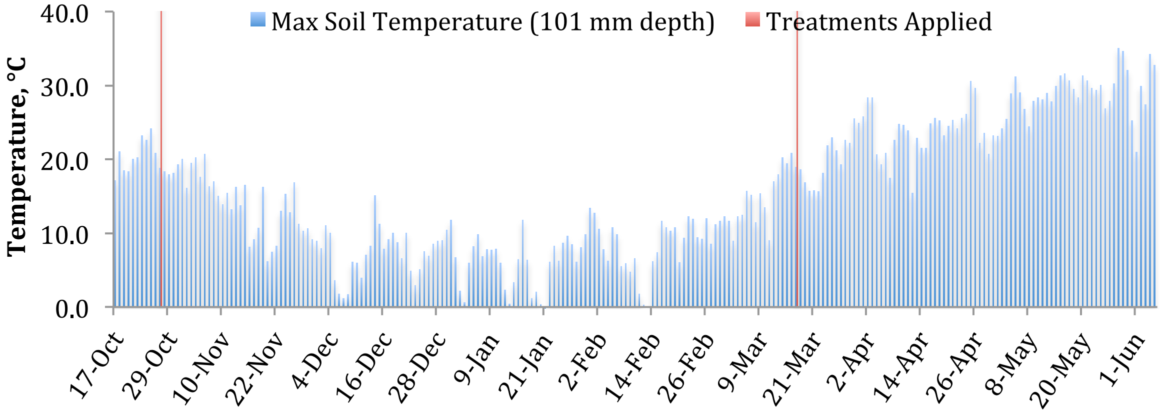

Figure 2.13 Soil Temperatures, Ottawa in 2011-2012

A strong response to the application of N in terms of total N uptake, flag leaf N, and yield was observed at Ottawa in 2012 (Table 2.12). No difference between fall and spring applications of a significance level greater than 0.10 at the 67 kg rate were observed (0.10 significance level). This suggests that losses from volatilization due to the application methods of either fall or spring were negligible. Also, denitrification over the winter months was also likely negligible. The major rainfall events that occurred were within a few days after the fall or spring N applications. Eighty-three mm of rain (Figure 2.12) occurred five days after fall applications were made so most of the N would still have been in the NH_4^+ form even without the use of an inhibitor and loss would be minimal. Ninety-one mm of rain was received one day after urea was applied in the spring ensuring that minimal volatilization losses would occur.

The performance of N-Serve at this location was similar to Manhattan in 2012 (Figure 2.14, Table 2.12). It increased flag leaf N content, but it was not carried through to total N uptake or yield in comparison with fall applied N alone at the same rate. N-Serve did increase yield in comparison with spring N, showing it had a slight improvement, but it was very small.

As a result, N-Serve would not be recommended at this location under these dry conditions due to its lack of performance.

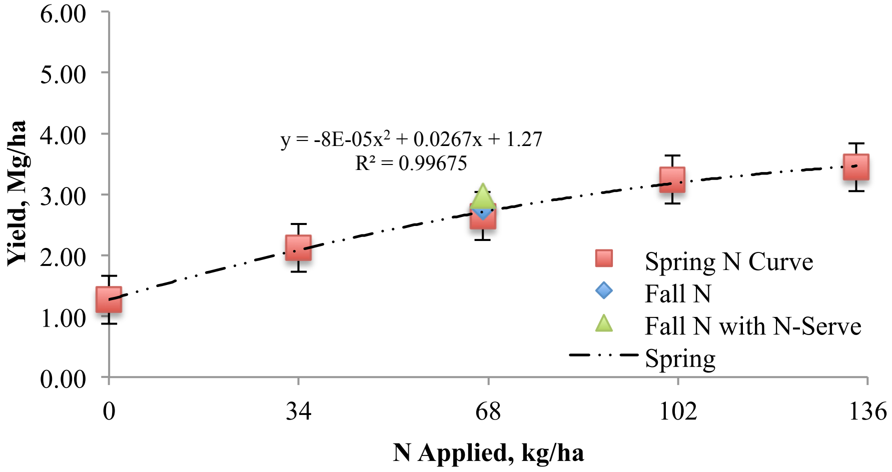

Figure 2.14 Spring N Curve, Ottawa in 2012

In the comparison of N-Serve with the new inhibitor, G77, differences were negligible (Table 2.12). N-Serve increased yield significantly at the 0.10 alpha level in comparison with rate 2 of the new product, as well as, showed better performance in N content in the flag leaf than rate 3. However, overall N uptake and yield were similar across the board between the two inhibitors. Neither inhibitor provided any enhancement of N uptake or yield at these low N loss conditions. At this location, we saw N losses to be minimal just like Manhattan in 2012. A response to applying N was seen, but the timing differential and the use of an inhibitor was negligible.

Table 2.12 Results and Contrasts for Ottawa in 2012

Treatment	Treatment N	Inhibitor Rate	Flag Leaf N	Protein Content	Total N Uptake	NUE Recovery	Yield
	kg ha^{-1}	L ha^{-1}	g kg^{-1}	g kg^{-1}	kg ha^{-1}	kg kg^{-1}	Mg ha^{-1}
Fall NH3 only	67		30.6	116.8	128.5	1.02	2.78
Fall NH3 with G77	67	9.4	31.3	120.7	126.8	0.89	2.82
Fall NH3 with G77	67	18.7	31.5	117.8	118.1	0.92	2.69
Fall NH3 with G77	67	28.1	30.9	118.4	132.7	1.03	2.79
Fall NH3 with N-Serve	67	2.3	32.4	119.4	145.6	1.20	2.98
Control	0		26.9	126.4	45.9	NA[1]	1.27
Spring BC Urea	34		28.5	110.8	74.1	0.61	2.12
Spring BC Urea	67		31.7	116.6	125.6	0.99	2.64
Spring BC Urea	101		33.5	122.3	143.4	0.77	3.24
Spring BC Urea	134		34.3	130.8	169.9	0.77	3.45
SE			0.49	1.2	7.2	0.08	0.10
Treatments Pr > F			< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Contrasts							
Control vs. N Applied			(2.8)	3.4	(40.5)	NA	(0.79)
(6 vs. 1,7,8,9,10)			**	*	**		**
Fall N vs. Spring N			(0.5)	0.0	5.3	0.07	0.07
(1 vs. 8)							
Fall N with N-Serve vs. Fall N			0.9	1.5	6.3	0.08	0.09
(5 vs. 1)			*				
Fall N with N-Serve vs. Spring N			0.4	1.5	11.6	0.15	0.17
(5 vs. 8)							*
N-Serve vs. G77 (1x)			0.6	(0.4)	8.3	0.10	0.07
(5 vs. 2)							
N-Serve vs. G77 (2x)			0.5	1.0	10.4	0.13	0.14
(5 vs. 3)							*
N-Serve vs. G77 (x3)			0.8	0.8	6.4	0.08	0.09
(5 vs. 4)			*				
G77 (1x) vs. G77 (2x)			(0.1)	1.4	2.2	0.03	0.06
(2 vs. 3)							
G77 (2x) vs. G77 (3x)			0.3	(0.3)	(4.0)	(0.05)	(0.05)
(3 vs. 4)							

* indicates significance <0.10, ** indicates significance <0.01 SAS 9.3 Proc Mixed

[1] NA – Not Applicable because the Control treatment is used within the calculation for NUE

Ottawa, 2013

The soil at this location was a poorly drained silt loam with a high OM level of 30 g kg^{-1} and a pH of 6.4 (Table 2.7). This site also has a high potential for N loss from denitrification. However, weather conditions were once again unsuitable for major losses from this type of loss mechanism. Nitrogen in the mobile NO$_3^-$ form was most likely not the limiting factor in terms of denitrification losses. Suitable conditions for nitrification likely occurred over the winter months (Figure 2.15, 2.16). Anhydrous Ammonia has self-inhibiting properties in the first few weeks to a month after application when the free ammonia has a negative effect on the nitrifying bacteria. However, nitrification was possible during the months of January and February when soil temperatures (Figure 2.16) fluctuated above 8°C and rainfall provided moisture for the soil. Denitrification was limited by the lack of extensive moisture. Only two potential rain events over 38 mm occurred during the period between fall and spring applications (Figure 2.15), and only one potential event occurred toward the end of May after plant uptake of N was about finished. The total rainfall between fall and spring applications was 231 mm which was a fair amount in comparison with the other locations. However, conditions were not feasible for denitrification, as the data will show below.

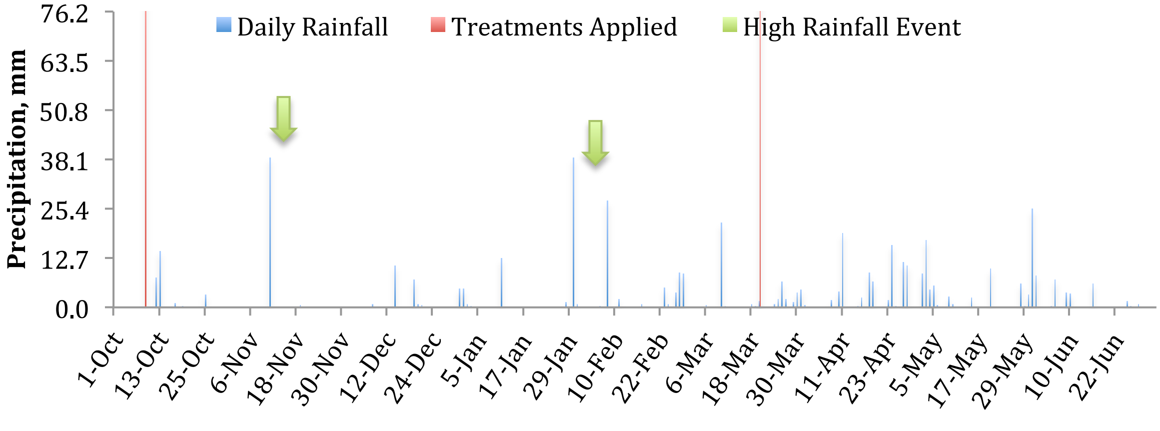

Figure 2.15 Precipitation Levels, Ottawa in 2012-2013

At the time of fall AA applications, loss from volatilization due to poor sealing was minimal. Rain was received 13 days prior to application and the soil was a finer texture with high OM so the sorption capacity at the time of application was excellent.

Spring top-dress of urea had a high potential for loss due to volatilization at this location. Conditions after applications were conducive for high volatilization losses. High air temperatures (15°C), for the seven days before a 6.6 mm rain event pushed the urea into the profile, three rain events less than 2 mm, and a fair amount of surface residue all played a role in creating excellent conditions for ammonia loss (Hargrove, 1988).

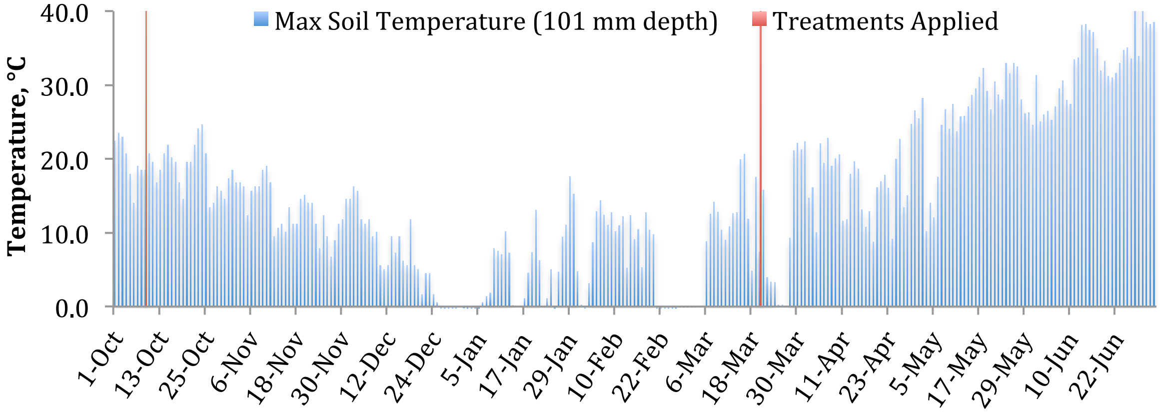

Figure 2.16 Soil Temperatures, Ottawa in 2012-2013

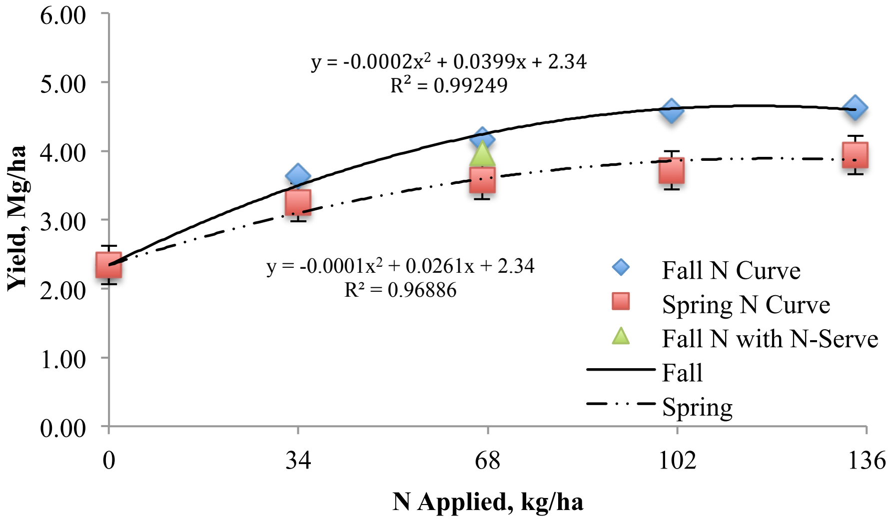

Figure 2.17 Impact of Fall vs. Spring N Application, Ottawa in 2013

At Ottawa, we saw an excellent response in yield with the addition of N (Figure 2.17). Fall applications with AA increased yield, flag leaf N, total N uptake and NUE significantly more than spring applications with urea (Table 2.13). Factors involved in this result likely include high volatilization loss under the no-till situation when the urea was applied. Also, spring applications in the dry environment were not able to make up enough biomass to capture the difference in DM present where N was fall applied (Figure 2.18). A balance in biomass is critical for an environment, and it differs with weather patterns and rainfall/moisture received

Table 2.13 Results and Contrasts for Ottawa in 2013

Treatment	Treatment N	Inhibitor Rate	Flag Leaf N	Protein Content	Total N Uptake	NUE Recovery	Yield
	kg ha^{-1}	L ha^{-1}	g kg^{-1}	g kg^{-1}	kg ha^{-1}	kg kg^{-1}	Mg ha^{-1}
Fall NH3 only	67		32.5	122.8	134.7	0.92	4.16
Fall NH3 with G77	67	9.4	34.4	125.5	135.8	0.93	4.15
Fall NH3 with G77	67	18.7	33.5	124.5	124.7	0.79	4.09
Fall NH3 with G77	67	28.1	33.9	127.3	155.3	1.18	4.11
Fall NH3 with N-Serve	67	2.3	33.3	134.5	148.6	1.10	3.97
Control	0		25.5	116.3	63.8	NA[1]	2.34
Spring BC Urea	34		28.4	119.5	86.9	0.49	3.26
Spring BC Urea	67		31.0	123.0	117.6	0.70	3.58
Spring BC Urea	101		33.9	134.5	136.5	0.66	3.72
Spring BC Urea	134		34.1	130.0	184.6	0.84	3.94
Fall NH3 only	34		30.0	114.3	100.0	0.83	3.63
Fall NH3 only	101		36.0	137.3	155.0	0.82	4.58
Fall NH3 only	134		38.0	140.5	209.3	1.01	4.63
SE			0.5	1.35	4.8	0.05	0.1
Treatments Pr > F			< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Contrasts							
Control vs. N Applied			(3.8)	(5.7)	(38.1)	NA	(0.80)
(6 vs. 1,7,8,9,10)			**	**	**		**
All Fall N vs. All Spring N			1.1	1.0	17.8	0.19	0.31
(1,11,12,13 vs. 7,8,9,10)			**		**	**	**
Fall 67 N vs. Spring 67 N			0.8	(0.1)	19.3	0.25	0.29
(1 vs. 8)					**	**	**
Fall N with N-Serve vs. Fall N			0.4	5.9	(2.3)	(0.03)	(0.09)
(5 vs. 1)				**			
Fall N with N-Serve vs. Spring N			1.1	5.8	17.0	0.22	0.20
(5 vs. 8)			*	**	**	**	**
N-Serve vs. G77 (1x)			(0.6)	4.5	(0.2)	(0.00)	(0.09)
(5 vs. 2)				*			
N-Serve vs. G77 (2x)			(0.1)	5.0	0.7	0.01	(0.06)
(5 vs. 3)				**			
N-Serve vs. G77 (3x)			(0.3)	3.6	(2.0)	(0.02)	(0.07)
(5 vs. 4)				*			
G77 (1x) vs. G77 (2x)			0.5	0.5	0.9	0.01	0.03
(2 vs. 3)							
G77 (2x) vs. G77 (3x)			(0.2)	(1.4)	(2.4)	(0.03)	(0.01)
(3 vs. 4)							
G77 (1x) vs. G77 (3x)			0.3	(0.9)	(1.5)	(0.02)	0.02
(2 vs. 4)							

* indicates significance <0.10, ** indicates significance <0.01 SAS 9.3 Proc Mixed

[1] NA – Not Applicable because the Control treatment is used within the calculation for NUE

(Asebedo, Personal Communication). As a result, fall applications had the edge in more N uptake and higher yields across the board. Also, another factor that benefited fall applications was the reduced potential for loss. Spring applications had a high potential for volatilization after application, resulting in reduced availability of N for the plant. The combination of minimal fall growth and spring ammonia volatilization losses resulted in reduced yields from spring treatments.

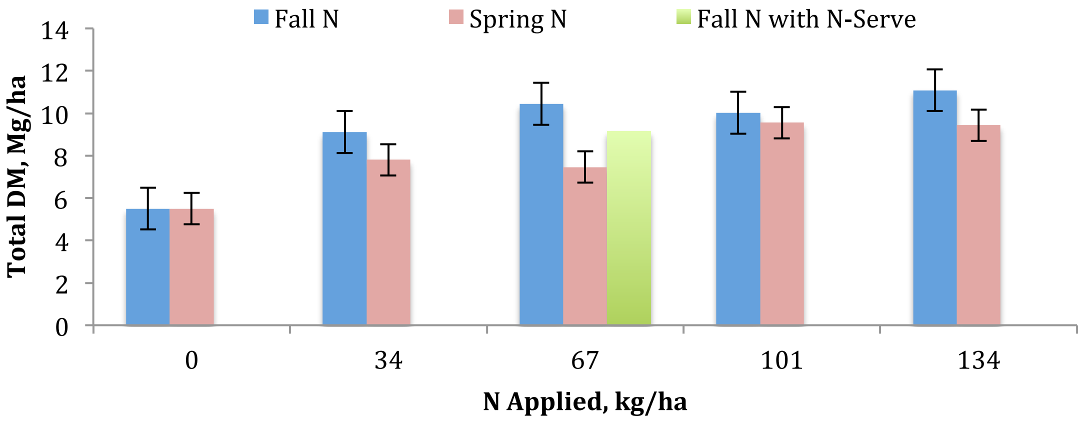

Figure 2.18 Total Dry Matter, Ottawa in 2013

In comparing fall AA applications with or without the use of N-Serve, we saw no difference in N uptake or yield (Figure 2.17). However, an increase in protein content was once again seen, similar to that found at the 2013 Manhattan location. More N was available to move into the grain at the end of the season. Yield was capped due to environment stresses, but more N was translocated at the end of the season while grainfill was occurring.

Usage of N-Serve as an inhibitor was useful in increasing the quality of grain (Table 2.13). G77 did not provide a similar increase in protein content as N-Serve. Anhydrous ammonia with G77 treatments had significantly lower protein content in comparison with plots receiving AA with N-Serve. All other factors like flag leaf N, NUE, N uptake, and yield were all similar. No benefit was seen from the use of G77 at this location in comparison with N-Serve.

G77 Performance

Table 2.14 G77 Rate Comparison

Effect	Flag Leaf N	Protein Content	Total N Uptake	NUE Recovery	Yield
			P > F		
Inhibitor Rate	0.879	0.633	0.253	0.182	0.747
Inhibitor Rate*Year	0.605	0.525	0.976	0.946	0.682
Inhibitor Rate*Location	0.146	0.138	0.758	0.398	0.588
Inhibitor Rate*Location*Year	0.883	0.961	0.853	0.896	0.545

In looking at the interactions between rates across years and locations, no difference was found between the rates of G77 at the 0.10 significance level. However, these rates were selected arbitrarily for the experiment to determine which way to focus rates in future experiments. Below is a chart showing the rate variability within the study.

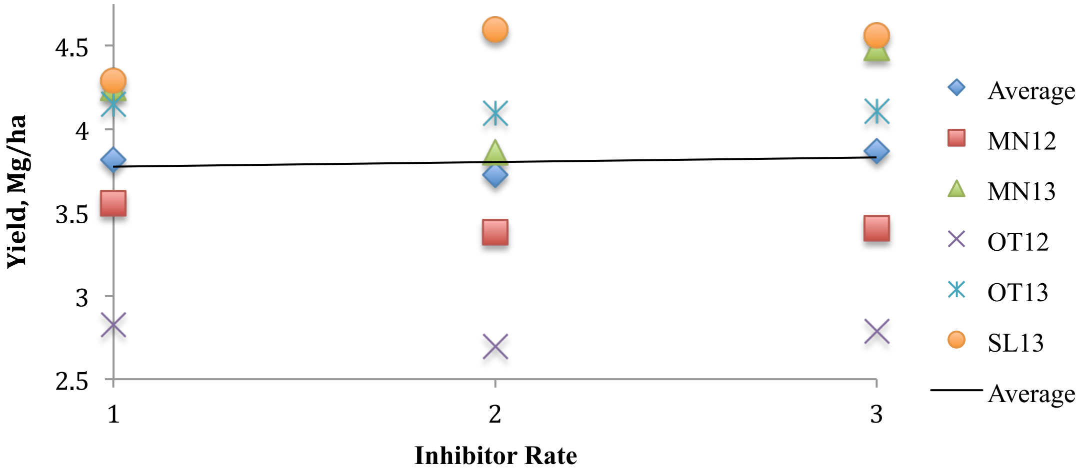

Figure 2.19 G77 Rate by Yield Comparison

With this type of work, precise placement with minimal error in relation to rate is required for an experiment of this nature. The equipment used in this study for placement of the experimental inhibitor was potentially variable. Calibration of the variable rate pump to measure specific rates was done each study year. As a result, proper rates were made accurately. However, distribution between the coulters at the differing rates was likely variable. Steps were taken to minimize the variability in the system, but exact distribution between coulters within the plot area is not guaranteed.

In future work, research should look at possibly raising the inhibitor rates to determine whether or not effectiveness will increase because rate three (highest rate) trended toward the highest yield, but was not significant, as can be seen by the pooled table above.

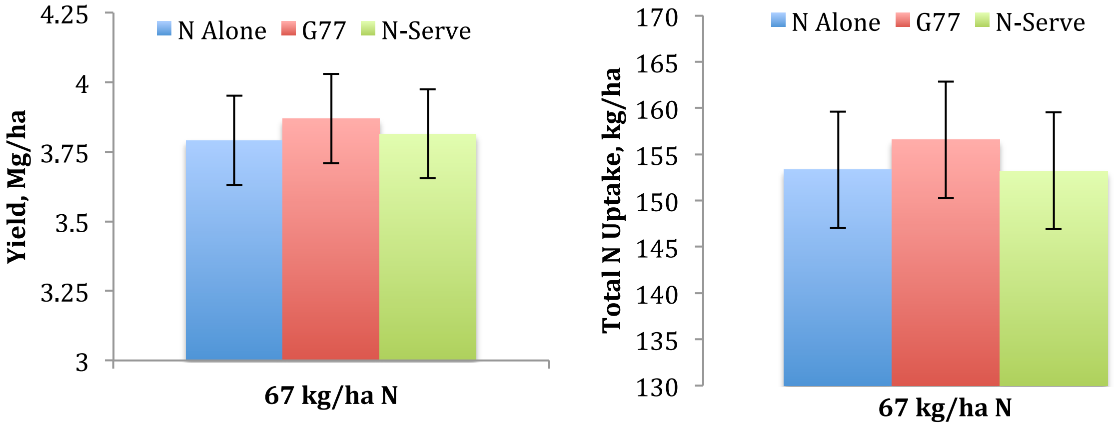

Figure 2.20 Combined Data Inhibitor Comparison

In the comparison between G77 and N-Serve, G77 improved yield and total N uptake slightly across all sites. The performance was not significant, however, it may have a future because of its slight increase across all sites in comparison with N-Serve. The performance of G77 as a nitrification inhibitor applied on wheat will need further research to determine the extent of its usefulness.

Conclusions

In the past two years at six locations, we have seen a variety of results from fall vs. spring application of N and the use of a nitrification inhibitor with fall applied AA. This is likely due to differences in soils between sites, and differences in weather between years, as nitrogen response and efficiency has a direct interaction with weather patterns. Nitrogen loss mechanisms are triggered and impacted strongly by temperature and moisture. With the past two years being low rainfall years, the response to specific management tools like timing, source, and use of a nitrification inhibitor were minimal. One must be sure to remember location and weather patterns when correlating this research with production. High moisture environments require a different strategy to attack N loss mechanisms than low moisture environments. With the low moisture environments, especially during winter months, commonly found in Kansas, producers have more flexibility in terms of nitrogen management for wheat, than producers in the mid-south of the eastern corn-belt.

In terms of fall application of AA pre-plant versus spring application of urea as top-dress at Feekes 4, conclusions are site-specific. In environments where moisture is commonly the limiting factor during the early spring growing season, applying N in the fall will allow more N to be available to the plant close to the root surface and support good fall growth. With limited N available to the plant over winter in the traditional spring application system, fall growth is often reduced. However, this can be easily dealt with by applying a starter nitrogen application with the grain drill, air-seeder, or broadcast preplant. Some fall N applications are critical for fall growth in winter wheat in dry, coarse-textured soil environments where water is often limited and N loss mechanisms such as leaching are an issue.

However, this does not work in all situations. With too much biomass early, yields can be reduced from disease or inefficient use of soil moisture. This phenomenon was seen at KRV/SL13, where two fall irrigations and N applied in the fall provided an avenue for very lush wheat. In this coarse-textured soil, some N was also probably lost over the winter months because of leaching. As a consequence, applying all N as a fall application in coarse textured soils with low OM is not recommended. Soils with a high leaching potential are less likely to be able to hold N in the soil for an extended period of time. Smaller rainfall events are able to move N out of the system in a coarse-textured soil in comparison with heavy textured soils. As a result, timely management of N applications is crucial.

Being able to apply all N in the fall on winter wheat will assist the producer in balancing the heavy-laden time schedule in the spring months when managing other aspects of his production system. In the dry Kansas environments, as seen in 2012 and 2013, a producer can apply all N in the fall as ammonia on many medium to fine textured soils. But to maximize yield and NUE, the producer must also strive maintain appropriate biomass levels for the environment, as well as, being site-specific in his applications. Managing fall growth can be done using practices other than just fall N rates Practices such as a later planting date or a reduced seeding rate with an earlier plant date can also be used. As a result, if the producer decides fall N applications are his main option, then he must take note of his soil type. Coarse-textured soils that are highly leachable may require spring applications to reduce N loss and maximize productivity. Heavy-textured soils with limited leaching potential normally have a higher water holding capacity which can buffer N loss. In these soils, higher levels of rainfall/ moisture are often required for substantial N losses.

If a producer decides fall applications are his only option on coarse-textured soils, then the use of a nitrification inhibitor may be considered. Performance was mixed across all locations in this study. However, AA with NI did increase yield in comparison with fall N alone at SL13, producing yield equivalent to spring topdressing. N-Serve also increased protein content at MN13 and OT13. N-Serve, even in this low moisture environment, added benefit to the system in 3 0f the 5 studies. In the current wheat market with high protein content not rewarded, but low protein penalized, the use of N-Serve would not likely be profitable in dry, heavy-textured soil environments. However, use with fall applications on coarse-textured soils, while not recommended, showed positive results at SL13.

The final objective of the study dealt with the performance of G77 in comparison with N-Serve. In general, while slight differences in performance of the two inhibitors were noted, no significant difference in yield was observed between yield or N uptake at any of the five sites between N-Serve and the highest rate of G77. Only limited differences were found between the different rates of G77, but the highest rate trended to have the best performance over the five sites measured. In future research under conditions more suitable to N loss, G77 may perform better than at these locations. Also, by increasing the rate, performance may improve. While G77 at the highest rate did not differ in performance with N-Serve, G77 did show a slight trend towards an increase in yield and N uptake over N-Serve and only N applied when all sites are combined together. G77 shows weak, but somewhat consistent performance across sites. Maybe with an increase in rate, performance may increase.

It is important to also note that at the Ottawa location in 2013, spring urea did not perform as well as fall AA. At that site, conditions were ideal for volatilization losses from the surface applied urea. One important N management tool that was not evaluated in this study was a urease inhibitor. Future work comparing fall AA and spring urea should consider the use of a urease inhibitor such as NBPT.

This research evaluated some N management strategies to increase yield, minimize N loss, and increase the efficiency of wheat production, while under a time-sensitive system.

Environmental impacts, population inflation, and high input costs all plague our current society, placing pressure on the agricultural sector to fine-tune the system. As a result, producers need to develop a better understanding of their soil types, weather patterns, and yield potentials to be site-specific in managing the nitrogen nutrition of the their crop for optimal performance at a high efficiency level with minimum N loss.

References

Asebedo, A. R., December 10, 2013. Personal Communication.

Bockus, W. W., et. al. 2010. Compendium of Wheat Diseases and Pests, 3rd Ed.

Brown, J. M., and W. V. Bartholomew. 1962. Sorption of Anhydrous Ammonia by Dry Clay Systems. *Soil Sci. Soc. Am. J. 26*(3):258-262.

Combs, S., J. Denning, and K. D. Frank. 1998. Sulfate-Sulfur. *North Central Regional Research Publication.* 221:35-40

Combs, S. M., and M. V. Nathan. 1998. Soil Organic Matter. *North Central Regional Research Publication.* 221:53-58

Frank, K., D. Beegle, and J. Denning. 1998. Phosphorus. *North Central Regional Research Publication.* 221:21-30

Gelderman, R. H., and D. Beegle. 1998. Nitrate-Nitrogen. *North Central Regional Research Publication.* 221:17-20

Gelderman, R. H., J. L. Denning, and R. J. Goos. 1998. Chlorides. *North Central Regional Research Publication.* 221:49-52

Hargrove, W. L. (1988). Evaluation of Ammonia Volatilization in the Field. *Production Agriculture , 1* (2), 104-111.

Keller, G. D., and D. B. Mengel. 1986. Ammonia Volatilization from Nitrogen Fertilizers Surface Applied to No-till Corn. Soil Science Society of America Journal. 50.

Papendick, R. I., and J. C. Engibous. 1980. Performance of Nitrification Inhibitors in the Northwest. Nitrification Inhibitors-Potentials and Limitations. 107-117.

Rice, C. W., and M. S. Smith. 1984. Short-term immobilization of fertilizer nitrogen at the surface of no-till and plowed soils. Soil Science Society of America Journal. 48:295-297.

Roberts, T. L. 2007. Right product, right rate, right time and right place...the foundation of best management practices for fertilizer. Retrieved from IPNI:

http://www.ipni.net/ipniweb/portal.nsf/0/55C6FA392D96B89885257A8C0057EDAA/$FILE/Roberts_2007_4Rs.pdf.

SAS Institute. 2011. Release 9.3 ed. SAS Inst., Cary, NC.

Touchton, J. T., R. G. Hoeft, and L. F. Welch. 1978. Effect of Nitrapyrin on Nitrification of Fall and Spring-Applied Anhydrous Ammonia. Agronomy Journal. 70.

Touchton, J. T., R. G. Hoeft, L. F. Welch, and W. L. Argyilan. 1979. Loss of Nitrapyrin from Soils as Affected by pH and Temperature. Agronomy Journal. 71.

Touchton, J. T., R. G. Hoeft, L. F. Welch, D. L. Mulvaney, M. G. Oldham, and F. E. Zajicek, 1979. N Uptake and Corn Yield as Affected by Applications of Nitrapyrin with Anhydrous Ammonia. *Agronomy Journal*. *71*:238-242.

Watson, M. E., and J. R. Brown. 1998. pH and Lime Requirement. *North Central Regional Research Publication.* 221:13-16

Warncke, D., and J. R. Brown. 1998. Potassium and Other Basic Cations. *North Central Regional Research Publication.* 221:31-34

Web Soil Survey. USDA. Accessed 9-20-2013. http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

Wolt, J. D. 2004. A meta-evaluation of nitrapyrin agronomic and environmental effectiveness with emphasis on corn production in the Midwestern USA. Nutrient Cycling in Agroecosystems. 69:23-41.

Chapter 3 - Timing of Nitrogen Application and Nitrification Inhibitors as Management Tools to Enhance Nitrogen Use Efficiency in Corn (*Zea maize*)

Abstract

Two of the mechanisms of nitrogen (N) loss common in Kansas corn production are denitrification and leaching. By reducing these losses, producers can increase yield and lower input costs with less impact on the environment. This study compares the relative efficiency, as measure by N uptake and yield of fall versus spring preplant ammonia N applications. In addition, the use of a nitrification inhibitor applied with anhydrous ammonia (AA) as a means to retain N in the ammonium form, lower N losses and increase N uptake, was also compared.

This project was initiated in the fall of 2011 and was conducted through the 2012 and 2013 growing seasons at three locations differing in N loss potential among the soils and rainfall patterns. Three different soils were chosen: a high yielding silt loam site at the Agronomy North Farm in Manhattan with moderate potential for denitrification loss; a lower yielding silt loam site near Ottawa KS with a high potential for denitrification loss; and a high yielding irrigated, sandy loam near Rossville KS with a very high potential for leaching loss. Conditions in the eastern part of Kansas were not conducive to high losses of N through leaching or denitrification due to the low level of rainfall throughout the two growing seasons. Small responses to an inhibitor were still noted at some locations, as well as, a response to timing was seen at some locations.

Introduction

Environmental impacts from the overuse of nutrients are very high. The Gulf of Mexico and the Chesapeake Bay area are two examples of water bodies that are impacted by that phenomenon. As a result, nutrient management has become a great concern in the U.S. One of main nutrients that is responsible for pollution of water sources is nitrogen (N) (Keeney, 1982). In Kansas, losses of N through denitrification or leaching have been measured and indeed are possible under high rainfall events. Nitrogen is a very mobile nutrient in the soil system when in the form of NO_3^-. Using tools such as fertilizer source or nitrification inhibitors to minimize the amount of N present in the mobile form NO_3^- in the soil is but one tactic of current day N management. The use of anhydrous ammonia (AA) as an N source is a tool to keep from increasing N in the NO_3^- form for a period of time, since AA is applied completely in the NH_3 form, and reacts with water to form NH_4^+. Another benefit to the use of AA is cost. Ammonia has traditionally been the lowest cost source of N on the market, making it very popular with farmers. However, since it is a gas, applied as a liquid under pressure, it is highly volatile when applied to the surface. As a result, subsurface applications are required. Subsurface applications in previous years required extensive tillage, high fuel costs, and a large amount of precious time. With technologies such as the John Deere 2510H High Speed Low Draft Applicator, producers in no-till systems are able to utilize AA with minimal soil disturbance, lower time required for application, and lower horsepower requirement.

The lower cost of AA as a fertilizer as well as its potential for reducing N losses makes it a valuable tool for production. One major drawback with AA applications is time required for application. Nitrogen applications are only one of the activities that take up the time of the producer in the overall production. Other time sensitive activities like planting, spraying etc. make fertilizer applications difficult to balance. Ammonia requires more time to apply than other products like urea. Thus, balancing applications within the year when activity is decreased is greatly desired. Many producers prescribe to the strategy of fall applications with AA late in the fall, after harvest, to manage the time-balance factor. This practice, for corn, leaves N in a vulnerable position for loss for at least seven months from application in late October or early November, until uptake by the corn plant the following June or July.

Weather and soil textures play a major role in the amount of N lost in a system, as well as, the mechanism by which the N may be lost. Differing soil textures affect the level of which N can be held in the soil, whether organic or inorganic (Tremblay, et al., 2012). In re-evaluating the practice of fall applications for corn, soil texture and weather conditions must be taken into account. As a result, in this research we will compare fall applications to spring applications of AA in different soil types under differing moisture regimes. This research will not measure N loss directly between fall and spring applications, but will measure the differences in total N uptake and crop yield at the different N rates. There are many different strategies available for producers to apply N under high N loss environments, including N timing. In some areas, controls are in place today to limit N application options. Under low N loss environments, more flexibility is commonly available.

Another tool available to help increase the longevity of N in the NH_4^+ form is the usage of a nitrification inhibitor. The purpose of a nitrification inhibitor is to slow down the nitrification process in which NH_4^+ is converted to NO_3^- by microbial populations. Nitrification inhibitors are formulated to target the microbial populations involved. In Kansas, success from the use of N-Serve (nitrapyrin, marketed by Dow Chemical) has been noted (Ball, et.al, 1978). Its performance has been variable at best, due to many different factors such as temperature or rainfall patterns leading to N loss. In a meta-analysis completed by Wolt, it was found that there was only a 75% success rate in the performance of the product under varying conditions (Wolt, 2004). Work completed by Touchton saw a lack of performance, as measured by enhanced N uptake or crop yield under dry environments (Touchton, et. al, 1978). However, even in studies where N-Serve did not increase yield, it was found decrease nitrate accumulation and increase ammonium retention under certain soil/weather conditions (Touchton, et. al, 1978).

N-Serve is a volatile compound which works well in AA, but still requires incorporation when applied with other products. As a result, in today's no-till production systems where urea or UAN solutions are left on the soil surface, there is a need for new and improved nitrification inhibitors with less variability, less volatility, and increased retention of ammonium. G77 is a new nitrification inhibitor being tested against N-Serve for better performance and stability.

The usage of AA with a nitrification inhibitor is an important option for corn production in the Midwest where producers must balance the tradeoffs between time with increasing input costs and increasing environmental concerns. The objectives of this project were to: determine the relative impact of fall and spring applications of AA with and without a nitrification inhibitor on corn N uptake and yield on soils with differing N loss potentials; and evaluate the performance of a new nitrification inhibitor being tested by Koch Agronomic Services LLC. in comparison with the established product, N-Serve.

Materials and Methods

The study was initiated in the fall of 2011 and was conducted for two years, 2012 and 2013. The locations at which the study was conducted were the KSU Agronomy North Farm (NF) at Manhattan; Kansas River Valley (KRV) Experiment Field, Rossville unit; and the East Central (ECK) Experiment Field. Plots were arranged in the field using a randomized complete block design with four replications. The blocks at each location were arranged to maximize uniformity within the block. All locations were set up using 3 m by 15 m plots with 7.6 m alleys between blocks. Alleys were used for equipment maneuvering between treatments and applicator calibration.

The study consisted of a total of 17 treatments. Only 14 treatments were implemented in 2012, with the three added in 2013. Specifics about the treatments can be found in Table 3.1. The treatments were split into two application timings: fall applications of AA made when soil temperatures averaged 13°C or below; and spring applications with AA made approximately seven days or more prior to planting. Tables 3.2 and 3.3 include key dates which define the specific dates or application. A John Deere 2510 H, High Speed Low Draft applicator was used to make the AA applications. The three m coulter toolbar was set up at 0.5 m coulter spacing, and the AA was applied at a depth about 13 cm. The applicator was calibrated over a distance of 91 m to apply 67 kg N ha^{-1} at a speed of 11.2 km h^{-1} using onboard weigh scales. Different application rates were made by adjusting application speed. The nitrification inhibitors were applied using a Raven Sidekick variable rate injection system mounted to the tool bar. N-Serve was applied directly into the AA stream right before the manifold at the recommended rate of 2.3 L ha^{-1}. G77 was applied 1.3 cm behind the AA stream directly in the application furrow. Since G77 was not mixed directly with the ammonia prior to application, it is likely that the distribution of G77 with the AA was not uniform. This could explain why the results with G77 were more variable that those with N-Serve. Since the G77 product at the high rate of application contained approximately 10 kg N, the different G77 rates were balanced with added UAN to maintain a constant N rate. UAN was also applied at a rate of 10 kg N ha^{-1} with all AA applications that did not receive a G77 treatment to make all treatments similar.

Table 3.1 Treatments Utilized in the Experiment

Year	Treatment	Nitrogen Rate		N Source	Inhibitor	
		Fall	Spring		Source	Rate
		kg ha^{-1}				L ha^{-1}
2012-2013	1	112		NH_3		
2012-2013	2	112		NH_3	G77	9.4
2012-2013	3	112		NH_3	G77	18.7
2012-2013	4	112		NH_3	G77	28.1
2012-2013	5	112		NH_3	N-Serve	2.3
2012-2013	6		0	Control		
2012-2013	7		56	NH_3		
2012-2013	8		112	NH_3		
2012-2013	9		112	NH_3	G77	9.4
2012-2013	10		112	NH_3	G77	18.7
2012-2013	11		112	NH_3	G77	28.1
2012-2013	12		112	NH_3	N-Serve	2.3
2012-2013	13		168	NH_3		
2012-2013	14		224	NH_3		
2013 only	15	56		NH_3		
2013 only	16	168		NH_3		
2013 only	17	224		NH_3		

Cultural Practices

The corn was planted in 76 cm wide row spacing on the dates found in Tables 3.2 and 3.3. Phosphorus, K, and Gypsum were applied corresponding to the KSU recommendations for the soil test levels found at each site each year. At the Manhattan location in 2012 and 2013, a starter fertilizer application, of 18 kg N ha^{-1} and 18 kg P ha^{-1} as a UAN/APP fertilizer was made in-furrow with the planter. At the Ottawa location in 2012, a broadcast application of 10 kg N ha^{-1}, 47 kg P ha^{-1}, 56 kg K ha^{-1}, and 43.5 kg^{-1} Cl ha^{-1} was made prior to planting. In 2013 at Ottawa, 19 kg N ha^{-1} and 47 kg P ha^{-1} as DAP was broadcast one day prior to planting. At Rossville in 2012, a broadcast application of 5 kg N ha^{-1}, 23 kg P ha^{-1}, 14 kg K ha^{-1}, and 7 kg S ha^{-1} as a MAP/KCl/Gypsum blend were made two weeks prior to planting. MAP was broadcast at a rate of 112 kg ha^{-1} over the 2013 Rossville site in late fall prior to the growing season.

Table 3.2 Key Dates of Field Activities, 2012

	Location		
Activities	Manhattan	Rossville	Ottawa
Fall AA Treatments Applied	21-Nov-11	15-Nov-11	18-Nov-11
Spring AA Treatments Applied	15-Mar-12	16-Apr-12	17-Apr-12
Planting Date	10-Apr-12	23-Apr-12	9-May-12
Ear Leaf Sampling Date (R-1)	1-Jul-12	2-Jul-12	Not Collected
Whole Plant Sampling Date (R-5)	23-Jul-12	24-Jul-12	Not Collected
Harvest Date	4-Sep-12	11-Sep-12	6-Sep-12

Table 3.3 Key Dates of Field Activities, 2013

	Location		
Activities	Manhattan	Rossville	Ottawa
Fall AA Treatments Applied	6-Nov-12	5-Nov-12	6-Nov-12
Spring AA Treatments Applied	4-Apr-13	5-Apr-13	17-May-13
Planting Date	30-Apr-13	29-Apr-13	18-May-13
Ear Leaf Sampling Date (R-1)	9-Jul-13	12-Jul-13	1-Aug-13
Whole Plant Sampling Date (R-5)	21-Aug-13	19-Aug-13	5-Sep-13
Harvest Date	19-Sep-13	23-Sep-13	4-Oct-13

Table 3.4 Key Cultural Practices in 2012

	Location		
Cultural Practices	Manhattan	Rossville	Ottawa
GPS Coordinates	39N 12'49.64 96W 35'34.66	39N 12'44.86 96W 35'56.14	38N 32'19.58 95W 14'41.83
Previous Crop	Corn	Double-crop Soybeans	Double-crop Soybeans
Tillage	No-Till	No-Till	No-Till
Irrigation	None	Irrigated	None
Corn Hybrid	P1498HR (Pioneer)	H-9138 3000GT (Golden Harvest)	DKC6269 (Dekalb)
Plant Population	70600 pl ha^{-1}	61800 pl ha^{-1}	52600 pl ha^{-1}

Table 3.5 Key Cultural Practices in 2013

	Location		
Cultural Practices	Manhattan	Rossville	Ottawa
GPS Coordinates	39N 12'44.67 96W 35'42.21	39N 07'06.16 95W 55'30.16	38N 32'19.58 95W 14'41.83
Previous Crop	Double Crop Soybeans	Soybeans	Double Crop Soybeans
Tillage	No-Till	No-Till	No-Till
Irrigation	None	Irrigated	None
Corn Hybrid	DKC61-89RIB (Dekalb)	H9138 3000GT (Golden Harvest)	552RR (Midland)
Plant Population	68000 pl ha^{-1}	75000 pl ha^{-1}	65500 pl ha^{-1}

Soil Sampling and Analysis

In the fall prior to the growing season, soil samples were collected using a Concord hydraulic soil probe, to a depth of 91 cm. A plastic sleeve was placed inside the probe to collect the sample and save it for processing. If the samples were not processed directly after sampling, they were frozen separating them into their specific segments and drying. Four composite samples were taken per location, one per block. Twelve cores were taken per block, separated into different segments and combined to form the composite sample. Each core was separated into 0-15 cm, 15-30 cm, 30-61 cm, 61-91 cm segments. Each segment of cores was then carefully broken up, mixed, and placed into a sample bag.

The samples were then submitted to the KSU Soil Testing Lab for analysis. There the samples were dried at 60°C then ground to pass through a 2 mm sieve. After the soil samples were prepared, the following analysis measurements were made: pH (1:1 soil:water) (Watson and Brown, 1998), OM (Modified Walkley-Black) (Combs and Nathan, 1998), NH_4-N (KCl extraction) (Gelderman and Beegle, 1998), NO_3-N (KCl Extraction) (Gelderman and Beegle, 1998), P (Mehlich-3) (Frank, Beegle, and Denning, 1998), K (NH_4OAc Extraction) (Warncke and Brown, 1998), Ca (NH_4OAc Extraction) (Warncke and Brown, 1998), Mg (NH_4OAc Extraction) (Warncke and Brown, 1998), S (Calcium Phosphate Extraction) (Combs, Denning, and Frank, 1998), and Cl (Calcium Nitrate Extraction) (Gelderman, Denning, and Goos, 1998). The results from the soil sampling can be found in Table 3.7. The values can be converted to kg ha^{-1} by using the following equation: nutrient (ug^{-1}) * 0.134 * depth (cm) = kg (nutrient) ha^{-1}.

Tables 2.6 and 2.7 include key information about the study site and soil test results from the study locations.

Table 3.6 Key Soil Information from Web Soil Survey

Location	Soil Series	Soil Description	Drainage Class	Flooding Class
Manhattan 2012	Reading Silt Loam	Fine-silty alluvium	Well Drained	Rare
Manhattan 2013	Ivan and Kennebec Silt Loams	Fine-silty alluvium	Moderately, Well Drained	Occasional
Rossville 2012, 2013	Eudora Silt Loam	Coarse-silty alluvium	Well Drained	Very Rare
Ottawa 2012, 2013	Woodson Silt Loam	Silty and clayey alluvium	Somewhat, Poorly Drained	None

Table 3.7 Soil Analysis Results

Site	Block	pH	OM	P	K	NH_4-N	$N0_3$-N
Sampling Depth (cm)		15	15	15	15	91	91
			g kg^{-1}	*u*g g^{-1}			
Manhattan 2012	1	6.1	2.2	10.4	158	10.8	3.8
	2	6.3	2.7	11.3	177	9.6	1.9
	3	6.2	2.6	15.9	228	7.9	2.2
	4	6.2	2.8	34.8	246	9.3	2.0
	Average	6.2	2.6	18.1	202	9.4	2.5
Rossville 2012	1	6.8	0.8	17.5	99	4.7	2.6
	2	6.6	0.8	26.5	103	4.7	5.1
	3	6.7	0.8	18.0	134	5.5	5.6
	4	6.9	0.7	12.6	124	6.3	1.9
	Average	6.7	0.8	18.7	115	5.3	3.8
Ottawa 2012	1	6.2	3.0	9.1	145	6.9	2.6
	2	6.1	3.4	10.1	145	8.7	2.6
	3	6.4	2.6	7.4	167	9.1	2.3
	4	6.2	2.2	7.6	190	7.7	2.2
	Average	6.3	2.8	8.6	162	8.1	2.4
Manhattan 2013	1	6.6	2.6	56.1	400	5.8	2.9
	2	6.3	2.3	17.0	279	9.4	1.4
	3	6.6	2.3	47.0	267	8.6	3.5
	4	6.6	2.4	32.1	241	11.6	3.2
	Average	6.5	2.4	38.1	297	8.8	2.7
Rossville 2013	1	8.5	1.0	16.2	131	4.5	3.8
	2	7.7	1.3	15.8	131	5.0	1.7
	3	7.3	1.3	23.0	133	5.7	1.3
	4	6.9	1.1	26.3	133	5.3	1.3
	Average	7.6	1.2	20.3	132	5.1	2.0
Ottawa 2013	1	7.9	2.8	4.8	164	9.2	1.2
	2	7.2	2.9	4.9	175	8.2	1.1
	3	6.7	2.5	10.5	169	8.3	1.5
	4	7.0	2.2	4.1	152	10.5	1.2
	Average	7.2	2.6	6.1	165	9.0	1.2

Ear Leaf Sampling and Analysis

At the R1 growth stage, ear leaf samples were collected from each location in both years. A total of 20 ear leaves were selected from each plot by making two passes in the border rows through the length of the plot randomly selecting the leaf holding the ear. The leaves were then put into brown paper bags and dried at 60°C and ground to pass through a 0.5 mm sieve. The samples were then submitted to the KSU Soil Testing Lab for analysis. There the concentrations of N were determined using a sulfuric acid-hydrogen peroxide digest. The extract containing ammonia was analyzed with a colorimetric procedure (nitropruside-sodium hypochlorite) using RFA Methodology No. A303-S072, Total Kjeldahl Nitrogen.

Whole Plant Sampling and Analysis

At all locations in 2012 and 2013, whole plant samples were collected at the R5 growth stage, except Ottawa in 2012 due to drought. Ten plants were taken from each plot for a composite sample. The ten plants were cut at ground level, five randomly selected from each of the outside rows of the plot. The ears were then removed from the plants; husks and ear shanks were left on each plant. The plants were then weighed for total mass weight (less the ear), then sent through a garden size chipper chopper, breaking up the biomass. A subsample was selected from the shredded sample and placed in a brown paper bag. The subsample was then weighed prior to the drying process as well as after the drying process. The samples were dried at 60°C and ground to pass through a 0.5 mm stainless steel sieve.

After the samples were ground and put into vials, they were submitted to the KSU Soil Testing Lab for analysis. There the concentrations of N were determined using a sulfuric acid-hydrogen peroxide digest. The extract containing ammonia was analyzed with a colorimetric procedure (nitropruside-sodium hypochlorite) using RFA Methodology No. A303-S072, Total Kjeldahl Nitrogen.

Grain Sampling and Analysis

All locations were harvested. At the Manhattan location, the ears from a 1.5 by 5.4 m area from each plot were hand-harvested then shelled using an Almaco thresher/sheller. The bulk grain sample was then weighed, and a subsample taken for analysis purposes. The subsamples were sent through a Dickey John 2100 GAC moisture meter for determining grain moisture and test weight. All yields were then adjusted to the standard 155 g kg^{-1} moisture level for data analysis. All samples were then placed in white cloth bags and dried at 60°C and ground to pass through a 0.5 mm stainless steel sieve. The Rossville site was harvested using a John Deere 3300 combine with an HM 400 Classic Grain Gauge (Harvest Master). The total area per plot harvested for that location was 1.5 by 15.2 m. At the Ottawa location, 1.5 m by 15.2 m area was harvested using a Gleaner E combine with an HM 800 Classic Grain Gauge (Harvest Master). Grain samples were collected from the harvested grain from each plot for analysis.

After samples were harvested, dried, and ground, they were submitted in vials to the KSU Soil Testing Lab for analysis. There the concentrations of N were analyzed using a sulfuric acid-hydrogen peroxide digest. The extract containing ammonia was analyzed with a colorimetric procedure (nitropruside-sodium hypochlorite) using RFA Methodology No. A303-S072, Total Kjeldahl Nitrogen.

The following calculations were used in completing the data analysis:

- Grain N Uptake = Yield (Mg ha^{-1}) * Grain N Content (g kg^{-1})
- Stover N Uptake = Stover Dry Matter (kg ha^{-1}) * Stover N Content (g kg^{-1})/ 10
- Total N Uptake (kg ha^{-1}) = Stover N Uptake + Grain N Uptake (note: this measurement is a slight underestimate as it does not include the N present in the corn cob)
- NUE (kg kg^{-1}) = Total N Uptake Fertilized Treatment (kg ha^{-1}) – Total N Uptake Unfertilized Treatment (kg ha^{-1})) / Applied N Fertilizer (kg ha^{-1})
- Grain Protein Content = Grain N Content (g kg^{-1}) * 6.25

Statistical Analysis

Data analysis was completed using the PROC MIXED procedure at the alpha level 0.10. Blocks and treatments were both set as fixed effects in SAS 9.3 (SAS Institute, 2011). Fixed effect was used for blocks with the PROC MIXED procedure because the blocks were set up in a manner that captured the variability within the specific block. PROC MIXED was used to capture all the results, even with the deleted or missing data points. Outlier data points were removed and considered missing data when the CV for treatment exceeded 25% and there was a reasonable explanation for the extreme diversity in the treatment or in season measurements. Soil variability extremes and poor stand in the specific plot were the two primary reasons for data point deletions at the Manhattan 2013, Rossville 2012, and Rossville 2013 locations. The studies were monitored the entire season on a biweekly basis to assist with the explanations.

Results and Discussion

Combined Analysis

Table 3.8 Pooled Data Effects, Probability of a Greater F

Effects	Ear Leaf N	Total N Uptake	NUE Recovery	Yield
		P > F		
Treatment	<.0001	<.0001	<.0001	<.0001
Block	0.710	0.577	<.0001	0.043
Year	<.0001	<.0001	<.0001	<.0001
Location	<.0001	<.0001	<.0001	<.0001
Location*Year	<.0001	0.000	<.0001	<.0001
Treatment*Year	0.015	0.287	0.578	0.443
Treatment*Location	0.896	0.020	0.104	0.301
Treatment*Year*Location	0.525	0.212	0.553	0.296

All combined data displays strong effects due to treatment, year, and location, however, when combined a strong interaction does not occur. There is not a three-way interaction, but there is a strong location by year interaction. Therefore, the results will be discussed by site by year to uncover the issues involved at each location.

Manhattan, Agronomy North Farm Sites (NF)

Manhattan, 2012

The soil at the 2012 Manhattan site was a well-drained silt loam with an OM content of 26 g kg^{-1}, making it a location with high-yield potential and moderate water holding capacity. In the fall of 2011 and during the growing season of 2012, rainfall, displayed in Figure 3.1, was much lower than normal. Total rainfall between November 1 and March 30 was only 152 mm for the five-month period with soil conditions being dry prior to fall application (Figure 3.1). Only two rain events over 38 mm occurred within the five-month period, one prior to fall application which provided adequate soil moisture for fall AA applications to ensure slot closure and minimize volatilization loss, and one immediately after spring application of AA. The potential for denitrification due to anaerobic conditions was minimal over winter. The limited moisture was well-distributed throughout the winter months. Soil temperatures averaged 5°C (Figure 3.2) for the entire five-month period which created a potential for low levels of nitrification of NH_4^+ to NO_3^-. In the nitrification process, some moisture is needed for the nitrifying bacteria to thrive, which the well distributed rainfall provided.

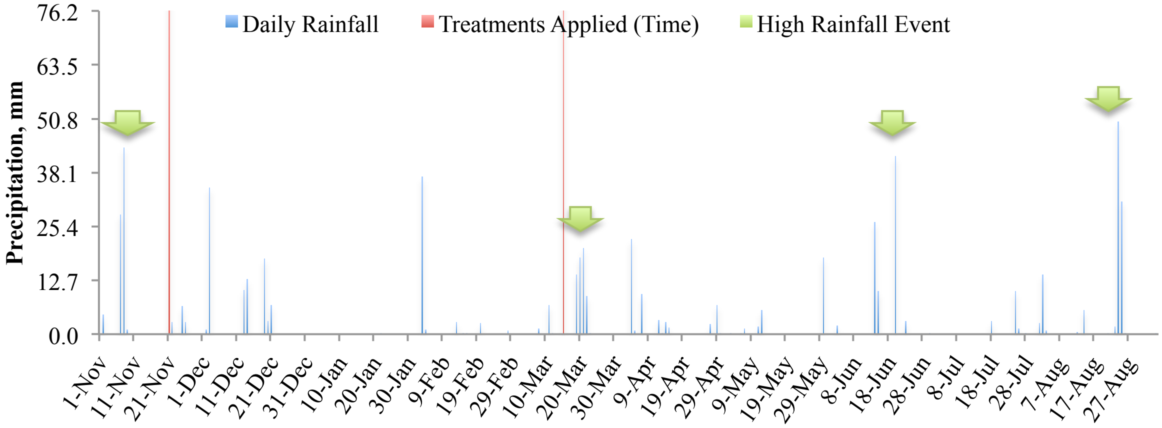

Figure 3.1 Precipitation Levels, Manhattan in 2011-2012

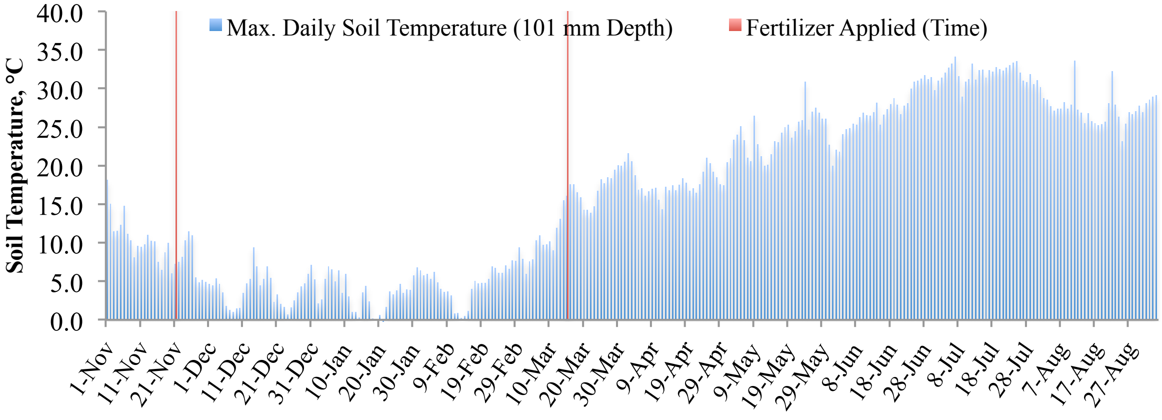

Figure 3.2 Soil Temperatures, Manhattan in 2011-2012

Also, wet interludes directly after dry periods often lead to a flush in nitrification (Alexander, 1960). Throughout the winter, conditions were dry with only two high rainfall events (Figure 3.1) leading to a potential flush of nitrification, though low temperatures would have limited the rate of nitrification. As a result, there was potential for a nitrification inhibitor to help reduce maximum nitrification rates at this site.

In the period between spring application and July 23 when the vast majority of the total N uptake had been completed, a total of only 225 mm (Figure 3.1) of moisture had been received. These levels were quite low, resulting in reduced yields, and minimal potential for N loss from spring applied N. The soil was a well-drained silt loam with an OM content of 26 g kg^{-1}, making it a location with high-yielding potential and moderate water holding capacity. There were two possible events of denitrification, one being four days after spring AA application and the other in late July, well after the majority of the N was already taken up. However, the rainfall event shortly after spring application could have resulted in N loss from fall applied N which had been nitrified over winter.

Looking at the measured results, N in the ear leaf was significantly higher (Table 3.9) in the plots which received 112 kg spring applied N, than those which received 112 kg fall applied N, and the yield showed a similar trend. This likely was the result of N losses of fall applied N being nitrified, over the winter months and denitrified in late March, leading to the observed trend in higher performance for spring applications. This is not totally unexpected with N sitting in the soil profile at least seven months prior to uptake. However, these yield differences between fall and spring applications were relatively small, promoting the potential for fall applications without fear of excessive losses. No difference in total N uptake (Figure 3.4) was observed between fall and spring applications of N, though fall applications actually trended slightly higher. Yield (Figure 3.5) peaked at the 112 kg N rate, making total N uptake a defining factor for measuring N loss.

Fall applications of AA with the use of N-Serve significantly increased yields in comparison with fall N alone (Table 3.9). Total N uptake and NUE from fall AA with a NI were also increased significantly in comparison with spring N. Even though the moisture during the fall was relatively modest, it was adequate under the cold fall conditions to stimulate nitrification,

Table 3.9 Results and Contrasts for Manhattan in 2012

No.	Treatment	Treatment N kg ha^{-1}	Inhibitor Rate L ha^{-1}	Ear Leaf N g kg^{-1}	Total N Uptake kg ha^{-1}	NUE kg kg^{-1}	Yield Mg ha^{-1}
1	Fall N only	112		19.2	188	0.64	8.77
2	Fall N with G77	112	9.4	21.7	208	0.80	9.78
3	Fall N with G77	112	18.7	19.2	205	0.77	9.79
4	Fall N with G77	112	28.1	18.5	201	0.74	9.70
5	Fall N with N-Serve	112	2.3	20.2	206	0.78	9.66
6	Control	0		18.0	110	NA[1]	4.96
7	Spring N only	56		18.0	163	0.80	8.16
8	Spring N only	112		20.8	181	0.58	9.30
9	Spring N with G77	112	9.4	21.6	196	0.70	9.27
10	Spring N with G77	112	18.7	20.5	192	0.67	9.24
11	Spring N with G77	112	28.1	20.5	201	0.74	8.95
12	Spring N with N-Serve	112	2.3	20.2	204	0.77	9.49
13	Spring N only	168		19.6	203	0.52	8.91
14	Spring N only	224		21.2	213	0.44	9.30
SE				0.23	4	0.03	0.19
Treatments Pr > F				< 0.0001	< 0.0001	< 0.0001	< 0.0001
Contrasts							
Control vs. N Applied (6 vs. 1,7,8,13,14)				(0.90) *	(39.7) **	NA	(1.97) **
Fall 112 N vs. Spring 112 N (1 vs. 8)				(0.80) *	3.4	0.03	(0.27)
Fall N-Serve vs. Fall N (5 vs. 1)				0.48	8.7	0.07	0.44 *
Fall N-Serve vs. Spring N (5 vs. 8)				(0.33)	12.1 *	0.10 *	0.18
Fall N-Serve vs. Spring N-Serve (5 vs. 12)				0.00	0.7	0.01	0.08
Spring N-Serve vs. Spring N (12 vs. 8)				(0.33)	11.4 *	0.09 *	0.09
Fall N-Serve vs. Fall G77 (1x) (5 vs. 2)				(0.78)	(1.2)	(0.01)	(0.06)
Fall N-Serve vs. Fall G77 (2x) (5 vs. 3)				0.50	0.5	0.00	(0.07)
Fall N-Serve vs. Fall G77 (3x) (5 vs. 4)				0.81 *	2.3	0.02	(0.02)
Spring N-Serve vs. Spring G77 (1x) (12 vs. 9)				(0.71)	3.9	0.03	0.11
Spring N-Serve vs. Spring G77 (2x) (12 vs. 10)				(0.15)	6.2	0.05	0.13
Spring N-Serve vs. Spring G77 (3x) (12 vs. 11)				(0.14)	1.5	0.01	0.27

* indicates significance <0.10, ** indicates significance <0.01 SAS 9.3 Proc Mixed

[1] NA – Not Applicable because the Control treatment is used within the calculation for NUE

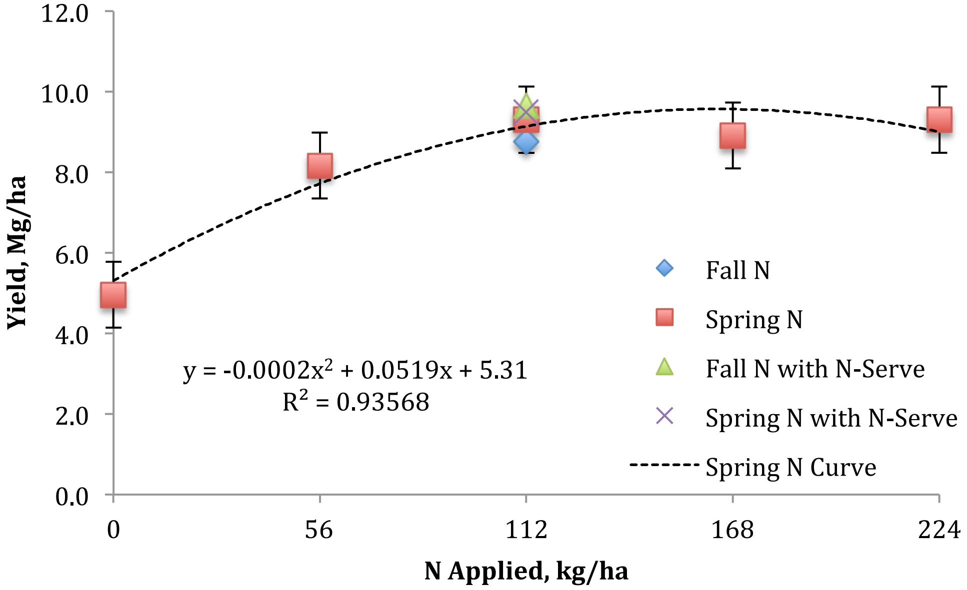

Figure 3.3 Yield N Curve, Manhattan in 2012

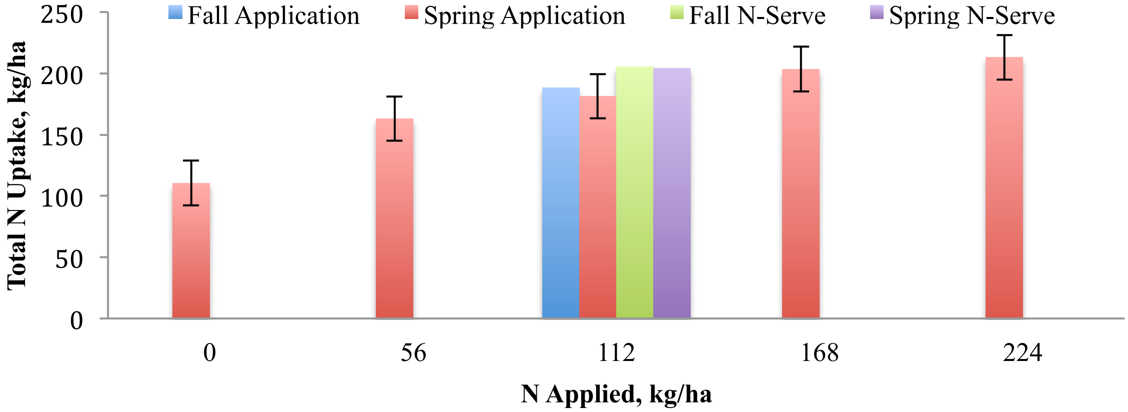

Figure 3.4 Total N Uptake, Manhattan in 2012

positioning fall applied ammonium for denitrification loss early in the spring. Adding N-Serve to the fall AA was successful in reducing the fall and winter nitrification and subsequent denitrification.

While the use of N-Serve with the spring applications of AA did not result in a yield increase, it increase NUE and total N uptake as seen in Table 3.9. In the comparison of G77 with N-Serve at the fall and spring applications, no significant differences were found (Table 3.9).

G77 performed similar to N-Serve in total N uptake and NUE. As discussed in the performance between rates of G77 in the combined analysis, variability was high between the rates so statistical power for showing significant trends was difficult. As a result, we found no difference between the inhibitors.

Manhattan, 2013

Moisture at Manhattan in 2013 came at all the proper times. Figure 3.5 shows very low rainfall between October – March. Moisture increased after application of N in the spring. It was not extreme, a total of 330 mm of rain came during the period between spring N applications and R5 growth stage. Also, the study was placed on a creek bottom location with a high water table, allowing moisture to be pulled from there as well. Yields (Figure 3.7) ranged between 9.8 – 15.4 Mg ha^{-1} which is quite surprising for a year with dry conditions. Potential N losses were quite minimal at this location during the winter months. Moisture was well-dispersed throughout the season and total rainfall between fall AA applications and spring applications was only 78 mm (Figure 3.5), creating a poor environment nitrification or denitrification. In comparison with Manhattan in 2012, more moisture came during the growing season, and less moisture came during the winter months prior to spring applications. Based on the moisture status, winter N

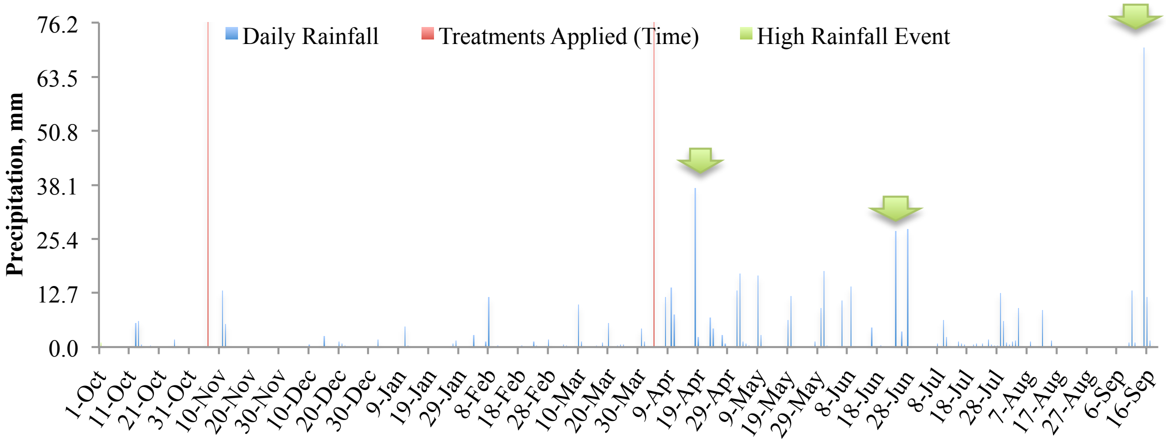

Figure 3.5 Precipitation Levels, Manhattan in 2012-2013

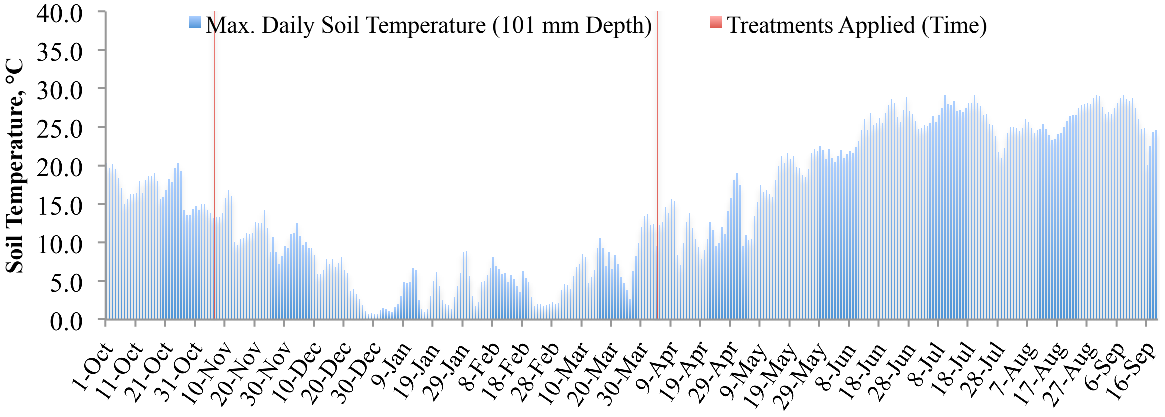

Figure 3.6 Soil Temperatures, Manhattan in 2012-2013

loss should have been quite minimal, however some N loss during the growing season was possible due to two major rainfall events which occurred in mid-April and late June (Figure 3.5). Nitrification was also reduced by the cool temperatures, which averaged around 5°C (Figure 3.6), during the dry winter months. As a result, potential N loss was likely only during mid-spring and the summer months.

Yields (Figure 3.7) ranged between 9.8 – 15.4 Mg ha^{-1} which is quite surprising for dryland corn in Kansas, especially in a year with dry conditions. A significant response to the

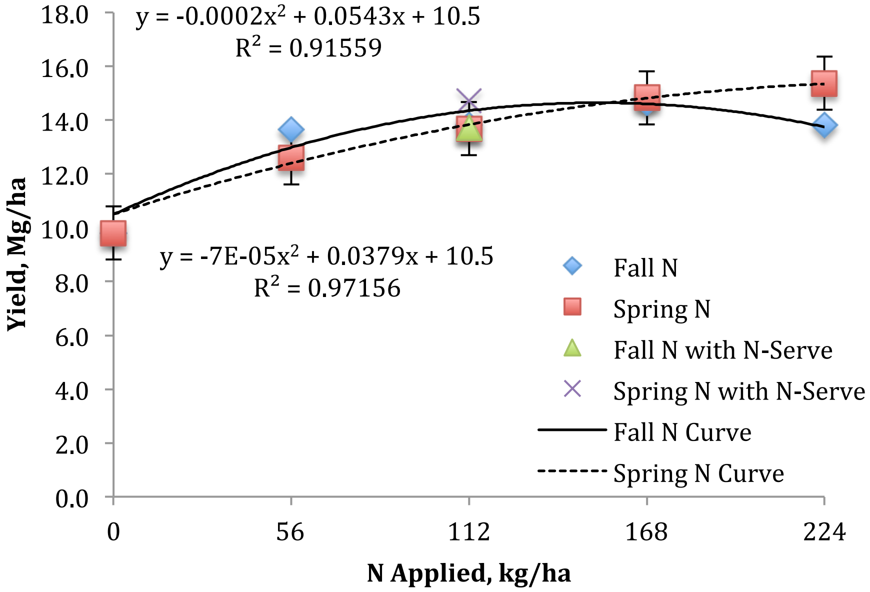

Figure 3.7 Yield N Response Curves, Manhattan in 2013

Table 3.10 Results and Contrasts for Manhattan in 2013

No.	Treatment	Treatment N	Inhibitor Rate	Ear Leaf N	Total N Uptake	NUE	Yield
		kg ha^{-1}	L ha^{-1}	g kg^{-1}	kg ha^{-1}	kg kg^{-1}	Mg ha^{-1}
1	Fall N only	112		24.3	230	0.80	13.81
2	Fall N with G77	112	9.4	23.9	248	0.85	14.56
3	Fall N with G77	112	18.7	24.6	245	0.92	14.62
4	Fall N with G77	112	28.1	24.5	236	0.85	14.20
5	Fall N with N-Serve	112	2.3	24.1	228	0.78	13.73
6	Control	0		19.2	133	NA	9.80
7	Spring N only	56		22.1	195	0.94	12.60
8	Spring N only	112		24.2	224	0.74	13.68
9	Spring N with G77	112	9.4	24.8	218	0.70	13.22
10	Spring N with G77	112	18.7	23.8	229	0.69	14.19
11	Spring N with G77	112	28.1	26.4	259	1.03	14.71
12	Spring N with N-Serve	112	2.3	24.3	243	0.81	14.73
13	Spring N only	168		26.4	255	0.69	14.83
14	Spring N only	224		24.8	279	0.58	15.37
15	Fall N only	56		24.2	211	1.18	13.65
16	Fall N only	168		24.1	247	0.57	14.66
17	Fall N only	224		25.5	243	0.47	13.81
SE				0.3	5	0.04	0.21
Treatments Pr > F				< 0.0001	< 0.0001	< 0.0001	< 0.0001
Contrasts							
Control vs. N Applied (6 vs. 1,7,8,13,14,15,16,17)				(2.65) **	(51.3) **	NA	(2.08) **
Fall N vs. Spring N (1,15,16,17 vs. 7,8,13,14)				0.03	(2.8)	0.01	(0.07)
Fall 112 N vs. Spring 112 N (1 vs. 8)				0.08	3.3	0.03	0.07
Fall N-Serve vs. Fall N (5 vs. 1)				(0.09)	(1.4)	(0.01)	(0.04)
Fall N-Serve vs. Spring N (5 vs. 8)				(0.01)	1.9	0.02	0.02
Fall N-Serve vs. Spring N-Serve (5 vs. 12)				(0.83)	(4.5)	(0.04)	(0.24)
Spring N-Serve vs. Spring N (12 vs. 8)				0.81	6.4	0.05	0.26
Fall N-Serve vs. Fall G77 (1x) (5 vs. 2)				0.42	(7.0)	(0.06)	(0.15)
Fall N-Serve vs. Fall G77 (2x) (5 vs. 3)				(0.20)	(8.8)	(0.07)	(0.45)
Fall N-Serve vs. Fall G77 (3x) (5 vs. 4)				(0.18)	(4.2)	(0.03)	(0.24)
Spring N-Serve vs. Spring G77 (1x) (12 vs. 9)				0.49	9.3	0.08	0.49
Spring N-Serve vs. Spring G77 (2x) (12 vs. 10)				0.73	7.1	0.06	0.27
Spring N-Serve vs. Spring G77 (3x) (12 vs. 11)				(0.31)	(11.0) *	(0.09)	(0.26)

* indicates significance <0.10, ** indicates significance <0.01 SAS 9.3 Proc Mixed

application of N was seen at this location, with yields maximized at 168 kg N fall applied and 224 kg N (Table 3.10, Figure 3.7). In comparing fall versus spring AA applications, there was no difference in yield at the 112 kg N rate where inhibitors were applied or all the rates combined. This outcome is possibly a result of the low moisture during the winter months between applications and dry soils in the spring capable of storing a significant part of the early spring moisture. Potential N loss was quite minimal over winter. NUE levels obtained in this study ranged in the 0.8 to 0.9 kg kg^{-1} (Table 3.10) which were exceptionally high. These ranges included fall applications which shows limited N losses for the season. Ear Leaf N, NUE, and total N uptake were also similar under both situations. In comparing the yield/ N response curves above (Figure 3.7), the two curves follow a close pattern only breaking apart at the 224 kg N rate. This phenomenon is also seen in the total N taken up by the plant in Figure 3.8. One possible explanation for this result is higher N loss through volatilization due to low soil moisture, minimizing the sorption of ammonia to the soil. Conditions were somewhat drier in the fall than in the spring when making the applications, and moisture assists in the initial capacity to retain ammonia (Parr Jr. and Papendick, 1966). The soil and OM content helped retain the AA applied at the lower rates. At the 224 kg N rate, the soil system was unable to retain and sorb all the AA. This similar phenomenon was seen in work completed by Stamper at KSU (2009) when he was comparing a traditional knife applicator with the JD HSLD applicator. The JD applicator displayed somewhat of a reduction or loss in yield at rates greater than 168 kg N rate. The higher N rates had increased post application emission losses in comparison with the traditional AA knife applicator (Stamper, 2009). With this in mind, possible reduction in N applied when applying under dry conditions is recommended.

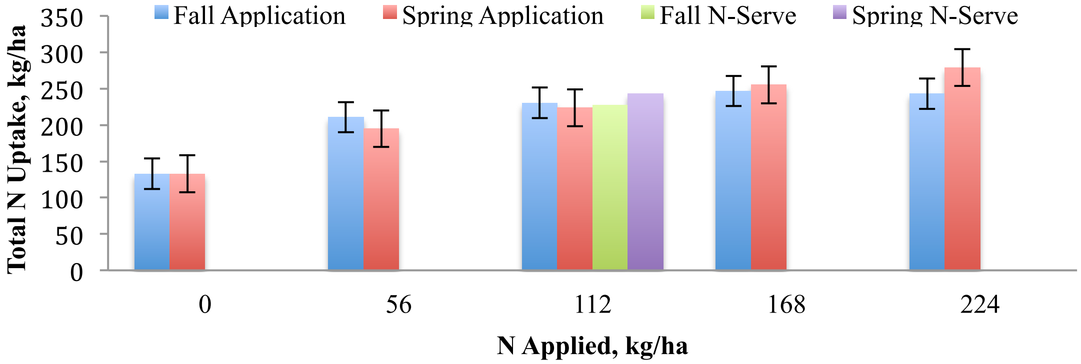

Figure 3.8 Total N Uptake, Manhattan in 2013

Since there was minimal N losses during the period between fall and spring applications as seen by the similar yields and NUE above, the use of an inhibitor for fall applications would not be expected to have positive results. Fall N with N-Serve did not increase yield or total N uptake in 2013 (Table 3.10). Spring N-Serve in comparison with spring N alone trended higher in NUE and yield, but it was not significant at the 0.10 alpha level. N-Serve has a bacteriostatic effect on the Nitrosomonas bacteria, meaning it slows the rate of growth, it does not stop the growth rate (Rodgers and Ashworth, 1982). Consequently, performance is weak and variable among locations. Also, microbial populations, under spring conditions when there is available moisture and warm temperatures, thrive at much greater levels with much higher performance in the nitrification process (McIntosh and Frederick, 1958). Because the limitation in nitrification under the dry winter months, N-Serve was only able to slow the nitrification process slightly, reducing its effect on yield and N uptake. Also, fall N-Serve performance was masked by the reduced retention of AA under the dry fall application conditions, increasing potential for AA volatilization.

Increased benefit from the use of G77 was seen at this location in comparison with N-Serve (Table 3.10). G77 trended higher at all rates in the fall in terms of yield and NUE, however there was no significant increase at the 0.10 alpha level. In the spring, the highest rate in comparison with spring applied N-Serve trended higher in yield and NUE, but significantly increased total N uptake at the 0.10 alpha level. With seeing the increasing trend in the use of N-Serve in the spring, G77 at the highest rate had an increased effect on slowing the nitrification process. Speculations for this result may be due to activity for longer periods. N-Serve has reduced effect and longevity above 13°C so applications during the spring when temperatures are increasing would have a negative effect on its performance (Touchton, et. al, 1979). G77 may have more resistance against the higher temperatures which would increase its performance in spring applications. This is only a theory and should be further researched before decisive conclusions are made.

Rossville, Kansas River Valley Sites (KRV)

Rossville, 2012

The soil at Rossville is a well-drained coarse textured soil with a very low OM content of 8 g kg^{-1}. As a result, loss potential was likely from ammonia volatilization through poor slot sealing, as well as, leaching from the profile. There is only a small amount of CEC in the profile to keep nutrients from moving out of the profile. Rainfall between fall and spring applications reached about 260 mm which was substantially higher than the Manhattan location (Figure 3.9). There were five rainfall events greater than 25 mm throughout the five-month period prior to spring application, creating a potentially high N loss situation. This soil has a high potential for leaching. A previous study was completed at or near this site measuring N loss through leaching and the results were very high (Maddux and Barnes, 1982). Overwinter losses from this site were much more likely than Manhattan.

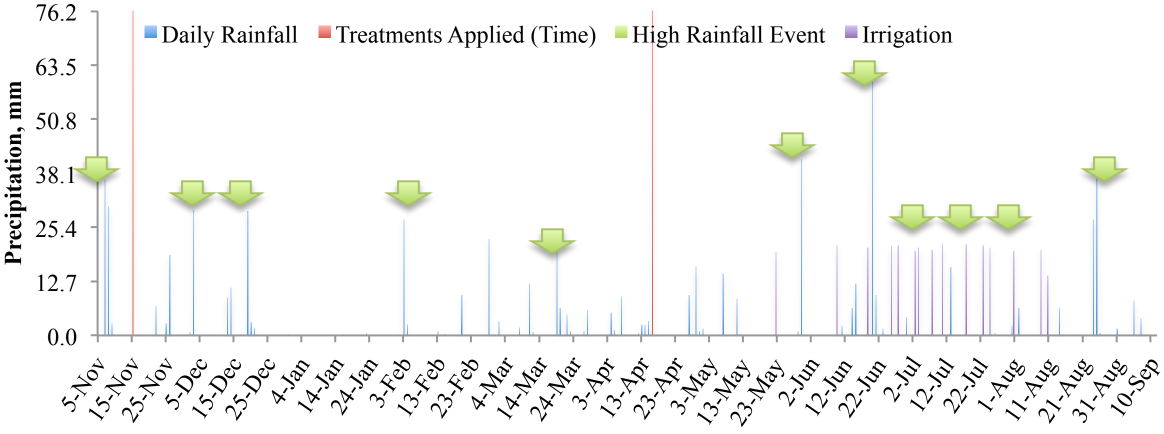

Figure 3.9 Precipitation Levels, Rossville in 2011-2012

Also, total moisture between spring applications to the end of N uptake by the plant was about 430 mm. The increased moisture in comparison to Manhattan was partially affected by application of water with a lateral move irrigation system. As a result, yield potential was much higher than that found at Manhattan. Five potential leaching events occurred between the spring application and the end of the N uptake period in late July (Figure 3.9). Also, soil temperatures reached above 4°C most of the winter, especially February and March (Figure 3.10), creating a potential for nitrification over winter. High nitrification over winter can result in the possibility of N loss at this location in this year from fall applications of AA.

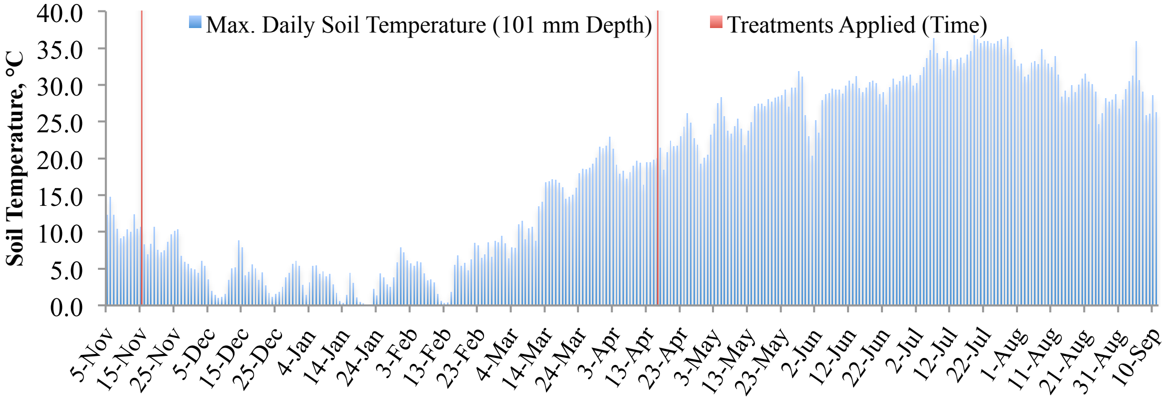

Figure 3.10 Soil Temperatures, Rossville in 2011-2012

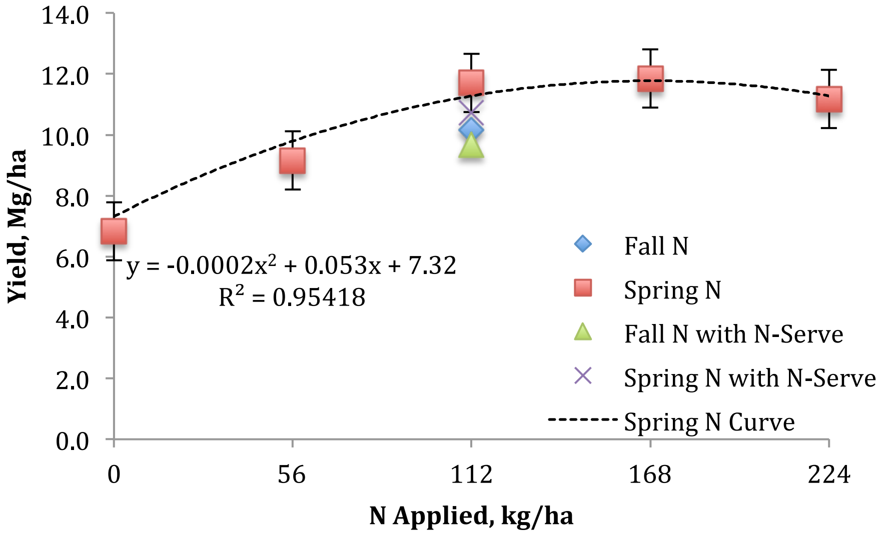

Figure 3.11 Yield N Curve, Rossville in 2012

A response to N as indicated by an increase in yield was seen at this location. Yields topped out at 11.8 Mg ha^{-1} with the 168 kg ha^{-1} N rate then leveled out (Figure 3.11). Consequently, the slightly lower 112 kg N rate provided a good opportunity to show whether the

Table 3.11 Results and Contrasts for Rossville in 2012

No.	Treatment	Treatment N	Inhibitor Rate	Ear Leaf N	Total N Uptake	NUE	Yield
		kg ha^{-1}	L ha^{-1}	g kg^{-1}	kg ha^{-1}	kg kg^{-1}	Mg ha^{-1}
1	Fall N only	112		24.5	186	0.37	10.15
2	Fall N with G77	112	9.4	23.1	172	0.25	9.55
3	Fall N with G77	112	18.7	25.2	184	0.38	10.39
4	Fall N with G77	112	28.1	24.9	189	0.42	9.70
5	Fall N with N-Serve	112	2.3	25.2	175	0.28	9.67
6	Control	0		20.7	141	NA[1]	6.84
7	Spring N only	56		23.0	166	0.38	9.16
8	Spring N only	112		25.7	216	0.61	11.71
9	Spring N with G77	112	9.4	26.1	212	0.58	11.42
10	Spring N with G77	112	18.7	25.3	205	0.53	10.28
11	Spring N with G77	112	28.1	25.4	207	0.54	10.94
12	Spring N with N-Serve	112	2.3	26.2	199	0.48	10.72
13	Spring N only	168		26.4	225	0.47	11.85
14	Spring N only	224		25.0	221	0.34	11.17
SE				0.27	4	0.03	0.23
Treatments Pr > F				< 0.0001	< 0.0001	< 0.0001	< 0.0001
Contrasts							
Control vs. N Applied (6 vs. 1,7,8,13,14)				(2.09) **	(31.0) **	NA **	(1.99) **
Fall 112 N vs. Spring 112 N (1 vs. 8)				(0.59)	(15.0) *	(0.12) *	(0.78) *
Fall N-Serve vs. Fall N (5 vs. 1)				0.35	(5.4)	(0.04)	(0.24)
Fall N-Serve vs. Spring N (5 vs. 8)				(0.24)	(20.4) **	(0.17) *	(1.02) **
Fall N-Serve vs. Spring N-Serve (5 vs. 12)				(0.50)	(12.2)	(0.10)	(0.52)
Spring N-Serve vs. Spring N (12 vs. 8)				0.26	(8.3)	(0.12)	(0.78)
Fall N-Serve vs. Fall G77 (1x) (5 vs. 2)				1.04 *	1.6	(0.12)	(0.78)
Fall N-Serve vs. Fall G77 (2x) (5 vs. 3)				0.00	(6.8)	(0.12)	(0.78)
Fall N-Serve vs. Fall G77 (3x) (5 vs. 4)				0.11	(9.4)	(0.12)	(0.78)
Spring N-Serve vs. Spring G77 (1x) (12 vs. 9)				0.04	(6.4)	(0.12)	(0.78)
Spring N-Serve vs. Spring G77 (2x) (12 vs. 10)				0.43	(3.0)	(0.12)	(0.78)
Spring N-Serve vs. Spring G77 (3x) (12 vs. 11)				0.40	(3.8)	(0.12)	(0.78)

* indicates significance <0.10, ** indicates significance <0.01 SAS 9.3 Proc Mixed

[1] NA – Not Applicable because the Control treatment is used within the calculation for NUE

use of nitrification inhibitors would perform or not. At this site, an N response curve was only added with the spring applications, not allowing for the peak yielding capacity of fall applications to be compared to spring applications.

However, at the 112 kg N rate, spring applications increased yield significantly over fall applications of N at the 0.10 alpha level. As seen in Figure 3.12, spring applications also increased N uptake in comparison with fall applications. Potential N losses over the winter were high. From the yields and NUE uptake seen at this site, N losses were definitely a cause for the reduction in yields. NUE from fall application of AA alone was only 0.37 kg kg^{-1} which is very low. Spring application of N at the same rate almost doubled NUE at this location at 0.61 kg kg^{-1} (Table 3.11). At the Manhattan 2012 location, all NUE levels were in the 0.6 to 0.7 kg kg^{-1} range which points to the fact that different locations require different management tactics. Fall applications at this location are not recommended under the high N loss environment.

In the high N loss situation found at this site, the use of N-Serve should be advantageous. However, the results from this location proved otherwise. The use of N-Serve in the fall or the spring did not improve yield, NUE, or N uptake (Table 3.11). The reason for this lack in response under these high N loss conditions, where performance should have been strong, include the low OM, coarse textured soil in which the study was conducted. Work by Touchton (1978) discusses that soils with low OM (less than 10 g kg^{-1}) has a reduced ability to hold nitrapyrin in the soil. As a result, the nitrapyrin was not adequately sorbed to the soil system and lost by possible volatilization or leaching. N-Serve can follow similar loss mechanisms to that of N under soil situations where it is not able to bind to the OM or clay. The use of N-Serve under these situations is not recommended. Being site-specific in applying management tools such as timing and the use of N-Serve is important as seen by the comparison of the Manhattan and Rossville sites in 2012.

Lastly, taking a glance at the performance of G77 in comparison with N-Serve, results are similar (Table 3.11). OM levels might have had a similar effect on G77 sorption as with N-Serve. Similar to N-Serve, G77 could have moved away from the AA application center by leaching, resulting in a loss of performance by the product. A large amount of leaching occurred at this location characterized by the coarse-textured soil resulting in extensive N loss as shown by the decreased yield and N uptake values from fall application shown in Figure 3.12. In comparing the contrasts for Rossville 2012 (Table 3.11), there were no significant differences between N-Serve and G77 at any rate applied in the fall or spring. Trends pointed toward an improvement with the use of G77, but the results were variable. Increasing the rate at which G77 is to be applied may prove fruitful in future research.

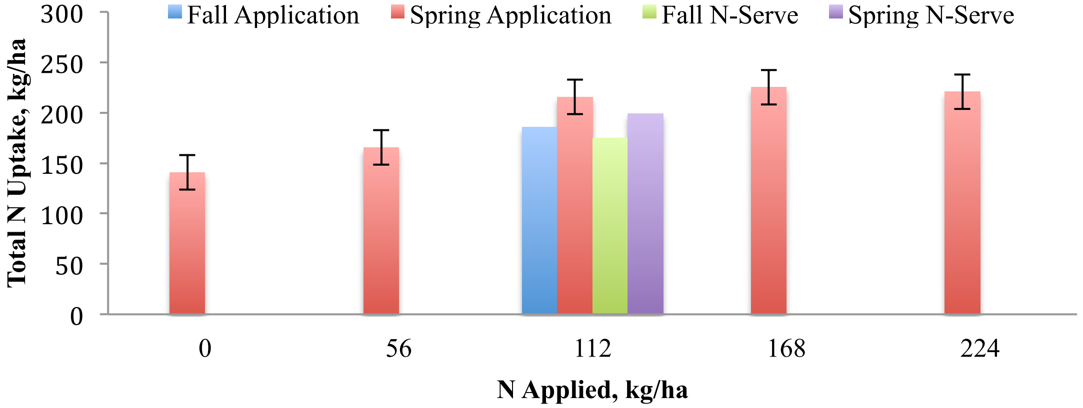

Figure 3.12 Total N Uptake, Rossville in 2012

At locations with high susceptibility for N loss under coarse textured soils with low OM, the use of fall AA applications and usage of N-Serve as management tactics would not be recommended. Producers in Kansas need to be selective in the locations in which they choose to implement these practices. Fall AA applications will free up time for other activities in the spring season, but the N lost under conditions like Rossville would be harmful to the producer's profitability as well as increase N levels to the environmental high risk areas.

Rossville, 2013

The yield potential of the soil at Rossville on which the study was placed in 2013 was lower than the 24.2 g kg^{-1} OM silt loam at the Manhattan 2013 location. The OM content at the Rossville 2013 site was 10.7 g kg^{-1} (Table 3.7) which was a slight improvement over the 2012 site. However, this location did not yield as well as Manhattan in 2013 even though the Rossville site was irrigated and the Manhattan site was not. Yields ranged from 8.06 – 14.12 Mg ha^{-1}. Late in the growing season grey leaf spot (*Cercospora zeaemaydis)* came in heavily and may have had some negative effects on final yield of the crop.

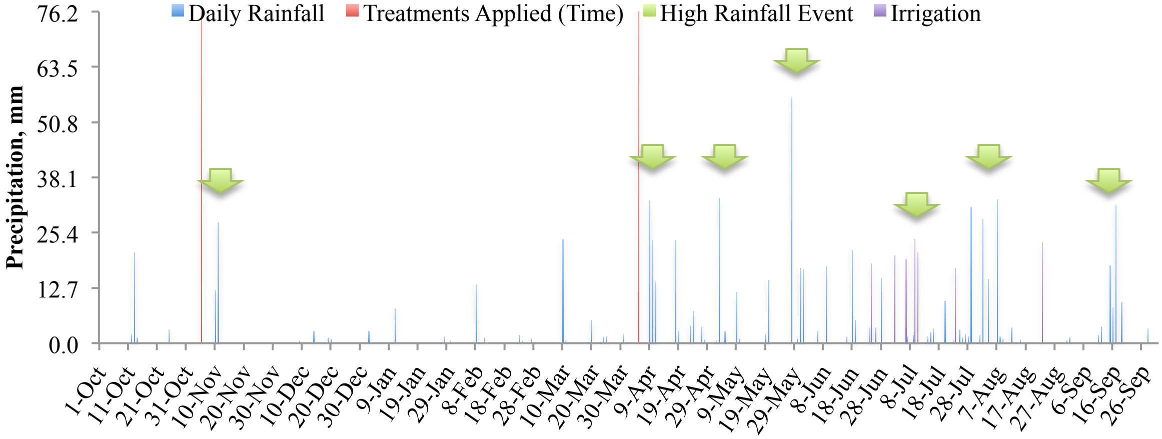

Figure 3.13 Precipitation Levels, Rossville in 2012-2013

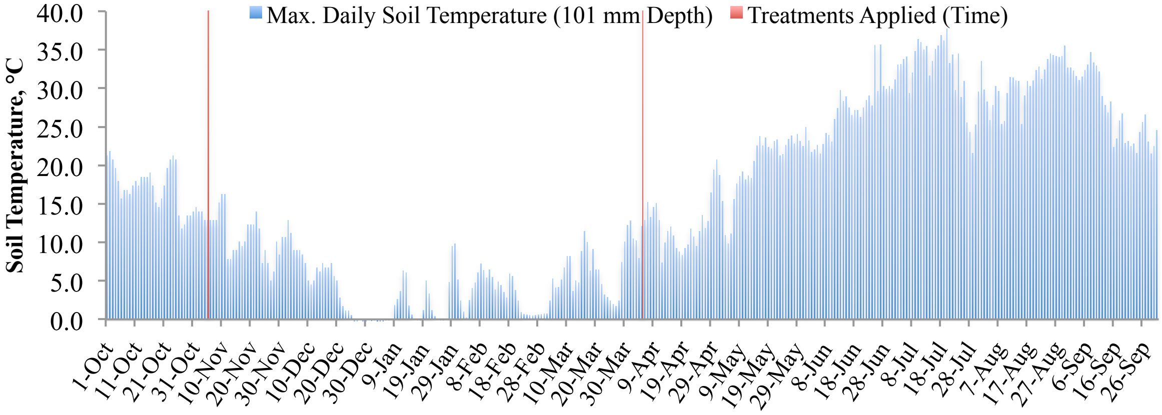

Figure 3.14 Soil Temperatures, Rossville in 2012-2013

Nitrogen loss potential at this location was moderate. Total moisture between fall and spring AA applications was only 112 mm of rainfall (Figure 3.13). One major event of 26 mm came four days after application that most likely led to some leaching of both ammonia and nitrate from the profile. However, fall NUE levels at the 112 kg N rate were quite high for fall applications ranging between 0.8-0.9 kg kg^{-1} (Table 3.12). For the coarse textured soil on which this study was set up, the expected values from fall applications would normally be much lower. In 2012, at the Rossville site, the NUE levels ranged in the 0.2-0.4 kg kg^{-1} range (Table 3.11). Reasons for such a drastic difference between site years of studies placed directly next to each other include reduced moisture during the winter months, especially of high rainfall events, as well as, some subtle subsurface changes in soil type. The soil in 2013 had a slight increase in OM content, but also a clay lens was noted only 0.46 meter below the surface, providing a limiting layer to hold moisture and nutrients for a longer period of time. The study site did include a swath of area where the sandy surface layer was deeper than one meter that made a diagonal across three of the blocks. Soil probing and aerial photos were used to determine the specific location of the deep sand layer. Those data points were then removed from the study because of the variability added to the main study. In Figure 3.15, two graphs are shown displaying the extensive differences in yield and N uptake caused by this soil variability within the study area. At the 112 kg N rate, at least 4 Mg yield ha^{-1} and 125 kg total N uptake ha^{-1} were lost because of the extensive leaching in the deep sand. Because the site in 2012 did not have an extensive clay lens below the surface over most of the study, losses observed in 2012 were much greater than those seen on the deep silt loam soil at Manhattan. The two graphs below are both from spring applications showing that under deep, coarse soils, N timing applications are very critical or major losses will result.

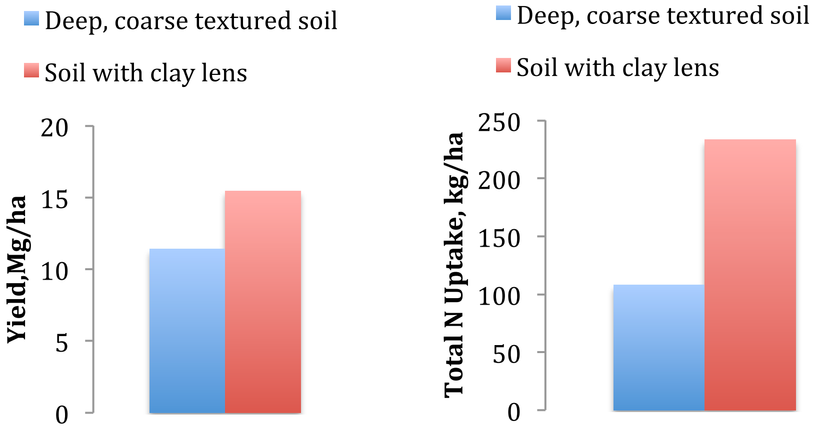

Figure 3.15 Impact of a Clay Lens on Yield and Total N Uptake on Corn (112 kg N rate)

Table 3.12 Results and Contrasts for Rossville in 2013

No.	Treatment	Treatment N kg ha^{-1}	Inhibitor Rate L ha^{-1}	Ear Leaf N g kg^{-1}	Total N Uptake kg ha^{-1}	NUE kg kg^{-1}	Yield Mg ha^{-1}
1	Fall N only	112		26.5	225	0.96	14.05
2	Fall N with G77	112	9.4	26.5	215	0.89	13.53
3	Fall N with G77	112	18.7	25.8	206	0.80	13.52
4	Fall N with G77	112	28.1	26.4	217	0.89	13.39
5	Fall N with N-Serve	112	2.3	28.5	231	1.02	13.85
6	Control	0		18.7	122	NA	8.06
7	Spring N only	56		24.3	151	0.68	9.93
8	Spring N only	112		27.8	221	0.94	14.12
9	Spring N with G77	112	9.4	25.1	232	0.81	13.53
10	Spring N with G77	112	18.7	26.4	225	0.97	13.70
11	Spring N with G77	112	28.1	28.1	230	1.01	14.11
12	Spring N with N-Serve	112	2.3	26.5	206	0.82	12.87
13	Spring N only	168		28.0	219	0.63	13.67
14	Spring N only	224		29.3	236	0.56	13.90
15	Fall N only	56		23.2	167	0.68	11.60
16	Fall N only	168		26.0	232	0.62	13.62
17	Fall N only	224		26.0	213	0.39	13.05
SE				0.4	5	0.06	0.25
Treatments Pr > F				< 0.0001	< 0.0001	< 0.0001	< 0.0001
Contrasts							
Control vs. N Applied (6 vs. 1,7,8,13,14,15,16,17)				(4.34) **	(45.3) **	NA	(2.55) **
Fall N vs. Spring N (1,15,16,17 vs. 7,8,13,14)				(0.28)	1.4	0.03	0.13
Fall 112 N vs. Spring 112 N (1 vs. 8)				0.65	4.3	0.04	0.09
Fall N-Serve vs. Fall N (5 vs. 1)				(0.30)	0.6	(0.00)	(0.22)
Fall N-Serve vs. Spring N (5 vs. 8)				0.35	4.9	0.04	(0.13)
Fall N-Serve vs. Spring N-Serve (5 vs. 12)				0.98	12.7	0.10	0.49
Spring N-Serve vs. Spring N (12 vs. 8)				(0.63)	(7.8)	(0.06)	(0.62)
Fall N-Serve vs. Fall G77 (1x) (5 vs. 2)				0.98	8.2	0.07	0.16
Fall N-Serve vs. Fall G77 (2x) (5 vs. 3)				0.25	10.2	0.08	0.05
Fall N-Serve vs. Fall G77 (3x) (5 vs. 4)				0.50	4.7	0.03	0.11
Spring N-Serve vs. Spring G77 (1x) (12 vs. 9)				(1.21)	(15.9)	(0.01)	(0.53)
Spring N-Serve vs. Spring G77 (2x) (12 vs. 10)				0.05	(9.7)	(0.08)	(0.42)
Spring N-Serve vs. Spring G77 (3x) (12 vs. 11)				(0.80)	(11.9)	(0.10)	(0.62)

* indicates significance <0.10, ** indicates significance <0.01 SAS 9.3 Proc Mixed

A large amount of moisture came after spring applications were made. Two high N loss periods occurred within two weeks of spring AA applications (Figure 3.13). Also, a total of 488 mm of precipitation came between spring applications and the R5 growth stage. Moisture during the growing season did not hinder yields. Irrigation applications were targeted during the times of low rainfall to maximize yield. The potential for N loss was high because there were eight rainfall events over 25 mm with potential of causing leaching. However, the clay lens below the surface most likely perched the moisture and NO_3^- above it, slowing the rate of N loss. NUE levels at the 112 kg N rate were all over 0.8 kg kg^{-1} (Table 3.12). Since the majority of the site had the clay lenses below the surface, those plots that did not have a limiting layer within a meter of the surface were not included in the analysis. The increased summer precipitation in 2013 and the limiting layer approximately 0.4 to 0.5 meters below the surface were the likely factors causing differences between the study years at this location.

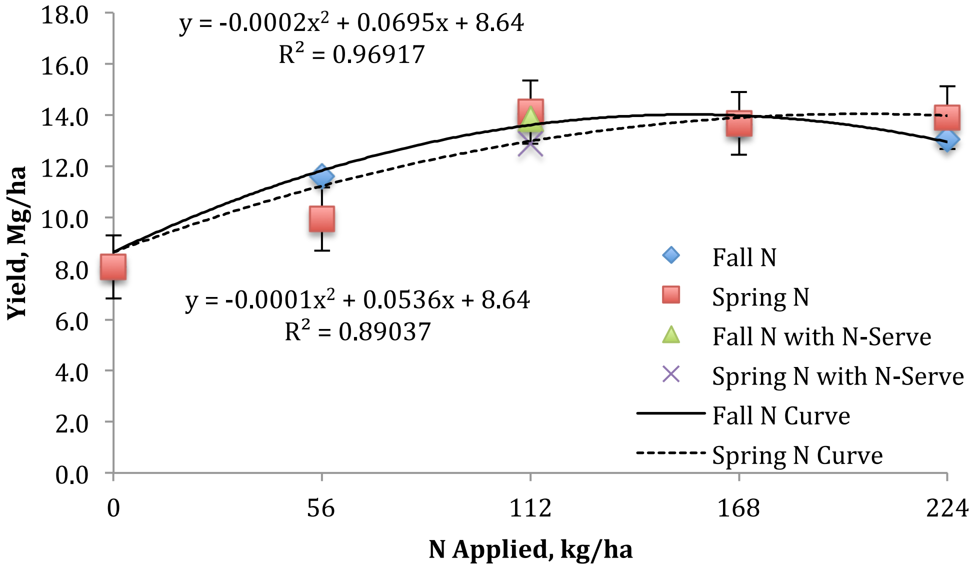

Figure 3.16 Yield N Curves, Rossville in 2013

The impact of the limiting layer restricting N and water loss at this site can be seen clearly in Figure 3.16, corn yields at Rossville in 2013. Both fall and spring application response curves are similar with no significant differences between fall and spring application indicated in the contrasts, Table 3.12. In looking at N uptake, Figure 3.17, again no difference is seen between fall and spring applications. Fall and spring applications were statistically similar in Ear Leaf N content and NUE as well (Table 3.12).

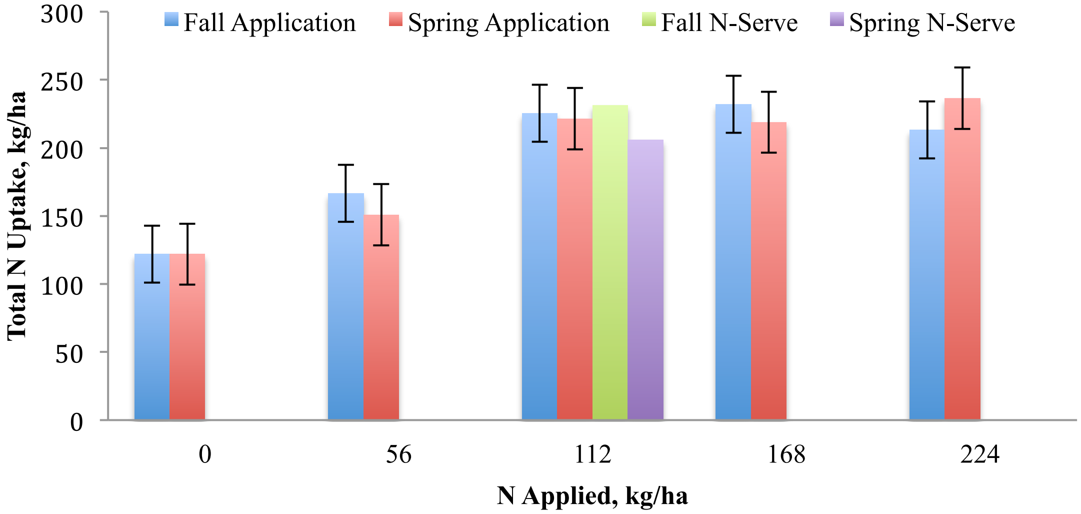

Figure 3.17 Total N Uptake, Rossville in 2013

In pondering the data in Figures 3.16 and 3.17 above, N-Serve was shown not to provide any increased benefit with its application in either the spring or the fall. Neither yield or total N uptake was increased. With the high NUE's across the board, N loss was not significant so the use of a nitrification inhibitor to increase yield and NUE significantly would not have occurred. The performance of G77 was again similar to that of N-Serve at this site. No statistically significant differences between inhibitors were observed, however, the spring applied G77 seems to show a slight trend towards increased performance.

Ottawa, East Central Kansas Sites (ECK)

Ottawa, 2012

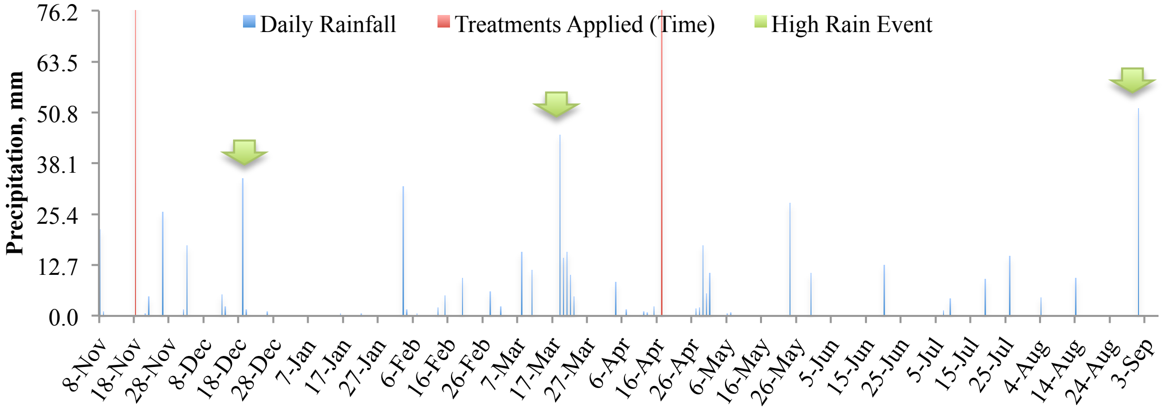

Figure 3.18 Precipitation Levels, Ottawa in 2012

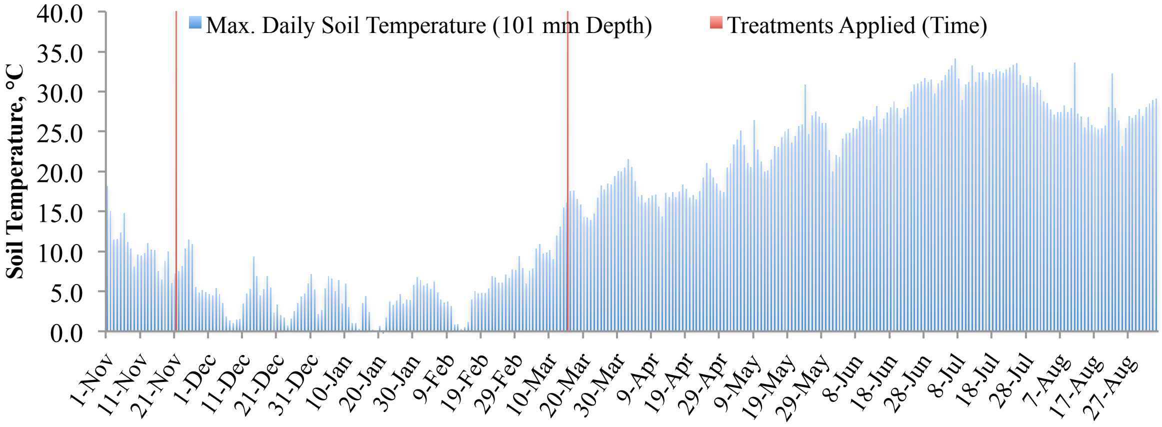

Figure 3.19 Soil Temperatures, Ottawa in 2012

In 2012 at the Ottawa corn site, treatments were applied, soil samples taken, ear leaf samples taken, and yield collected from this location; but no data will be presented because drought reduced yield extensively. Figures 3.18 and 3.19 show the very poor conditions for corn growth under the high soil temperatures and limited rainfall. The frequency of rain events decreased after planting in May and never recovered. Figure 3.20 provides a visual of end-of-season conditions at this location.

Figure 3.20 Drought-Stricken Ottawa in 2012

Ottawa, 2013

Ottawa in 2013 was the sixth and final site in the study, showing different findings from the other sites. The soil at this site is a Woodson silt loam, with a significant clay pan at 25 to 35 cm depth. This creates a significant limiting layer for water movement and greatly enhances denitrification potential at this site. In the two years in which this study was placed at the Ottawa location, moisture levels during the season were low. In 2013, moisture during the growing season totaled 254 mm between spring applications and R5 growth stage (Figure 3.21). As a result, yields were substantially reduced by a lack of moisture. Yields ranged between 2.89-7.58

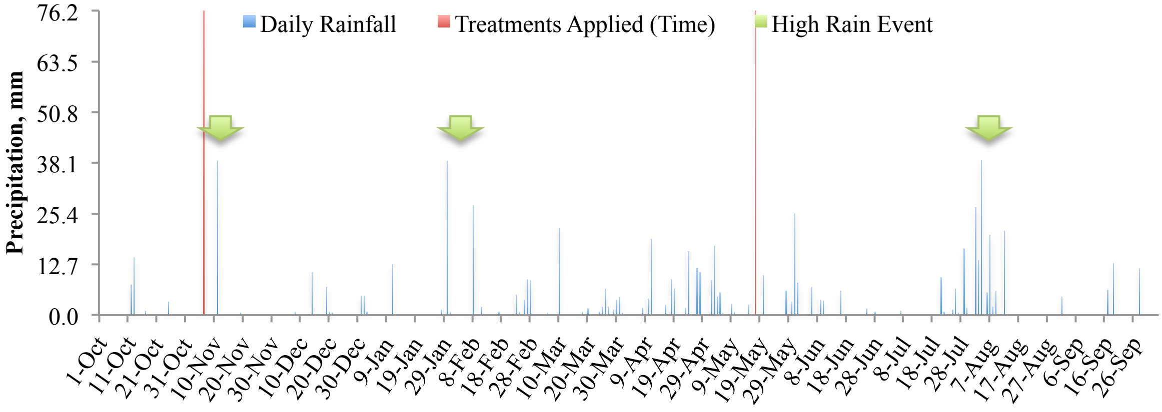

Figure 3.21 Precipitation Levels, Ottawa in 2012-2013

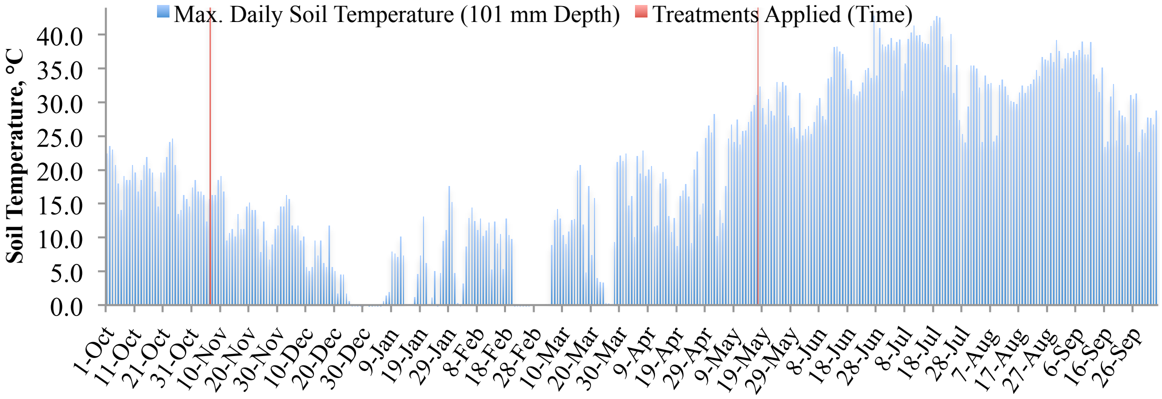

Figure 3.22 Soil Temperatures, Ottawa in 2012-2013

Mg ha^{-1} (Figure 3.23) which is much lower than the other sites in 2013. Two major rainfall events resulting in the potential for N loss were seen between spring applications and R5 growth stage. These events were quite substantial providing most of the moisture for the whole season. One occurred 10 days after planting and spring application, and the other began shortly before tasselling. The first event occurred after a large amount of moisture can during the winter period (Figure 3.21).

The events were distributed mostly during the early spring months. One event came five days after fall N application which totaled 37 mm, being the only rain event prior to winter. With the large volume of moisture during the early spring months, only a small window was available for application and planting in the spring. Consequently, application and planting were made within a day of each other.

An attempt was made to capture some of the spring rains before they shut off by planting as early as possible. In 2012, a late planting significantly hindered yields. Most publications recommend at least a seven-day no-plant period after AA applications for soil equilibrium to occur, but the window of opportunity was greatly reduced in this system. These are the tight situations producers will face in real life situations so a comparison of these conditions is fruitful. In-field visual assessment during the growing season showed no signs of plant injury, except for at the 224 kg N rate. As discussed in previous sections of this chapter with the use of the JD 2510 applicator, emission losses are higher at the higher rates potentially causing some plant injury early in the season. However, those treatments grew out of the early symptoms and yield performance increased up through the 224 kg N rate for the spring-applied treatments. Fall applied treatments plateaued in yield at the 168 kg N rate (Figure 3.23). A similar phenomenon was seen at the 224 kg N rate as seen with all other sites in 2012, a decrease in yield possibly due to the increased volatilization losses.

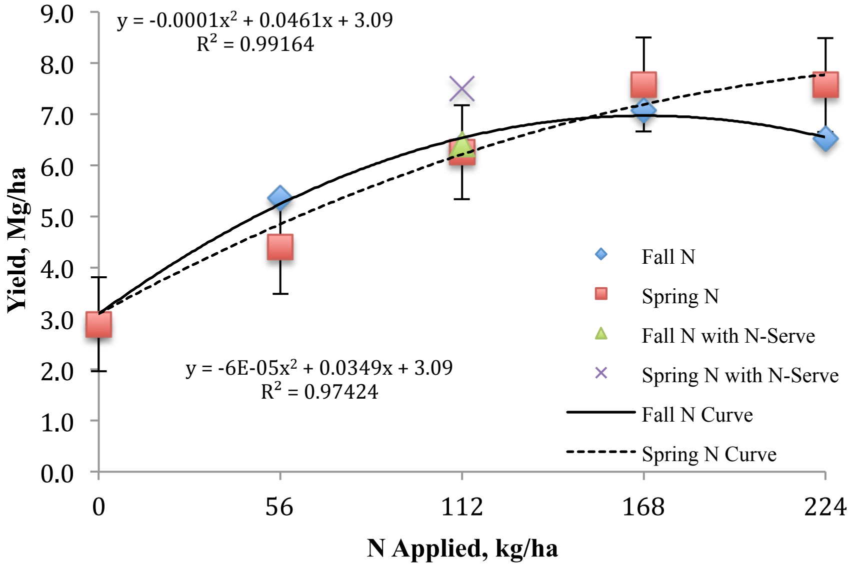

Figure 3.23 Yield N Curves, Ottawa in 2013

At this location, no difference in yield between fall and spring applications were seen, similar to the other two locations. There was no statistical difference in yield, NUE, or total N uptake between fall and spring applications at the 0.10 alpha level at either the 112 kg N rate or all the rates combined (Table 3.13). However, one significant difference between the Ottawa site and the other locations was the relatively low yield, low levels of N uptake, and N deficient plant tissue values found in the ear leaves. Standard values for ear leaf N in corn are 27 to 30 g kg^{-1}, while at Ottawa values were in the 19 to 23 g kg^{-1}. It is very likely that N loss from both fall and spring applications contributed to the low N uptake at this site. The dry weather which limited yields substantially was also likely a contributing factor. Nitrogen moves to the plant for uptake as nitrate by mass flow. During periods of water stress, N uptake is often restricted, unless higher concentrations of N are maintained in the soil solution. Thus, one of the reasons that the crop responded to the highest rate of N applied in the spring was a reduction in N transport to the plant by a reduction in water uptake.

Table 3.13 Results and Contrasts for Ottawa in 2013

No.	Treatment	Treatment N $kg\ ha^{-1}$	Inhibitor Rate $L\ ha^{-1}$	Ear Leaf N $g\ kg^{-1}$	Total N Uptake $kg\ ha^{-1}$	NUE $kg\ kg^{-1}$	Yield $Mg\ ha^{-1}$
1	Fall N only	112		20.3	108	0.44	6.37
2	Fall N with G77	112	9.4	20.3	108	0.44	6.21
3	Fall N with G77	112	18.7	20.9	102	0.39	6.00
4	Fall N with G77	112	28.1	20.6	113	0.48	6.83
5	Fall N with N-Serve	112	2.3	21.1	111	0.46	6.40
6	Control	0		13.3	54	NA[1]	2.89
7	Spring N only	56		16.7	73	0.29	4.40
8	Spring N only	112		20.6	112	0.47	6.26
9	Spring N with G77	112	9.4	20.0	107	0.43	6.32
10	Spring N with G77	112	18.7	21.1	109	0.45	5.97
11	Spring N with G77	112	28.1	20.3	107	0.43	6.18
12	Spring N with N-Serve	112	2.3	19.8	136	0.67	7.51
13	Spring N only	168		22.1	141	0.49	7.58
14	Spring N only	224		22.8	156	0.43	7.57
15	Fall N only	56		18.7	83	0.44	5.36
16	Fall N only	168		23.1	136	0.46	7.07
17	Fall N only	224		24.1	146	0.39	6.52
SE				0.3	3	0.02	0.16
Treatments Pr > F				< 0.0001	< 0.0001	< 0.0001	< 0.0001
Contrasts							
Control vs. N Applied				(3.60)	(31.7)	NA	(1.78)
(6 vs. 1,7,8,13,14,15,16,17)				**	**		**
Fall N vs. Spring N				0.51	(1.1)	0.01	(0.06)
(1,15,16,17 vs. 7,8,13,14)				*			
Fall 112 N vs. Spring 112 N				(0.13)	(2.0)	(0.02)	0.06
(1 vs. 8)							
Fall N-Serve vs. Fall N				0.36	1.7	0.01	0.02
(5 vs. 1)							
Fall N-Serve vs. Spring N				0.24	(0.3)	(0.00)	0.07
(5 vs. 8)							
Fall N-Serve vs. Spring N-Serve				0.66	(12.4)	(0.10)	(0.55)
(5 vs. 12)					*	**	*
Spring N-Serve vs. Spring N				(0.43)	12.1	0.10	0.62
(12 vs. 8)					*	**	*
Fall N-Serve vs. Fall G77 (1x)				0.40	1.7	0.01	0.09
(5 vs. 2)							
Fall N-Serve vs. Fall G77 (2x)				0.08	4.3	0.04	0.20
(5 vs. 3)							
Fall N-Serve vs. Fall G77 (3x)				0.26	(1.1)	(0.01)	(0.21)
(5 vs. 4)							
Spring N-Serve vs. Spring G77 (1x)				(0.15)	14.4	0.12	0.59
(12 vs. 9)					**	**	*
Spring N-Serve vs. Spring G77 (2x)				(0.65)	13.4	0.11	0.77
(12 vs. 10)					**	**	**
Spring N-Serve vs. Spring G77 (3x)				(0.28)	14.2	0.12	0.66
(12 vs. 11)					**	**	*

* indicates significance <0.10, ** indicates significance <0.01 SAS 9.3 Proc Mixed

It is likely that a significant amount of nitrification of the fall applied AA occurred during March and April, prior to the delayed spring application and planting due to high soil temperatures and adequate soil moisture. It is also likely that a large amount of N would have also been denitrified during the wet period between April 9 and the end of May. It is also likely that with the high moisture and temperatures present at spring application, that conversion of NH_3 to NH_4^+, subsequent re-colonization of the application zone by Nitrosomonas and nitrobacter bacteria, and nitrification would have occurred quickly. Drier conditions in June and July would have definitely limited denitrification. Total N uptake was not affected by the timing factor even though a higher concentration was seen in the ear leaf. Even with the high moisture during the period between fall and spring AA applications, no quantitative evidence was collected to show spring applications to be superior to fall applications (Figure 3.23, 3.24, Table 3.12). NUE levels, in the range between 0.28-0.5 kg kg^{-1}, were substantially lower than at the other locations. Total N uptake was at least one-third less than that found at other locations. Moisture played a major role in this outcome. Denitrified N was moved out of the profile via the saturated soil early in the growing season. Later in the growing season, moisture was reduced. Water is used to transport N into and through the plant. Without adequate moisture, maximum uptake is not possible. Therefore, reduced NUE levels and total N uptake levels are found in comparison with high yielding sites like Manhattan and Rossville.

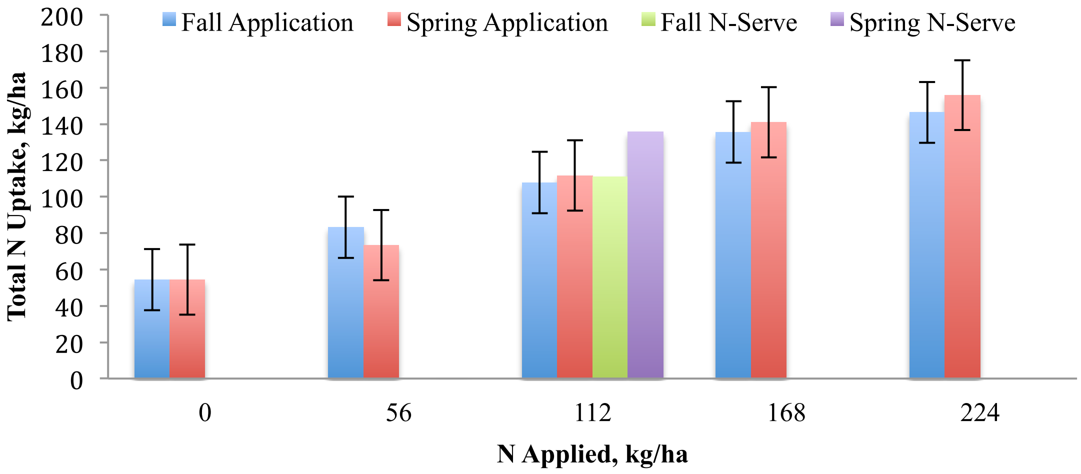

Figure 3.24 Total N Uptake, Ottawa in 2013

Even though yields were not very high because of poor moisture during the growing season, evidence of N losses was still seen. Eleven days after spring application a major N loss event occurred, and once again at the beginning of August (Figure 3.21). N loss was probably seen from both events, since N was available in the mobile NO_3^- form. This can be concluded because the soil temperatures (Figure 3.22) were very warm early in the spring and throughout the summer, resulting in high microbial activity. The use of N-Serve with spring application improved yield and total N uptake (Figure 3.23, 3.24). N-Serve reduced the nitrification process for at least the period eleven days after application and reduced the decrease of NH_4^+ levels likely providing some benefit during the second major moisture event in August. Usage of N-Serve during the fall did not provide benefit because conditions were dry for such a long period after application with limited potential for N loss. Nitrapyrin is effective for a limited time frame. Its ability to inhibit the Nitrosomonas bacteria is a bacteriostatic effect that is reduced with time. Nitrosomonas with time will overcome the inhibition effects (Rodgers and Ashworth, 1982). Touchton also showed clearly that the half-life of N-Serve was strongly related to soil temperatures. The very high soil temperatures in March and April would have broken down the N-Serve and led to high rates of nitrification. Consequently, the wet period shortly after planting would have caused significant denitrification of fall applied N.

In the comparison of G77 with N-Serve, results were favorable for G77. At the Manhattan and Rossville sites in 2013, a slight non-significant increase in N uptake was seen with the use of G77 in comparison with N-Serve in the spring. At Ottawa in 2013, a significant increase in performance was seen with N-Serve, as compared with G77.

G77 Rate Performance and Overall Comparison with N-Serve

Table 3.14 G77 Rate Performance

Effects	Ear Leaf N	Total N Uptake	NUE Recovery	Yield
		P > F		
Inhibitor Rate	0.785	0.362	0.421	0.842
Fall vs. Spring Rates	0.093	0.133	0.536	0.921
Inhibitor Rate*Year	0.110	0.777	0.685	0.499
Inhibitor Rate*Location	0.280	0.983	0.958	0.820
Inhibitor Rate*Year*Location	0.433	0.526	0.808	0.879

Very little difference was found between rates and between timing of applications of G77. This lack of performance was in part the result of the variability in performance of the product itself. As can be seen by the graph below, performance between rates was inconclusive. Variability and performance of rate 1 between fall and spring was the lowest of the three rates for the fall and spring timings. Fall performance of rate 2 trended higher than performance of the spring rate. However, spring performance of rate 3 trended higher than all other rates and timing of rates. There may not be a significant difference between rates and timing of rates as seen by the table above, however, an increasing performance is seen with increasing the rate. Future research under higher N loss conditions with an increase in rate is needed to determine whether or not this product is effective. Figure 3.25 displays potential for success but is not conclusive.

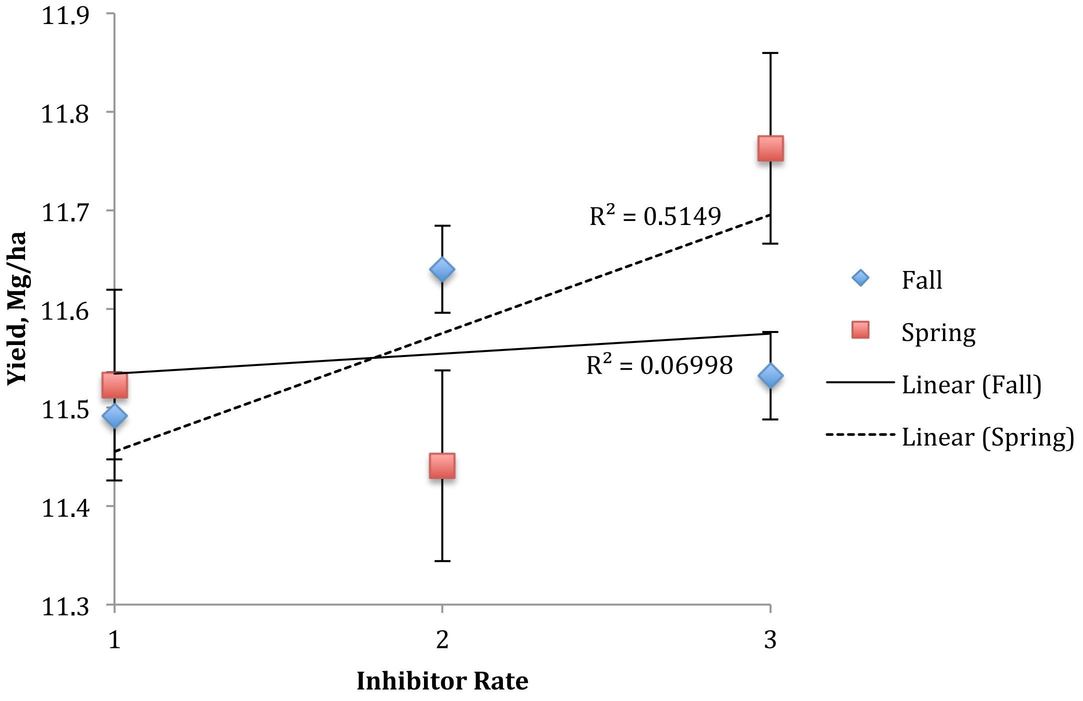

Figure 3.25 G77 Rate Performance

In the overall comparison in performance between N-Serve and G77, an increasing trend is seen with the use of G77 in total N uptake in the spring. However, similarity is seen in performance during the fall. An inhibitor shows performance greater than without an inhibitor. In terms of yield, there was no trend between N-Serve and G77. Fall applications displayed an increased trend from usage of an inhibitor, however there were no significant differences from the use of an inhibitor when all corn sites are grouped. P-values (0.9500) for the comparisons between inhibitors and without inhibitors showed strong insignificance. Variability was too high for conclusive results, one aspect of work with nitrification inhibitors. Their benefit is quite small so reduced variability in a study is extremely important.

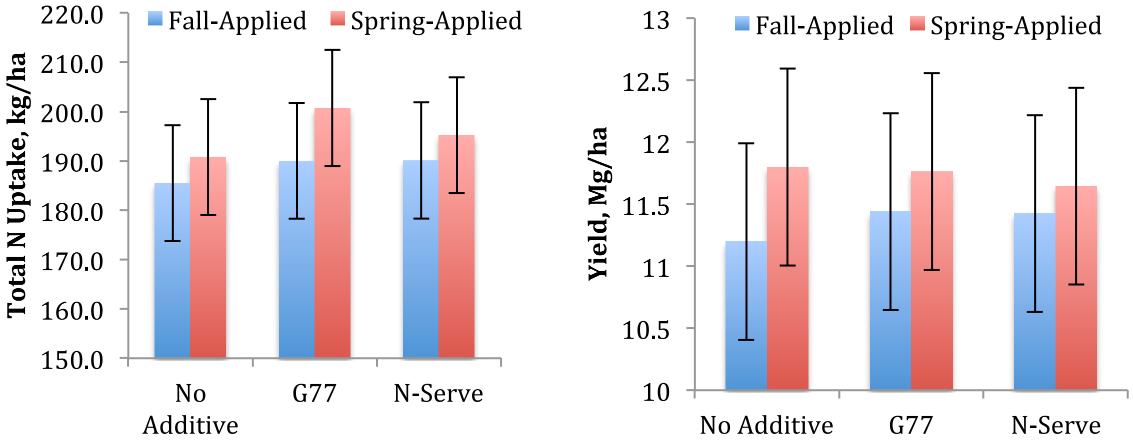

Figure 3.26 Inhibitor Comparison in Total N Uptake and Yield (Combined Analysis)

Conclusions

The impact of time of N application, fall or spring, and the value of a nitrification inhibitor on N uptake and yield of corn varied greatly across years and locations. Factors such as weather, both rainfall and temperature; soil texture, and drainage; and the difference in potential loss mechanisms such as leaching or denitrification all impacted the efficiency of different N management practices at different locations and years. The work of Tremblay, et. al. (2012) clearly shows the importance of these soil properties and climate on N loss and N management to overcome these challenges. Yield responses to N management varied largely due to weather and soil characteristics. In the two years in which this study took place, different responses in yield and N uptake to N timing or the use of NI were found each year. Low NUE levels and reduced yields were seen under prolonged moisture events where leaching was extensive or denitrification potential was high.

Specific site characteristics resulted in different effects at each location. In the combined analysis of all the data, no three-way interaction of location x year x treatment was observed. However, there were treatment differences, location differences, and year differences. Variability across the sites was often high and masked differences. Still, by looking at each experiment individually, site-specific information can be gleaned from the overall study.

In comparing fall versus spring pre-plant AA applications in corn without a nitrification inhibitor, no difference in yield or N uptake was seen at any location except for Rossville in 2012. Moisture at four out of the six total sites during the winter was limited and would not have led to over winter N losses. On the coarse textured soils at Rossville, especially in 2012, the utilization of the fall applied N was about half that found from spring applied N, and a significant reduction in yield where fall applied N was used was seen. At an adjacent site at Rossville in 2013, however, a water limiting layer approximately 0.5 m below the soil surface effectively limited leaching and N loss, holding the N in the root zone longer, and in turn resulted in high yields and N uptake which were similar from both fall and spring applications of N. Nitrogen use efficiency at this site was very high, with most treatments having NUE values of 0.8 g kg^{-1} or higher. This shows how important soil properties such as drainage and water holding capacity can be determining N loss and N use efficiency in corn.

On the medium textured clay pan soils at Ottawa in 2013, yields and N use from both fall and spring applied N were similar, however, they also were lower than those found at many of the high yielding sites. In this case, significant rainfall events occurred over a wet fall and winter, and N was likely lost from both fall and spring applications where no nitrification inhibitor was used. In addition, dry conditions during key growth stages also likely limited yield and N uptake.

In Kansas, moderate to low moisture conditions are common over winter, and our well-drained, fine-textured silt loam soils with 20-40 g kg^{-1} OM, are usually able to hold the fall applied N in the soil at levels that spring applications provided no added benefit, or the benefit is very slight. On many coarse-texture soils with low OM, particularly deep sands that do not have limiting fine textured layers in the subsoil to limit water movement and N leaching, a high potential for N loss through leaching exists, and spring applications are preferred over fall N applications. Ottawa in 2013 received a much higher amount of moisture between fall and spring applications

The use of a nitrification inhibitor, either N-Serve or the experimental product G77, enhanced N use and/ or yield at two of the five completed experiments in this study: at Manhattan in 2012 and Ottawa in 2013. At Manhattan, the application of fall N without an inhibitor resulted in a slight yield and decline in NUE as compared to fall N with an inhibitor or spring applications with or without an inhibitor. This likely due to a single rainfall event which occurred shortly after spring application and planting.

At Ottawa, N loss from denitrification likely occurred over an extended period in March, April and May, and again in August. This is common on these soils, with planting delayed by poor drainage, and N loss from denitrification occurring regularly. In 2013, a significant response to adding a NI to spring applied AA was seen. Loss conditions were so severe that no response was seen with the addition of a NI to fall applied AA.

When nitrogen is applied is an important issue impacting the efficacy and efficiency of N fertilization of corn. There is no question that previous work has shown that N losses are reduced, and NUE increased as the time of application is moved closer to the time N is taken up and utilized by the crop. However, as this data clearly shows, this is more important on soils, especially in climates with a greater potential for N loss, either from leaching or denitrification. The data from this study would suggest that fall application of AA is an application method which can be done relatively safely in Kansas on deep well drained, medium textured soils with limited impacts to the environment.

The addition of a nitrification inhibitor to fall applied AA may also serve as valuable risk management tool to mitigate potential loss in outlier years. Current recommendations are that N should not be applied in the fall for corn on coarse textured, well or excessively well drained soils, or on poorly drained soils where planting delays are common due to wet conditions. Again the results from this research would support this recommendation. Previous research has shown NI to work, especially on dark colored, medium or heavier textured soils when N loss events occur in the first few days after spring warm up. In two out of twelve applications made with N-Serve, the product did work when N loss potential was high. At Rossville in 2012, the product did not perform under high loss conditions. However, with the very low OM and CEC at this site, it is likely that the inhibitor moved away from the N applied reducing its ability to perform. Under sandy soils with low OM and a high potential for leaching, use of N-Serve is not recommended. Specific sites with high potential N loss with more than 20 g kg^{-1} OM would be more suitable locations to focus the use of N-Serve as a risk management strategy.

The assessment of the new experimental nitrification inhibitor, G77, compared to N – Serve or no inhibitor provided variable results. Looking at individual site evaluations, N-Serve provided improved N uptake and yield at two of twelve total applications made. The experimental product produced similar performance to N-Serve during the fall application at the Manhattan site in 2012. At the Manhattan site in 2013, the experimental product applied in the spring increased total N uptake in comparison with spring N alone at the 112 kg rate, as well as, in comparison with N-Serve. However, G77 did not provide improved or at least comparable performance at the Ottawa 2013 site when N-Serve improved yield, NUE, and N uptake. As a result, no strong conclusions can be reached based on this study. The results do indicate that future research is warranted with the product before a recommendation for usage can be given.

Spring applications of N with/without NI may reduce the risk of N loss on most soils. Although, in the two extreme loss cases in the study, Rossville in 2012 and Ottawa in 2013, the results measured as yield or NUE were still not acceptable. In both situations, additional tools such as split N applications utilizing sidedressing, fertigation, or controlled release N fertilizers may be needed to accomplish acceptable levels of efficiency.

Application rate is an additional factor that must also be taken into account when trying to balance high yields and minimal N loss. In none of these studies was yield optimized at N rates above 168 kg N ha^{-1}, and in some cases only 112 kg N ha^{-1} was required. Producers must be aware of the N needs of the crop and avoid over applications of N. The practice of adding a little additional N above normal recommendations as "insurance" leads to increased N loss and reduced NUE. At all locations in 2013 where N was applied in both the fall and spring at rates up to 224 kg ha^{-1}, a trend towards reduction in both N uptake and yield was seen at the highest rate applied in the fall. There are a number of possible reasons this yield reduction was seen, including running out of water during grain fill to additional vegetative growth stimulated by the additional N, or enhanced plant disease.

Nitrogen management techniques such as the use of anhydrous ammonia or other ammonium N sources, timing of applications, amount or rates applied, and the use of a nitrification inhibitor all play potential roles in the overall N management system for corn. However, each strategy must be site-specific based on soil properties and climate of the site.

There is currently no accurate way to predict specific weather conditions for a growing season so a balance between risk, profitability, and environmental impacts should be taken into consideration when implementing the specific strategies.

References

Alexander, M. 1960. Nitrification. *Soil Nitrogen.* 307–343.

Ball, J. D., G. Teneyck, R. E. Lamond, L. S. Murphy, D. F. Leikam, and D. Scott. 1978. Effects of Nitrification Inhibitors on the Yield of Irrigated Corn on Sandy Soils. *KSU Report of Progress*. 124–125.

Combs, S., J. Denning, and K. D. Frank. 1998. Sulfate-Sulfur. *North Central Regional Research Publication.* 221:35-40

Combs, S. M., and M. V. Nathan. 1998. Soil Organic Matter. *North Central Regional Research Publication.* 221:53-58

Frank, K., D. Beegle, and J. Denning. 1998. Phosphorus. *North Central Regional Research Publication.* 221:21-30

Gelderman, R. H., and D. Beegle. 1998. Nitrate-Nitrogen. *North Central Regional Research Publication.* 221:17-20

Gelderman, R. H., J. L. Denning, and R. J. Goos. 1998. Chlorides. *North Central Regional Research Publication.* 221:49-52

Keeney, D. R. 1982. Nitrogen Management for Maximum Efficiency and Minimum Pollution. *Nitrogen in Agricultural Soils*. 605–649.

Maddux, L. D., and P. L. Barnes. 1982. Nitrate Leaching. Kansas Fertilizer Report of Progress. 48-52.

McIntosh, T. H., and L. R. Frederick. 1958. Distribution and Nitrification of Anhydrous Ammonia in a Nicollet Sandy Clay Loam. *Soil Science Society of America.* 402-405.

Parr Jr., J. F. and R. I. Papendick. 1966. Retention of Ammonia in Soils. *Agricultural Anhydrous Ammonia Technology and Use.* 213-236.

Rodgers, G., and J. Ashworth. 1982. Bacteriostatic action of nitrification inhibitors. *Canadian Journal of Microbiology*. *28*:1093–1100.

SAS Institute. 2011. Release 9.3 ed. SAS Inst., Cary, NC.

Stamper, J. 2009. Evaluation of method of placement, timing, and rate of application for anhydrous ammonia in no-till corn production. Kansas State University

Touchton, J. T., R. G. Hoeft, and L. F. Welch. 1972. Effect of Nitrapyrin on Nitrification of Fall and Spring-Applied Anhydrous Ammonia. *Agronomy Journal*. *70*:805–810.

Touchton, J. T., R. G. Hoeft, L. F. Welch, and W. L. Argyilan. 1979. Loss of Nitrapyrin from Soils as Affected by pH and Temperature. *Agronomy Journal*. *71*:865–869.

Touchton, J. T., R. G. Hoeft, and L. F.Welch. 1978. Nitrapyrin Degradation and Movement in Soil. *Agronomy Journal*. *70:811-816*.

Tremblay, N., Y. M. Bouroubi, C. Belec, R. W. Mullen, N. R. Kitchen, W. E. Thomason, et al. 2012. Corn Response to Nitrogen is Influenced by Soil Texture and Weather. Agronomy J. 104:1658-1671.

Viets, F. G. 1965. The Plant's Need for and Use of Nitrogen. *Soil Nitrogen.* 503–549.

Watson, M. E., and J. R. Brown. 1998. pH and Lime Requirement. *North Central Regional Research Publication.* 221:13-16

Warncke, D., and J. R. Brown. 1998. Potassium and Other Basic Cations. *North Central Regional Research Publication.* 221:31-34

Web Soil Survey. USDA. Accessed 9-20-2013. http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

Wolt, J. D. 2004. A meta-evaluation of nitrapyrin agronomic and environmental effectiveness with emphasis on corn production in the Midwestern USA. Nutrient Cycling in Agroecosystems. 69:23-41.

Chapter 4 - Conclusions and Implications

Anhydrous ammonia is a valuable tool in the arsenal of N management tactics available to crop producers. Its reduced cost compared to other N sources, self-inhibition of the nitrification process, and reduced mobility in soil as an all ammonium source retained on the soil cation exchange capacity, makes it very useful. In the dry Kansas environment, many producers apply AA in the fall six to eight months prior to plant uptake for corn and four to five months prior to most plant uptake for wheat. This timing of application could potentially be detrimental under high N loss environments. However, since in most of Kansas winter and early spring precipitation is low, N loss from leaching and denitrification over winter is low. Although, the question becomes, would applying N as AA in the fall allow nitrification over winter which would predispose the fall applied N to leaching or denitrification in late spring when rainfall normally increases, while the planted crop, particularly corn, is not taking up large quantities of N? The objectives of these studies were: 1) To measure the relative performance of fall versus spring applications of AA nitrogen on corn and winter wheat, in terms of yield, N uptake, and NUE; 2) Determine if the addition of a NI such as N-Serve would enhance the performance of the applied N fertilizers and potentially narrow any differences in performance between fall and spring application; and 3) Compare an experimental NI, G77, to the currently registered N-Serve to determine if it may have any advantages. This work was conducted over two years, 2012 and 2013, at three locations in eastern Kansas on soils varying widely in N loss potential from denitrification and leaching.

In the comparison between fall and spring N applications of AA on corn, four of the five site years in which useful data was collected, showed no response in yield, NUE, or total N uptake from a timing of application of AA closer to plant uptake. Fall applications performed very similar to spring applications on moderately-well drained, silt loam soils or coarse textured soils underlain with heavier textured lenses that restricted water movement and N leaching. These silt loams were able to retain the majority of the N for the entire winter season without extensive losses that would reduce performance of the crop. However at a poorly drained site, Ottawa in 2013, no difference was seen without the addition of a NI, but the performance of both fall and spring application was less than desirable due to denitrification. In this case, some additional timing tool such as sidedressing or a split application could have been useful in reducing N loss and increasing NUE. Only at one site was benefit found from making spring applications, and that was the coarse-textured, well-drained soil at Rossville in 2012. This soil displays higher risk of loss via leaching from reduced amounts of rainfall than a finer-textured, well-drained soil. In an effort to reduce risk of environmental impact, fall AA applications for corn on coarse-textured soils are not recommended. Reduced risk of N loss does come from spring applications closer to the time of plant uptake, but fall applications are still a feasible tool under time-limited production systems.

Timing of applications for winter wheat was a bit more involved since spring applications made just prior to the start of plant uptake, are normally not made with AA, but rather use surface applications of urea or UAN solutions, which can be subject to additional N losses from ammonia volatilization or immobilization. Regardless, N losses were not extensive in the five site years analyzed in this study, and NUE's were quite high. At only one site, Silver Lake in 2013, was a benefit seen from spring applying N. Silver Lake was a site with a coarse-textured, low OM soil with high potential for leaching. At all other locations fall applied N was similar and even showed increased benefit at three locations compared to spring applied urea. As a result, applications of fall-applied AA would not be recommended on high leaching environments. However, fall applications of AA in fine-textured soils appear to be acceptable management practices for wheat.

N-Serve (nitrapyrin) and G77 (ai unknown) were two nitrification inhibitors utilized in the study. N-Serve has been on the market for many years and has proven efficacy, however, its performance is variable, primarily due to variation in N loss. Benefit from the use of N-Serve was noted at three wheat sites and two corn sites. This was out of a total of fifteen applications made at different timings on two crops across ten site years. N-Serve proved to be a valid risk management tool to consider. However, how frequently a significant or economic response will be obtained is difficult to predict. N-Serve did not work on a low SOM (less than 10 g kg^{-1}) coarse textured soil, Rossville corn in 2012, when N loss was high from fall applications. Previous research has also shown N-Serve did not perform under similar conditions. As a result, usage of N-Serve on low OM, coarse-textured soils is not recommended. N-Serve can increase yield, NUE, and plant N content, but to take advantage of that potential, it should be targeted towards sites with a moderate to high potential for N loss due to denitrification.

G77, the other nitrification inhibitor compared in the study, performed similar to N-Serve. No large differences in performance were seen between G77 and N-Serve in wheat. In wheat, only one of the twelve site years of data showed a benefit to the use of G77 when N-Serve did not perform. At one other site, Manhattan in 2012, was a benefit seen from N-Serve, and G77 was not statistically similar. G77 seems to be a weaker, but potentially longer lasting nitrification inhibitor. In the combined analysis of all wheat sites, a slight non-significant increase in total N uptake and yield was seen with G77 in comparison with N-Serve. When all the corn sites were evaluated, a slight non-significant trend for increased total N uptake was also seen with the use of G77.

Nitrification inhibitors were shown to have value in fall and spring N applications, but this study would suggest that one can improve the odds for success by focusing NI use on loam or silt loam soils, where N losses are not excessive. Spring applications may reduce risk slightly on these productive soils, but when time is a factor for the producer, a nitrification inhibitor could be added to help ensure the environment is not extensively injured by the decision to fall apply. Nitrogen management is site and crop specific. Different restrictions and allowances should be made for each field, even within the field, to reduce environmental impact and maximize yield potential.

Future Research

Past research has been extensively conducted on the usage of AA as an N source, also on the use of N-Serve as a nitrification inhibitor to enhance the benefit of using AA for fertilization on corn and wheat. However, limitations come from the use of N-Serve. Its performance is variable and short-lived. Also, its performance under high leaching conditions included on soils with coarse textures and low OM content is minimal. Lastly, its corrosive nature on equipment used to make applications of the product is expensive and removes from the value of the product. New nitrification inhibitors which are more effect and can be used over a broader range of soils are needed.

Products such as G77 may have value. Further work with G77 needs to be conducted to determine its true effectiveness. This product should be tested under higher N loss situations and at higher inhibitor rates. Much variation was seen with the different rates applied, however, the trend of increased performance with increasing rate was noted on both wheat and corn.

Appendix A - Wheat Sampling Components

Table A.1 Manhattan 2012 Wheat Sampling Components

Plot	Trt.	Timing	N Source	N Rate	Inhibitor	Flagleaf N	Stover N	Grain N	Stover DM	Total N Uptake	N Recovery	Protein	Moisture	Test Weight	Yield
				kg ha^{-1}		g kg^{-1}	g kg^{-1}	g kg^{-1}	kg ha^{-1}	kg ha^{-1}	kg kg^{-1}	g kg^{-1}	g kg^{-1}	kg hL^{-1}	Mg ha^{-1}
108	1	Fall	NH3	67		29.0	8.9	17.5	9044.5	141.5	0.82	109.1	119	77.8	3.51
102	2	Fall	NH3	67	G77 (1)	29.0	9.7	16.9	7486.5	131.4	0.69	105.9	122	77.8	3.49
105	3	Fall	NH3	67	G77 (2)	29.6	8.6	17.0	8658.9	129.3	0.66	106.5	120	77.6	3.24
103	4	Fall	NH3	67	G77 (3)	28.2	7.9	17.3	.	.	.	108.2	120	76.9	3.23
106	5	Fall	NH3	67	N-Serve	28.5	7.5	17.0	9068.6	124.9	0.61	106.2	117	76.1	3.34
110	6	Control		0		24.4	6.6	17.1	5271.2	78.0	0.00	106.8	118	77.4	2.51
109	7	Spring	Urea	34		27.6	6.9	17.2	.	.	.	107.8	120	77.8	3.27
104	8	Spring	Urea	67		31.2	9.7	17.5	7952.1	138.9	0.79	109.4	124	78.3	3.55
101	9	Spring	Urea	101		33.4	12.4	18.7	.	.	.	117.1	124	77.2	3.49
107	10	Spring	Urea	134		35.6	10.8	20.1	8204.4	155.6	0.54	125.5	121	77.6	3.33
209	1	Fall	NH3	67		31.0	13.0	17.8	10220.6	196.1	1.37	111.4	120	77.6	3.55
201	2	Fall	NH3	67	G77 (1)	28.6	9.8	17.1	10227.0	158.7	0.89	106.8	119	77.4	3.43
202	3	Fall	NH3	67	G77 (2)	28.6	.	16.8	8810.0	.	.	105.3	118	76.9	3.39
207	4	Fall	NH3	67	G77 (3)	30.8	10.4	17.0	8565.2	148.5	0.76	106.4	121	78.3	3.48
204	5	Fall	NH3	67	N-Serve	30.1	7.3	17.6	9338.1	128.1	0.50	110.1	124	77.3	3.42
206	6	Control		0		25.9	6.7	16.3	.	.	0.00	102.2	119	77.9	2.62
203	7	Spring	Urea	34		29.8	6.5	16.8	7123.8	101.6	0.27	105.2	122	77.9	3.27
208	8	Spring	Urea	67		31.8	12.9	18.8	8963.9	183.1	1.21	117.3	119	77.9	3.58
205	9	Spring	Urea	101		33.7	12.1	18.7	7825.0	159.3	0.63	116.8	120	77.9	3.47
210	10	Spring	Urea	134		36.2	14.3	19.3	8993.5	197.2	0.74	120.5	121	76.7	3.56

Table A.1 Manhattan 2012 Continued

Plot	Trt.	Timing	N Source	N Rate	Inhibitor	Flagleaf N	Stover N	Grain N	Stover DM	Total N Uptake	N Recovery	Protein	Moisture	Test Weight	Yield
				kg ha^{-1}		g kg^{-1}	g kg^{-1}	g kg^{-1}	kg ha^{-1}	kg ha^{-1}	kg kg^{-1}	g kg^{-1}	g kg^{-1}	kg hL^{-1}	Mg ha^{-1}
304	1	Fall	NH3	67		32.3	.	17.0	9986.8	.	.	106.5	120	77.4	3.42
306	2	Fall	NH3	67	G77 (1)	32.4	10.6	17.7	8745.8	159.6	0.80	110.8	120	77.1	3.76
303	3	Fall	NH3	67	G77 (2)	31.6	.	17.2	.	.	.	107.6	121	77.8	3.44
305	4	Fall	NH3	67	G77 (3)	32.6	11.8	17.9	9330.7	174.0	0.99	111.8	119	77.1	3.57
308	5	Fall	NH3	67	N-Serve	31.9	11.0	17.2	.	.	.	107.4	119	77.7	3.49
301	6	Control		0		26.2	.	17.0	5376.9	.	0.00	106.3	119	77.9	2.55
309	7	Spring	Urea	34		30.5	9.5	16.5	7457.5	121.4	0.55	103.3	120	78.1	3.05
310	8	Spring	Urea	67		32.9	10.9	17.9	8446.4	153.0	0.72	112.0	118	77.2	3.41
307	9	Spring	Urea	101		36.0	15.1	18.9	8292.4	196.6	0.89	118.3	122	78.3	3.79
302	10	Spring	Urea	134		37.1	13.7	19.7	7925.3	180.1	0.57	122.9	119	77.4	3.62
403	1	Fall	NH3	67		32.7	10.5	17.2	8673.0	157.8	0.81	107.6	120	77.2	3.87
407	2	Fall	NH3	67	G77 (1)	31.5	11.5	17.8	.	.	.	111.3	121	78.3	3.54
408	3	Fall	NH3	67	G77 (2)	31.3	9.7	17.8	7152.8	131.0	0.46	111.3	117	77.6	3.46
401	4	Fall	NH3	67	G77 (3)	32.4	.	17.3	8967.9	.	.	108.1	118	77.2	3.33
404	5	Fall	NH3	67	N-Serve	36.1	10.9	17.7	9271.7	164.7	0.89	110.4	121	77.7	3.62
402	6	Control		0		26.7	9.0	16.6	6217.2	95.6	0.00	103.6	117	76.7	2.38
406	7	Spring	Urea	34		32.0	.	16.7	7358.3	.	.	104.5	120	77.6	3.11
409	8	Spring	Urea	67		34.4	10.4	17.8	.	.	.	111.6	116	77.6	3.16
405	9	Spring	Urea	101		39.6	14.3	19.5	7388.1	172.2	0.69	121.8	121	76.7	3.42
410	10	Spring	Urea	134		41.3	12.4	20.6	.	.	.	128.9	112	76.2	3.42

Table A.2 Rossville 2012 Wheat Sampling Components

Plot	Trt.	Timing	N Source	N Rate	Inhibitor	Flagleaf N	Stover N	Grain N	Stover DM	Total N Uptake	N Recovery	Protein	Moisture	Test Weight	Yield
				kg ha^{-1}		g kg^{-1}	g kg^{-1}	g kg^{-1}	kg ha^{-1}	kg ha^{-1}	kg kg^{-1}	g kg^{-1}	g kg^{-1}	kg hL^{-1}	Mg ha^{-1}
107	1	Fall	NH3	67		33.2	9.6	25.8	3321.4	69.2	0.36	161.0	115	73.8	1.45
102	2	Fall	NH3	67	G77 (1)	36.5	12.0	25.5	7361.5	140.3	1.28	159.6	115	74.4	2.02
105	3	Fall	NH3	67	G77 (2)	30.4	10.8	24.8	4432.7	78.5	0.48	155.3	116	74.2	1.23
103	4	Fall	NH3	67	G77 (3)	37.6	12.5	24.5	6038.4	125.9	1.09	153.1	118	74.3	2.05
106	5	Fall	NH3	67	N-Serve	32.9	11.4	25.3	3373.3	67.6	0.33	158.4	114	73.8	1.15
110	6	Control		0		28.4	9.7	24.1	2403.5	41.7	0.00	150.7	117	74.8	0.76
109	7	Spring	Urea	34		34.3	13.1	24.4	2859.2	64.3	0.52	152.5	116	73.9	1.10
104	8	Spring	Urea	67		36.2	11.6	26.3	4804.0	85.7	0.57	164.6	116	74.7	1.14
101	9	Spring	Urea	101		39.3	15.1	24.7	3793.4	125.5	0.76	154.2	117	75.1	2.77
108	10	Spring	Urea	134		35.0	14.4	27.9	2125.6	68.9	0.19	174.2	116	74.3	1.37
209	1	Fall	NH3	67		34.2	10.3	25.8	3370.8	75.2	0.57	161.4	115	74.8	1.57
201	2	Fall	NH3	67	G77 (1)	36.7	10.9	25.2	4736.7	120.0	1.15	157.4	120	75.2	2.72
202	3	Fall	NH3	67	G77 (2)	40.6	11.5	25.9	4077.4	95.7	0.84	161.6	117	74.1	1.88
207	4	Fall	NH3	67	G77 (3)	37.1	11.3	26.9	2611.1	61.6	0.40	168.2	113	73.9	1.20
204	5	Fall	NH3	67	N-Serve	37.5	12.5	26.6	5095.5	106.9	0.98	166.6	115	74.6	1.62
206	6	Control		0		34.5	13.2	28.2	1562.8	30.8	0.00	176.0	123	75.8	0.36
203	7	Spring	Urea	34		41.7	13.7	23.8	4580.8	105.2	1.70	149.0	124	76.4	1.78
208	8	Spring	Urea	67		38.7	14.5	27.9	2772.8	58.6	0.36	174.4	118	74.8	0.66
205	9	Spring	Urea	101		38.6	13.7	28.9	2855.2	61.1	0.27	180.7	115	74.9	0.76
210	10	Spring	Urea	134		38.8	13.5	28.8	3343.4	63.0	0.22	180.0	112	73.7	0.62

Table A.2 Rossville 2012 Continued

Plot	Trt.	Timing	N Source	N Rate	Inhibitor	Flagleaf N	Stover N	Grain N	Stover DM	Total N Uptake	N Recovery	Protein	Moisture	Test Weight	Yield
				kg ha^{-1}		g kg^{-1}	g kg^{-1}	g kg^{-1}	kg ha^{-1}	kg ha^{-1}	kg kg^{-1}	g kg^{-1}	g kg^{-1}	kg hL^{-1}	Mg ha^{-1}
304	1	Fall	NH3	67		32.8	9.1	25.9	3828.1	71.4	0.06	161.9	117	74.9	1.41
306	2	Fall	NH3	67	G77 (1)	33.1	11.5	25.2	3218.1	71.1	0.06	157.5	117	74.7	1.35
303	3	Fall	NH3	67	G77 (2)	37.3	10.7	26.9	3628.4	83.6	0.22	168.0	117	74.8	1.66
305	4	Fall	NH3	67	G77 (3)	34.5	11.4	24.9	3475.5	74.9	0.11	155.4	117	75.3	1.42
308	5	Fall	NH3	67	N-Serve	37.3	14.1	26.6	3127.7	72.2	0.07	166.1	117	74.9	1.06
301	6	Control		0		37.2	14.7	26.2	2279.3	66.5	0.00	163.6	136	75.1	1.26
309	7	Spring	Urea	34		37.9	15.8	27.1	1956.8	47.0	-0.45	169.7	126	75.1	0.59
310	8	Spring	Urea	67		41.2	14.1	28.4	2126.1	44.4	-0.29	177.5	131	74.7	0.50
307	9	Spring	Urea	101		38.5	17.0	28.5	1954.5	64.6	-0.02	178.2	118	75.1	1.10
302	10	Spring	Urea	134		42.1	14.4	28.1	3451.8	97.1	0.21	175.6	128	74.3	1.69
403	1	Fall	NH3	67		36.5	12.8	26.5	3868.1	98.5	0.96	165.8	134	75.7	1.84
407	2	Fall	NH3	67	G77 (1)	37.0	12.6	26.5	2196.6	87.1	0.81	165.5	128	75.8	2.25
408	3	Fall	NH3	67	G77 (2)	41.6	11.5	26.3	5803.9	117.0	1.20	164.5	123	75.9	1.92
401	4	Fall	NH3	67	G77 (3)	37.7	14.5	25.9	3098.2	99.8	0.98	162.1	133	74.8	2.12
404	5	Fall	NH3	67	N-Serve	34.5	13.1	25.9	4575.3	123.5	1.28	162.1	123	75.8	2.45
402	6	Control		0		38.9	13.7	27.2	805.6	24.5	0.00	169.8	163	70.1	0.49
406	7	Spring	Urea	34		41.5	13.1	25.3	4156.2	84.0	1.36	157.9	129	76.1	1.18
409	8	Spring	Urea	67		42.8	17.4	25.8	2425.3	87.9	0.82	161.3	130	75.7	1.78
405	9	Spring	Urea	101		39.0	17.8	27.1	2446.0	93.5	0.62	169.1	126	75.7	1.84
410	10	Spring	Urea	134		43.2	18.0	28.4	1491.4	61.7	0.26	177.6	148	73.4	1.23

Table A.3 Ottawa 2012 Wheat Sampling Components

Plot	Trt.	Timing	N Source	N Rate	Inhibitor	Flagleaf N	Stover N	Grain N	Stover DM	Total N Uptake	N Recovery	Protein	Moisture	Test Weight	Yield
				kg ha^{-1}		g kg^{-1}	g kg^{-1}	g kg^{-1}	kg ha^{-1}	kg ha^{-1}	kg kg^{-1}	g kg^{-1}	g kg^{-1}	kg hL^{-1}	Mg ha^{-1}
107	1	Fall	NH3	67		32.0	12.4	18.4	8135.3	147.8	1.36	115.2	118	74.8	2.52
102	2	Fall	NH3	67	G77 (1)	32.2	.	20.2	10334.5	.	.	126.2	121	75.6	2.85
105	3	Fall	NH3	67	G77 (2)	32.9	9.4	19.4	9301.6	140.5	1.27	121.3	119	75.2	2.74
103	4	Fall	NH3	67	G77 (3)	32.9	9.1	19.5	8671.7	130.3	1.14	122.2	121	74.9	2.64
106	5	Fall	NH3	67	N-Serve	33.8	9.4	19.0	9600.1	145.4	1.33	118.5	120	75.6	2.92
110	6	Control		0		27.1	8.3	19.2	1721.4	42.5	0.00	119.9	122	74.7	1.47
109	7	Spring	Urea	34		30.8	8.5	18.5	4886.1	84.5	0.96	115.9	121	75.9	2.32
104	8	Spring	Urea	67		31.0	8.4	20.1	8508.8	128.7	1.11	125.6	121	75.9	2.83
101	9	Spring	Urea	101		36.2	.	22.0	7517.4	.	.	137.8	121	75.4	3.17
108	10	Spring	Urea	134		37.8	9.8	22.0	.	.	.	137.7	118	75.8	3.67
209	1	Fall	NH3	67		30.3	7.5	18.3	8087.3	115.4	0.77	114.5	119	75.2	2.98
201	2	Fall	NH3	67	G77 (1)	32.3	8.5	19.7	8890.4	125.8	0.90	123.4	121	75.3	2.53
202	3	Fall	NH3	67	G77 (2)	32.9	.	20.0	8836.3	.	.	124.8	119	75.2	2.73
207	4	Fall	NH3	67	G77 (3)	28.9	9.2	18.3	8309.1	129.2	0.95	114.2	119	75.8	2.87
204	5	Fall	NH3	67	N-Serve	31.8	11.0	19.0	10045.4	166.1	1.42	118.7	119	75.3	2.93
206	6	Control		0		26.3	7.9	19.1	3937.4	56.0	0.00	119.2	121	74.9	1.31
203	7	Spring	Urea	34		27.7	8.4	17.9	.	.	.	111.9	122	75.2	2.03
208	8	Spring	Urea	67		30.0	8.1	18.6	8556.3	122.5	0.86	116.2	120	75.6	2.88
205	9	Spring	Urea	101		32.7	10.5	19.7	9570.2	167.3	1.00	122.9	120	75.7	3.38
210	10	Spring	Urea	134		38.3	9.5	20.3	9848.7	163.6	0.74	126.7	118	76.2	3.46

Table A.3 Ottawa 2012 Continued

Plot	Trt.	Timing	N Source	N Rate	Inhibitor	Flagleaf N	Stover N	Grain N	Stover DM	Total N Uptake	N Recovery	Protein	Moisture	Test Weight	Yield
				kg ha^{-1}		g kg^{-1}	g kg^{-1}	g kg^{-1}	kg ha^{-1}	kg ha^{-1}	kg kg^{-1}	g kg^{-1}	g kg^{-1}	kg hL^{-1}	Mg ha^{-1}
304	1	Fall	NH3	67		29.6	10.0	19.0	9146.2	146.5	1.12	118.9	120	75.2	2.89
306	2	Fall	NH3	67	G77 (1)	31.5	8.8	18.4	8731.9	127.8	0.88	115.1	119	75.4	2.75
303	3	Fall	NH3	67	G77 (2)	31.7	8.1	18.2	6474.0	101.9	0.54	113.7	119	74.7	2.72
305	4	Fall	NH3	67	G77 (3)	31.5	9.5	17.9	8962.8	138.7	1.02	111.8	118	74.9	3.00
308	5	Fall	NH3	67	N-Serve	32.3	8.3	19.2	7952.9	125.2	0.84	119.7	118	74.7	3.08
301	6	Control		0		27.7	.	21.6	3455.4	.	0.00	135.1	122	75.1	1.15
309	7	Spring	Urea	34		27.5	7.1	16.8	5435.3	76.5	0.37	105.1	120	75.2	2.25
310	8	Spring	Urea	67		33.0	.	18.5	6678.9	.	.	115.6	118	75.7	2.51
307	9	Spring	Urea	101		32.0	8.9	18.8	6742.4	119.5	0.54	117.6	117	75.4	3.16
302	10	Spring	Urea	134		38.2	11.0	20.8	9496.3	176.2	0.80	130.1	118	75.7	3.43
403	1	Fall	NH3	67		30.5	7.5	18.9	6954.2	104.2	0.84	118.4	120	75.2	2.74
407	2	Fall	NH3	67	G77 (1)	29.0	8.0	18.9	.	.	.	118.0	120	75.8	3.17
408	3	Fall	NH3	67	G77 (2)	28.3	9.7	17.8	6765.5	111.9	0.94	111.3	120	75.1	2.59
401	4	Fall	NH3	67	G77 (3)	30.2	8.1	20.0	.	.	.	125.2	121	75.8	2.65
404	5	Fall	NH3	67	N-Serve	31.7	9.5	19.3	.	.	.	120.7	118	75.2	2.97
402	6	Control		0		26.4	7.2	21.0	2080.2	39.2	0.00	131.4	122	74.8	1.15
406	7	Spring	Urea	34		28.1	7.9	17.6	3529.8	61.3	0.51	110.2	122	75.2	1.89
409	8	Spring	Urea	67		32.7	7.4	17.4	.	.	.	108.9	121	75.4	2.34
405	9	Spring	Urea	101		32.9	10.6	17.8	.	.	.	111.0	120	75.9	3.24
410	10	Spring	Urea	134		38.1	8.5	20.6	.	.	.	128.5	118	75.4	3.24

Table A.4 Manhattan 2013 Wheat Sampling Components

Plot	Trt.	Timing	N Source	N Rate	Inhibitor	Flagleaf N	Stover N	Grain N	Stover DM	Total N Uptake	N Recovery	Protein	Moisture	Test Weight	Yield
				kg ha^{-1}		g kg^{-1}	g kg^{-1}	g kg^{-1}	kg ha^{-1}	kg ha^{-1}	kg kg^{-1}	g kg^{-1}	g kg^{-1}	kg hL^{-1}	Mg ha^{-1}
101	1	Fall	NH3	67		30.2	6.1	17.2	10820.1	131.8	0.87	107.3	123.0	72.9	3.84
108	2	Fall	NH3	67	G77 (1)	31.7	.	15.6	14052.1	.	.	97.7	124.0	75.1	4.60
113	3	Fall	NH3	67	G77 (2)	28.2	5.4	15.9	13014.0	129.3	0.84	99.6	122.0	71.3	3.74
102	4	Fall	NH3	67	G77 (3)	29.7	8.7	17.7	14021.4	212.0	1.91	110.7	123.0	74.7	5.06
107	5	Fall	NH3	67	N-Serve	35.4	6.8	19.7	.	.	.	123.2	122.0	74.2	3.52
110	6	Control		0		24.2	5.0	16.6	5609.9	64.5	0.00	103.5	122.0	72.7	2.21
105	7	Spring	Urea	34		25.4	5.1	15.8	5727.0	77.2	0.29	98.6	123.0	72.1	3.05
103	8	Spring	Urea	67		32.3	.	18.3	8364.5	.	.	114.2	121.0	73.3	4.41
109	9	Spring	Urea	101		31.4	5.5	17.9	9784.4	126.8	0.56	111.9	120.0	72.3	4.09
106	10	Spring	Urea	134		33.6	.	21.6	10787.7	.	.	135.2	120.0	74.1	4.58
104	11	Fall	NH3	34		25.1	4.8	15.9	10055.6	117.0	1.20	99.3	127.0	74.8	4.33
111	12	Fall	NH3	101		35.9	8.0	20.5	9017.0	157.6	0.84	128.0	123.0	75.4	4.17
112	13	Fall	NH3	134		38.7	7.3	20.0	16376.6	234.7	1.18	124.9	115.0	72.0	5.80
210	1	Fall	NH3	67		29.0	5.5	15.3	12137.9	130.6	0.80	95.5	124.0	72.7	4.14
207	2	Fall	NH3	67	G77 (1)	32.3	6.8	16.4	13491.9	171.8	1.33	102.5	124.0	74.6	4.90
208	3	Fall	NH3	67	G77 (2)	26.0	6.0	15.7	12279.1	133.6	0.84	98.0	123.0	71.3	3.86
203	4	Fall	NH3	67	G77 (3)	30.7	5.0	16.5	14296.0	148.4	1.03	103.0	123.0	74.4	4.65
209	5	Fall	NH3	67	N-Serve	31.4	6.3	16.9	14059.0	163.0	1.22	105.5	125.0	73.4	4.45
205	6	Control		0		26.6	5.4	17.5	5685.3	68.9	0.00	109.1	123.0	72.6	2.20
211	7	Spring	Urea	34		27.3	4.9	16.4	6659.3	95.3	0.60	102.6	123.0	74.1	3.84
202	8	Spring	Urea	67		28.4	6.6	19.7	7923.2	120.3	0.67	123.2	120.0	72.7	3.43
201	9	Spring	Urea	101		31.6	6.3	18.9	8633.0	130.5	0.56	118.4	121.0	73.6	4.03
213	10	Spring	Urea	134		36.0	7.8	19.3	12450.4	194.9	0.87	120.6	120.0	73.6	5.07
204	11	Fall	NH3	34		25.7	4.8	15.7	8838.0	83.6	0.34	98.1	125.0	72.2	2.61
206	12	Fall	NH3	101		34.1	5.9	18.8	11709.4	154.8	0.78	117.7	124.0	74.4	4.56
212	13	Fall	NH3	134		36.8	6.7	20.6	12971.9	189.6	0.84	128.5	122.0	72.1	4.97

Table A.4 Manhattan 2013 Continued

Plot	Trt.	Timing	N Source	N Rate	Inhibitor	Flagleaf N	Stover N	Grain N	Stover DM	Total N Uptake	N Recovery	Protein	Moisture	Test Weight	Yield
				kg ha^{-1}		g kg^{-1}	g kg^{-1}	g kg^{-1}	kg ha^{-1}	kg ha^{-1}	kg kg^{-1}	g kg^{-1}	g kg^{-1}	kg hL^{-1}	Mg ha^{-1}
313	1	Fall	NH3	67		29.8	6.1	16.4	12322.9	142.1	1.01	102.6	127.0	72.7	4.08
311	2	Fall	NH3	67	G77 (1)	26.2	4.8	15.5	13074.0	129.1	0.85	96.6	128.0	73.3	4.27
308	3	Fall	NH3	67	G77 (2)	24.9	5.4	16.7	9772.6	116.5	0.68	104.3	124.0	73.2	3.80
302	4	Fall	NH3	67	G77 (3)	34.6	6.3	16.5	10898.6	137.7	0.96	103.4	122.0	74.2	4.20
304	5	Fall	NH3	67	N-Serve	.	.	.	.	.	.	.	.	.	.
309	6	Control		0		22.6	5.6	18.9	5421.5	63.8	0.00	118.4	122.0	73.1	1.77
307	7	Spring	Urea	34		24.2	5.2	15.6	6436.6	88.2	0.56	97.5	126.0	72.9	3.50
312	8	Spring	Urea	67		28.8	5.3	15.8	8807.0	112.1	0.63	98.8	123.0	73.2	4.14
306	9	Spring	Urea	101		33.2	7.0	19.1	.	.	.	119.4	122.0	74.4	4.66
305	10	Spring	Urea	134		33.5	7.3	21.9	10859.9	195.1	0.91	136.7	120.0	72.9	5.32
310	11	Fall	NH3	34		24.4	5.9	16.4	.	.	.	102.8	123.0	72.7	2.32
301	12	Fall	NH3	101		39.4	7.4	18.9	.	.	.	118.1	123.0	73.3	4.98
303	13	Fall	NH3	134		35.6	7.9	20.5	15147.7	223.2	1.10	127.9	122.0	71.8	5.09
410	1	Fall	NH3	67		28.9	5.7	15.8	11545.2	134.2	0.99	99.0	125.0	72.8	4.30
409	2	Fall	NH3	67	G77 (1)	27.1	4.7	15.6	11814.0	106.3	0.62	97.4	128.0	73.3	3.23
411	3	Fall	NH3	67	G77 (2)	32.1	4.7	16.8	10901.2	119.2	0.79	105.1	126.0	73.4	4.04
407	4	Fall	NH3	67	G77 (3)	29.8	5.2	16.1	11233.7	123.0	0.84	100.7	127.0	73.8	4.02
401	5	Fall	NH3	67	N-Serve	31.9	5.8	17.2	11492.2	134.2	0.99	107.4	126.0	74.2	3.93
413	6	Control		0		24.0	5.7	18.0	3870.2	58.0	0.00	112.4	126.0	73.3	2.00
402	7	Spring	Urea	34		25.0	5.7	16.7	.	.	.	104.1	125.0	73.4	3.40
403	8	Spring	Urea	67		26.7	5.3	17.3	9076.3	120.3	0.81	107.9	125.0	73.8	4.18
412	9	Spring	Urea	101		32.7	6.3	19.5	11221.7	152.3	0.85	121.7	125.0	74.8	4.21
406	10	Spring	Urea	134		32.1	6.8	19.5	10620.5	164.0	0.73	121.9	122.0	72.6	4.70
405	11	Fall	NH3	34		24.4	4.9	16.1	10613.8	99.5	0.95	100.9	126.0	71.5	2.96
408	12	Fall	NH3	101		31.1	6.1	17.7	12541.6	152.5	0.85	110.5	127.0	73.3	4.33
404	13	Fall	NH3	134		33.4	5.6	20.4	16145.5	189.8	0.91	127.3	121.0	71.1	4.88

Table A.5 Silver Lake 2013 Wheat Sampling Components

Plot	Trt.	Timing	N Source	N Rate kg ha^{-1}	Inhibitor	Flagleaf N g kg^{-1}	Stover N g kg^{-1}	Grain N g kg^{-1}	Stover DM kg ha^{-1}	Total N Uptake kg ha^{-1}	N Recovery kg kg^{-1}	Protein g kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield Mg ha^{-1}
101	1	Fall	NH3	67		25.6	4.9	14.8	.	.	.	92.5	147.5	73.8	3.37
108	2	Fall	NH3	67	G77 (1)	27.4	5.4	14.3	11566.2	107.1	0.46	89.5	142.8	74.3	3.15
113	3	Fall	NH3	67	G77 (2)	33.2	5.1	17.1	13873.9	147.4	0.98	106.7	138.4	73.9	4.46
102	4	Fall	NH3	67	G77 (3)	27.6	5.3	14.3	12669.8	122.3	0.65	89.6	146.2	73.2	3.83
107	5	Fall	NH3	67	N-Serve	30.3	5.8	15.2	11246.2	125.2	0.69	94.9	140.3	73.1	3.97
110	6	Control		0		24.6	5.0	15.9	6701.4	71.9	0.00	99.2	141.1	75.1	2.43
105	7	Spring	Urea	34		27.5	5.6	15.8	9245.7	107.9	0.82	98.6	140.5	73.0	3.54
103	8	Spring	Urea	67		32.4	5.9	15.1	9838.0	120.8	0.63	94.5	139.3	71.4	4.15
109	9	Spring	Urea	101		36.5	5.1	17.3	12451.9	147.4	0.68	108.4	133.9	72.6	4.81
106	10	Spring	Urea	134		35.8	6.6	18.0	12504.0	161.8	0.62	112.8	131.7	70.6	4.39
104	11	Fall	NH3	34		24.9	4.5	14.4	.	.	.	90.0	146.2	72.5	2.68
111	12	Fall	NH3	101		26.5	5.9	15.6	13893.1	144.0	0.65	97.3	138.8	74.2	3.99
112	13	Fall	NH3	134		34.1	6.7	15.8	13400.3	159.4	0.61	98.8	141.6	75.0	4.39
210	1	Fall	NH3	67		32.9	5.6	18.6	17694.2	178.1	0.92	116.0	138.3	74.5	4.27
207	2	Fall	NH3	67	G77 (1)	29.7	5.6	16.2	15357.7	159.0	0.67	101.3	141.3	75.8	4.52
208	3	Fall	NH3	67	G77 (2)	37.9	5.1	17.8	15863.4	154.6	0.61	111.3	138.0	75.1	4.16
203	4	Fall	NH3	67	G77 (3)	29.3	6.0	15.6	13797.4	152.3	0.58	97.2	139.5	74.4	4.45
209	5	Fall	NH3	67	N-Serve	30.6	5.3	17.6	13663.5	148.7	0.54	109.8	135.8	74.7	4.36
205	6	Control		0		35.9	5.4	18.8	8870.8	107.4	0.00	117.3	140.9	75.7	3.15
211	7	Spring	Urea	34		30.6	5.3	15.9	13860.8	143.2	0.82	99.6	136.3	74.2	4.36
202	8	Spring	Urea	67		33.1	6.1	15.8	11139.7	132.1	0.32	98.5	137.0	72.6	4.06
201	9	Spring	Urea	101		36.2	6.0	17.0	12721.0	159.0	0.47	106.2	135.0	72.7	4.83
213	10	Spring	Urea	134		41.0	6.7	20.3	15345.1	203.7	0.67	126.9	130.0	72.2	5.01
204	11	Fall	NH3	34		35.4	5.9	18.1	12688.8	138.8	0.72	113.2	142.1	75.6	3.50
206	12	Fall	NH3	101		34.8	6.3	18.2	15478.0	189.9	0.74	113.9	139.2	75.2	5.06
212	13	Fall	NH3	134		37.0	6.1	18.4	18382.9	213.8	0.74	114.8	137.3	75.5	5.56

Table A.5 Silver Lake 2013 Continued

Plot	Trt.	Timing	N Source	N Rate	Inhibitor	Flagleaf N	Stover N	Grain N	Stover DM	Total N Uptake	N Recovery	Protein	Moisture	Test Weight	Yield
				kg ha^{-1}		g kg^{-1}	g kg^{-1}	g kg^{-1}	kg ha^{-1}	kg ha^{-1}	kg kg^{-1}	g kg^{-1}	g kg^{-1}	kg hL^{-1}	Mg ha^{-1}
313	1	Fall	NH3	67		31.1	5.9	16.9	17537.1	179.6	0.53	105.6	133.8	74.5	4.54
311	2	Fall	NH3	67	G77 (1)	37.8	5.3	19.2	13306.9	172.0	0.43	120.0	133.9	75.1	5.26
308	3	Fall	NH3	67	G77 (2)	36.1	6.7	19.0	13623.0	192.7	0.70	118.8	135.5	74.7	5.34
302	4	Fall	NH3	67	G77 (3)	33.2	6.0	16.9	17646.0	188.2	0.64	105.5	137.0	74.8	4.89
304	5	Fall	NH3	67	N-Serve	36.3	6.3	17.5	15063.8	188.1	0.64	109.4	134.6	74.5	5.30
309	6	Control		0		32.1	5.8	17.2	.	.	0.00	107.5	137.6	74.4	3.63
307	7	Spring	Urea	34		35.7	6.3	18.7	14975.9	196.1	1.31	116.7	136.5	74.4	5.48
312	8	Spring	Urea	67		31.8	7.6	18.7	14859.4	220.4	1.06	117.2	131.0	73.6	5.75
306	9	Spring	Urea	101		35.5	7.7	18.7	16261.3	233.1	0.85	116.8	129.6	73.6	5.73
305	10	Spring	Urea	134		39.3	7.4	19.9	17177.7	240.7	0.71	124.3	132.8	73.5	5.71
310	11	Fall	NH3	34		30.1	7.4	16.2	18977.2	214.5	1.73	101.4	137.1	74.8	4.55
301	12	Fall	NH3	101		34.0	6.7	18.0	15893.9	212.3	0.66	112.7	136.8	75.3	5.84
303	13	Fall	NH3	134		38.2	7.7	19.7	17131.0	246.4	0.75	123.1	136.4	75.8	5.81
410	1	Fall	NH3	67		36.1	5.9	18.9	16758.6	195.7	0.89	118.1	133.8	75.0	5.15
409	2	Fall	NH3	67	G77 (1)	33.5	5.5	17.3	15667.3	159.8	0.43	108.4	136.3	75.3	4.23
411	3	Fall	NH3	67	G77 (2)	33.0	6.0	18.3	13172.0	160.1	0.43	114.3	134.3	74.5	4.42
407	4	Fall	NH3	67	G77 (3)	37.5	6.1	18.1	18047.4	202.8	0.98	113.2	134.6	75.0	5.07
401	5	Fall	NH3	67	N-Serve	33.7	6.2	16.1	18279.6	198.2	0.93	100.5	134.1	74.8	5.30
413	6	Control		0		34.1	4.6	19.6	9985.4	126.7	0.00	122.3	135.0	76.1	4.11
402	7	Spring	Urea	34		35.5	6.0	18.8	14971.3	189.8	1.45	117.5	134.8	74.6	5.30
403	8	Spring	Urea	67		36.0	7.8	18.3	14996.6	214.3	1.13	114.4	134.0	74.5	5.31
412	9	Spring	Urea	101		37.5	8.2	20.0	17074.6	258.2	1.19	125.2	130.9	74.7	5.86
406	10	Spring	Urea	134		40.0	6.9	20.9	15225.0	225.7	0.69	130.4	132.6	73.0	5.78
405	11	Fall	NH3	34		31.6	6.8	18.4	16598.9	202.6	1.74	114.9	136.0	76.4	4.92
408	12	Fall	NH3	101		38.2	7.6	18.4	16487.3	228.7	0.92	114.8	133.4	75.0	5.62
404	13	Fall	NH3	134		38.4	7.9	18.2	18465.5	246.7	0.83	113.8	135.4	75.2	5.52

Table A.6 Ottawa 2013 Wheat Sampling Components

Plot	Trt.	Timing	N Source	N Rate kg ha^{-1}	Inhibitor	Flagleaf N g kg^{-1}	Stover N g kg^{-1}	Stover DM g kg^{-1}	Grain N kg ha^{-1}	Total N Uptake kg ha^{-1}	N Recovery kg kg^{-1}	Protein g kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield Mg ha^{-1}
101	1	Fall	NH3	67		30.5	8.9	79692.4	2.3	154.3	0.96	129.1	104.5	72.4	3.64
108	2	Fall	NH3	67	G77 (1)	34.5	7.8	100324.2	2.4	162.9	1.07	134.0	98.3	73.1	3.49
113	3	Fall	NH3	67	G77 (2)	36.0	8.7	75763.1	2.3	139.8	0.77	130.5	96.5	71.7	3.16
102	4	Fall	NH3	67	G77 (3)	32.8	8.1	76055.9	2.3	144.1	0.82	129.1	102.1	73.2	3.62
107	5	Fall	NH3	67	N-Serve	35.1	7.8	74126.4	2.5	141.7	0.79	139.0	101.0	73.7	3.46
110	6	Control		0		27.5	7.2	53487.4	2.1	80.5	0.00	119.3	96.7	71.9	1.94
105	7	Spring	Urea	34		31.5	.	68829.3	2.2	.	.	120.3	102.4	72.8	2.74
103	8	Spring	Urea	67		31.1	8.1	74407.6	2.4	132.5	0.67	133.3	102.6	72.3	3.05
109	9	Spring	Urea	101		33.0	.	82838.7	2.7	.	.	149.0	97.4	72.0	3.35
106	10	Spring	Urea	134		37.3	8.1	94302.8	2.5	162.3	0.57	141.7	105.4	71.4	3.38
104	11	Fall	NH3	34		28.2	6.4	63800.5	2.0	102.4	0.50	113.3	101.5	73.2	3.13
111	12	Fall	NH3	101		36.0	9.9	85439.4	2.6	190.1	0.99	145.8	96.7	72.4	4.09
112	13	Fall	NH3	134		39.0	11.2	93802.8	2.5	211.7	0.91	139.8	94.6	71.7	4.20
210	1	Fall	NH3	67		30.9	7.8	88500.4	2.2	164.2	1.21	123.9	99.8	73.0	4.37
207	2	Fall	NH3	67	G77 (1)	35.5	7.8	93745.5	2.3	165.7	1.23	129.5	101.2	73.6	4.07
208	3	Fall	NH3	67	G77 (2)	30.4	7.9	79016.6	2.2	148.8	1.01	122.8	100.9	74.3	4.03
203	4	Fall	NH3	67	G77 (3)	35.3	9.3	91005.8	2.4	180.4	1.42	133.3	103.7	74.1	4.00
209	5	Fall	NH3	67	N-Serve	29.8	7.3	77828.8	2.3	143.6	0.94	128.0	101.1	73.8	3.89
205	6	Control		0		24.2	7.1	41926.6	2.1	70.6	0.00	119.2	104.4	75.4	1.95
211	7	Spring	Urea	34		24.8	6.8	79057.8	2.3	128.8	1.33	126.5	99.6	73.9	3.38
202	8	Spring	Urea	67		32.4	7.8	69525.3	2.3	130.9	0.78	126.1	103.8	74.4	3.46
201	9	Spring	Urea	101		36.0	8.4	95346.2	2.5	169.8	0.89	139.7	105.8	73.1	3.58
213	10	Spring	Urea	134		30.6	8.5	74875.9	2.4	155.8	0.59	131.3	97.3	72.5	4.02
204	11	Fall	NH3	34		30.6	7.2	84629.2	2.1	131.1	1.38	117.3	103.9	74.7	3.33
206	12	Fall	NH3	101		35.7	8.4	77602.2	2.4	174.4	0.94	136.5	101.8	73.8	4.64
212	13	Fall	NH3	134		34.6	9.5	86185.7	2.5	195.4	0.86	139.3	97.4	73.1	4.67

Table A.6 Ottawa 2013 Continued

Plot	Trt.	Timing	N Source	N Rate	Inhibitor	Flagleaf N	Stover N	Stover DM	Grain N	Total N Uptake	N Recovery	Protein	Moisture	Test Weight	Yield
				kg ha^{-1}		g kg^{-1}	g kg^{-1}	g kg^{-1}	kg ha^{-1}	kg ha^{-1}	kg kg^{-1}	g kg^{-1}	g kg^{-1}	kg hL^{-1}	Mg ha^{-1}
313	1	Fall	NH3	67		33.6	7.9	110686.4	2.2	185.5	1.29	122.9	100.5	74.9	4.43
311	2	Fall	NH3	67	G77 (1)	32.3	7.6	85045.2	2.2	164.1	1.01	122.5	101.3	74.9	4.69
308	3	Fall	NH3	67	G77 (2)	33.0	6.9	107591.0	2.2	169.4	1.08	122.7	102.4	75.0	4.38
302	4	Fall	NH3	67	G77 (3)	33.3	8.2	89826.9	2.2	164.6	1.02	125.4	107.9	74.0	4.11
304	5	Fall	NH3	67	N-Serve	33.5	8.8	92098.8	2.4	174.7	1.15	132.6	106.5	75.9	3.96
309	6	Control		0		24.9	6.6	52012.4	2.0	85.8	0.00	112.5	101.4	75.5	2.62
307	7	Spring	Urea	34		27.9	6.4	69438.4	2.2	114.5	0.66	120.7	102.3	74.9	3.33
312	8	Spring	Urea	67		29.3	7.5	61929.9	2.0	123.6	0.49	113.1	101.0	74.1	3.94
306	9	Spring	Urea	101		33.1	8.3	88825.6	2.2	163.3	0.70	125.4	102.5	74.7	4.02
305	10	Spring	Urea	134		33.9	7.3	88522.9	2.3	156.1	0.49	125.6	102.4	73.6	4.17
310	11	Fall	NH3	34		27.8	5.7	86624.6	2.1	127.9	0.97	115.6	102.2	75.5	3.94
301	12	Fall	NH3	101		36.1	9.2	108641.7	2.4	212.9	1.15	134.8	105.8	74.2	4.70
303	13	Fall	NH3	134		36.5	9.2	107179.8	2.6	217.6	0.91	147.7	105.0	74.6	4.55
410	1	Fall	NH3	67		34.9	7.4	93986.5	2.1	154.7	0.67	114.7	103.7	75.7	4.20
409	2	Fall	NH3	67	G77 (1)	35.3	7.0	85934.0	2.1	149.2	0.60	117.5	101.8	75.0	4.36
411	3	Fall	NH3	67	G77 (2)	34.5	7.6	97701.3	2.2	176.8	0.96	122.1	101.8	74.7	4.80
407	4	Fall	NH3	67	G77 (3)	34.0	7.8	83723.8	2.2	165.0	0.81	121.9	105.1	75.2	4.70
401	5	Fall	NH3	67	N-Serve	34.6	8.5	82440.9	2.5	180.1	1.00	138.2	106.7	74.0	4.58
413	6	Control		0		25.3	7.4	.	2.1	.	.	114.7	102.6	76.0	2.85
402	7	Spring	Urea	34		29.5	5.8	61561.3	2.0	102.8	0.00	109.6	109.0	91.8	3.57
403	8	Spring	Urea	67		31.1	6.3	60680.7	2.2	117.3	0.19	120.1	108.2	75.5	3.86
412	9	Spring	Urea	101		33.3	7.0	74414.5	2.2	136.2	0.30	123.7	105.9	74.6	3.93
406	10	Spring	Urea	134		34.5	6.4	79421.6	2.2	137.2	0.24	121.0	103.6	74.6	4.17
405	11	Fall	NH3	34		33.4	6.5	90266.0	2.0	139.2	0.83	111.3	107.9	75.7	4.14
408	12	Fall	NH3	101		36.1	8.5	86171.4	2.4	185.6	0.75	131.3	103.2	74.9	4.91
404	13	Fall	NH3	134		42.0	8.2	108687.7	2.4	208.9	0.73	134.8	107.7	74.4	5.08

Appendix B - Corn Sampling Components

Table B.1 Manhattan 2012 Corn Sampling Components

Plot	Trt.	Timing	N Rate	Inhibitor	Plant Pop.	Earleaf N	Stover N	Grain N	Stover DM	Total N Uptake	N Recovery	Moisture	Test Weight	Yield
			kg ha^{-1}		pl ha^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	kg ha^{-1}	kg ha^{-1}	kg kg^{-1}	g kg^{-1}	kg hL^{-1}	Mg ha^{-1}
112	1	Fall	112		72660	16.5	6.6	12.3	7056.5	131.4	0.27	161.0	72.0	6.92
108	2	Fall	112	G77 (1)	69792	23.5	9.0	14.3	8159.6	221.0	1.00	176.0	69.1	10.33
102	3	Fall	112	G77 (2)	72660	19.4	8.5	13.9	7865.9	202.6	0.85	165.0	72.3	9.75
114	4	Fall	112	G77 (3)	69792	18.2	7.6	13.0	9113.6	202.0	0.85	167.0	71.7	10.22
105	5	Fall	112	N-Serve	70748	20.7	7.6	13.5	8466.1	187.6	0.73	170.0	71.5	9.14
111	6	Control	0		69792	16.1	5.9	12.0	7405.3	98.4	0.00	149.0	69.3	4.58
103	7	Spring	56		70748	17.7	7.6	13.5	7962.2	170.0	1.08	174.0	70.3	8.09
113	8	Spring	112		68836	21.4	6.6	13.1	7887.4	167.0	0.56	167.0	72.3	8.77
109	9	Spring	112	G77 (1)	69792	21.6	8.7	13.1	8005.8	186.0	0.72	177.0	70.8	8.88
110	10	Spring	112	G77 (2)	63099	18.2	7.4	13.6	7612.5	176.2	0.64	178.0	70.5	8.81
101	11	Spring	112	G77 (3)	71704	19.7	8.6	13.7	8134.5	180.2	0.67	162.0	71.6	8.02
106	12	Spring	112	N-Serve	66923	19.6	10.4	13.8	7927.4	213.8	0.94	180.0	69.6	9.52
104	13	Spring	168		69792	21.3	8.9	14.4	7844.3	185.4	0.49	191.0	69.6	8.03
107	14	Spring	224		69792	18.9	9.1	14.5	8059.3	189.1	0.39	180.0	69.5	8.01
203	1	Fall	112		71704	18.9	9.9	13.5	8095.2	204.5	0.62	160.0	71.7	9.23
202	2	Fall	112	G77 (1)	71704	22.0	8.4	14.1	7862.4	202.1	0.60	173.0	69.7	9.63
210	3	Fall	112	G77 (2)	73616	19.1	8.9	13.3	7423.6	206.0	0.63	172.0	71.7	10.49
209	4	Fall	112	G77 (3)	72660	16.5	8.0	13.4	7844.3	202.6	0.60	178.0	72.7	10.44
213	5	Fall	112	N-Serve	69792	20.9	9.5	13.2	8912.3	224.2	0.78	164.0	72.3	10.51
205	6	Control	0		66923	17.3	7.5	11.9	8097.6	128.8	0.00	156.0	70.2	5.76
212	7	Spring	56		70748	17.0	9.2	12.8	7429.8	177.4	0.73	168.0	72.2	8.51
206	8	Spring	112		71704	20.8	7.5	13.5	9000.2	199.5	0.58	170.0	72.0	9.75
211	9	Spring	112	G77 (1)	66923	20.1	8.5	13.6	9049.5	210.8	0.67	182.0	71.2	9.88
204	10	Spring	112	G77 (2)	70748	21.3	8.3	13.4	8607.3	195.1	0.54	186.0	707.0	9.24

Table B.1 Manhattan 2012 Corn Continued

Plot	Trt.	Timing	N Rate	Inhibitor	Plant Pop.	Earleaf N	Stover N	Grain N	Stover DM	Total N Uptake	N Recovery	Moisture	Test Weight	Yield
			kg ha^{-1}		pl ha^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	kg ha^{-1}	kg ha^{-1}	kg kg^{-1}	g kg^{-1}	kg hL^{-1}	Mg ha^{-1}
208	11	Spring	112	G77 (3)	70748	19.5	9.0	13.1	7375.2	201.1	0.59	184.0	70.7	10.23
201	12	Spring	112	N-Serve	75528	20.4	8.9	14.0	7742.3	202.9	0.61	158.0	70.7	9.53
207	13	Spring	168		71704	18.5	12.4	14.0	7380.0	230.4	0.57	174.0	71.3	9.95
214	14	Spring	224		69792	22.6	10.3	13.5	8523.3	228.4	0.43	182.0	71.1	10.42
305	1	Fall	112		65967	21.9	9.6	13.5	9290.0	209.8	0.90	158.0	72.6	8.89
306	2	Fall	112	G77 (1)	70748	20.5	9.5	13.7	8460.5	208.8	0.89	162.0	73.1	9.34
308	3	Fall	112	G77 (2)	69792	18.9	9.7	13.3	8084.3	202.9	0.85	170.0	70.5	9.34
301	4	Fall	112	G77 (3)	73616	19.5	8.1	13.8	9326.2	193.0	0.76	153.0	71.1	8.52
307	5	Fall	112	N-Serve	69792	18.3	8.9	13.8	7688.7	179.4	0.65	150.0	71.6	8.02
313	6	Control	0		75528	17.8	6.7	12.4	6926.1	99.7	0.00	133.0	68.0	4.29
310	7	Spring	56		72660	18.5	5.9	13.4	7433.1	143.7	0.67	154.0	72.3	7.45
302	8	Spring	112		70748	21.1	7.2	14.3	8145.2	173.9	0.61	156.0	72.7	8.07
303	9	Spring	112	G77 (1)	73616	21.6	7.2	13.8	7802.1	177.7	0.64	165.0	69.8	8.79
309	10	Spring	112	G77 (2)	71704	20.9	9.6	15.0	7055.0	193.0	0.76	157.0	72.2	8.37
304	11	Spring	112	G77 (3)	69792	20.3	9.3	14.1	8992.5	198.8	0.81	164.0	71.3	8.16
311	12	Spring	112	N-Serve	67880	20.5	8.4	14.3	7809.7	191.1	0.75	159.0	72.2	8.74
314	13	Spring	168		67880	20.2	10.5	15.1	7785.9	219.4	0.67	170.0	72.2	9.14
312	14	Spring	224		66923	20.6	8.7	15.8	8100.1	212.1	0.48	186.0	70.6	8.94
414	1	Fall	112		71704	19.6	9.1	13.2	8236.1	206.9	0.75	173.0	71.1	10.04
408	2	Fall	112	G77 (1)	67880	20.9	8.3	14.1	7467.5	200.2	0.70	167.0	71.3	9.81
407	3	Fall	112	G77 (2)	74572	19.3	9.0	14.5	7570.3	206.7	0.75	161.0	71.8	9.58
404	4	Fall	112	G77 (3)	69792	20.0	8.3	14.2	8440.2	206.1	0.75	166.0	72.3	9.60
410	5	Fall	112	N-Serve	72660	20.8	9.1	13.5	9146.4	231.2	0.95	166.0	71.7	10.95
401	6	Control	0		68836	20.7	7.0	11.6	7782.5	114.9	0.00	147.0	68.0	5.21
403	7	Spring	56		73616	18.8	5.8	13.7	7432.1	161.4	0.70	153.0	71.0	8.61
411	8	Spring	112		71704	20.0	9.3	10.8	7543.1	184.9	0.57	172.0	72.1	10.62

Table B.1 Manhattan 2012 Corn Continued

Plot	Trt.	Timing	N Rate kg ha^{-1}	Inhibitor	Plant Pop. pl ha^{-1}	Earleaf N g kg^{-1}	Stover N g kg^{-1}	Grain N g kg^{-1}	Stover DM kg ha^{-1}	Total N Uptake kg ha^{-1}	N Recovery kg kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield Mg ha^{-1}
413	9	Spring	112	G77 (1)	71704	23.1	9.7	13.2	8718.6	211.0	0.79	174.0	72.1	9.54
412	10	Spring	112	G77 (2)	69792	21.5	8.5	12.5	8326.0	202.7	0.72	171.0	72.2	10.53
409	11	Spring	112	G77 (3)	69792	22.3	9.0	15.1	9167.1	225.1	0.90	188.0	70.0	9.40
405	12	Spring	112	N-Serve	73616	20.2	8.6	13.2	8706.6	209.0	0.77	166.0	72.0	10.18
402	13	Spring	168		74572	18.3	7.4	14.3	7639.5	178.8	0.36	168.0	71.5	8.54
406	14	Spring	224		76484	22.7	9.1	14.1	9147.9	222.8	0.46	186.0	71.2	9.85

Table B.2 Rossville 2012 Corn Sampling Components

Plot	Trt.	Timing	N Rate kg ha^{-1}	Inhibitor	Plant Pop. pl ha^{-1}	Earleaf N g kg^{-1}	Stover N g kg^{-1}	Grain N g kg^{-1}	Stover DM kg ha^{-1}	Total N Uptake kg ha^{-1}	N Recovery kg kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield Mg ha^{-1}
112	1	Fall	112		64533	23.7	9.2	13.1	5696.6	199.3	0.58	162.7	71.2	11.21
108	2	Fall	112	G77 (1)	61952	22.8	7.5	11.2	7099.5	162.5	0.28	168.6	70.7	9.70
102	3	Fall	112	G77 (2)	60231	24.7	7.1	12.0	5981.2	158.8	0.25	164.9	70.9	9.73
114	4	Fall	112	G77 (3)	66254	25.8	10.5	12.9	6271.4	198.6	0.58	162.1	71.3	10.33
105	5	Fall	112	N-Serve	59371	27.3	7.1	9.9	6452.7	142.5	0.12	163.4	70.8	9.72
111	6	Control	0		61952	20.6	8.9	12.1	5277.4	128.3	0.00	158.5	69.2	6.70
103	7	Spring	56		57650	21.3	8.3	10.6	6228.3	150.1	0.33	157.6	70.1	9.30
113	8	Spring	112		65394	23.9	7.9	12.2	6530.6	185.9	0.47	162.0	70.3	10.94
109	9	Spring	112	G77 (1)	64533	24.9	7.6	11.1	7167.3	169.0	0.33	157.6	70.4	10.32
110	10	Spring	112	G77 (2)	61952	25.1	10.0	12.8	7510.0	216.1	0.72	165.8	70.9	11.07
101	11	Spring	112	G77 (3)	64533	23.2	9.1	12.1	6677.1	167.1	0.32	159.9	70.5	8.81
106	12	Spring	112	N-Serve	62812	26.5	8.1	12.0	5949.3	179.6	0.42	164.6	71.8	10.97
104	13	Spring	168		60231	24.8	9.1	12.0	6614.2	194.8	0.37	168.1	70.8	11.24
107	14	Spring	224		52487	26.4	9.2	11.0	7250.7	189.2	0.26	169.6	70.4	11.14

Table B.2 Rossville 2012 Corn Continued

Plot	Trt.	Timing	N Rate	Inhibitor	Plant Pop.	Earleaf N	Stover N	Grain N	Stover DM	Total N Uptake	N Recovery	Moisture	Test Weight	Yield
			kg ha^{-1}		pl ha^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	kg ha^{-1}	kg ha^{-1}	kg kg^{-1}	g kg^{-1}	kg hL^{-1}	Mg ha^{-1}
203	1	Fall	112		60231	22.1	9.1	12.8	5521.3	147.9	0.11	145.9	68.8	7.67
202	2	Fall	112	G77 (1)	59371	22.5	10.2	13.1	5453.8	160.2	0.21	157.4	69.1	7.98
210	3	Fall	112	G77 (2)	62812	24.8	9.5	12.8	6247.4	189.1	0.45	167.3	70.6	10.13
209	4	Fall	112	G77 (3)	62812	23.8	11.5	12.4	6103.5	182.7	0.40	169.1	69.4	9.04
213	5	Fall	112	N-Serve	60231	24.6	9.4	12.9	6034.8	172.2	0.31	163.5	69.4	8.93
205	6	Control	0		65394	20.2	8.8	12.5	5938.1	134.0	0.00	155.0	69.5	6.52
212	7	Spring	56		64533	22.5	9.3	13.4	6564.0	180.7	0.71	164.1	70.8	8.91
206	8	Spring	112		64533	26.6	11.3	12.7	6841.1	205.1	0.58	160.8	70.2	10.06
211	9	Spring	112	G77 (1)	63673	26.0	11.3	13.8	5598.3	212.4	0.64	177.4	70.2	10.84
204	10	Spring	112	G77 (2)	59371	25.3	9.7	13.5	6663.1	183.6	0.41	149.2	68.9	8.79
208	11	Spring	112	G77 (3)	59371	25.4	10.4	14.2	6365.4	206.4	0.59	175.7	70.3	9.85
201	12	Spring	112	N-Serve	61952	26.1	9.2	13.3	5099.6	174.1	0.33	147.6	69.2	9.58
207	13	Spring	168		54208	27.3	12.3	14.2	6853.7	240.9	0.60	176.2	69.7	11.00
214	14	Spring	224		61952	20.2	10.4	13.2	6731.9	205.9	0.31	168.8	70.0	10.28
305	1	Fall	112		59371	25.9	9.9	14.1	6287.5	223.0	0.61	168.1	70.4	11.40
306	2	Fall	112	G77 (1)	64533	24.1	8.1	13.9	5130.3	177.9	0.24	176.1	69.8	9.81
308	3	Fall	112	G77 (2)	63673	.	.	.	.	.	.	.	.	.
301	4	Fall	112	G77 (3)	61952	.	.	.	.	.	.	.	.	.
307	5	Fall	112	N-Serve	56789	24.3	9.7	13.6	5534.3	167.6	0.16	157.8	68.8	8.37
313	6	Control	0		61092	20.5	8.4	14.8	6118.5	148.5	0.00	159.6	69.4	6.59
310	7	Spring	56		64533	24.1	8.3	13.3	5600.2	156.8	0.13	161.6	69.7	8.30
302	8	Spring	112		65394	26.3	9.9	13.1	7542.8	245.0	0.79	181.3	70.8	12.98
303	9	Spring	112	G77 (1)	64533	25.2	9.5	14.8	8043.4	265.7	0.96	179.9	70.6	12.74
309	10	Spring	112	G77 (2)	61092	25.6	9.0	13.7	7153.2	188.3	0.33	149.4	68.7	8.99
304	11	Spring	112	G77 (3)	61952	27.9	10.1	13.7	6765.6	241.9	0.77	187.0	70.1	12.68
311	12	Spring	112	N-Serve	61092	26.1	9.6	14.0	6445.9	202.2	0.44	163.8	70.3	10.04

Table B.2 Rossville 2012 Corn Continued

Plot	Trt.	Timing	N Rate kg ha^{-1}	Inhibitor	Plant Pop. pl ha^{-1}	Earleaf N g kg^{-1}	Stover N g kg^{-1}	Grain N g kg^{-1}	Stover DM kg ha^{-1}	Total N Uptake kg ha^{-1}	N Recovery kg kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield Mg ha^{-1}
314	13	Spring	168		62812	26.4	9.6	13.4	7395.8	230.1	0.46	177.1	69.9	11.86
312	14	Spring	224		60231	25.9	11.6	14.4	7230.1	233.6	0.36	179.1	69.6	10.36
414	1	Fall	112		61952	26.2	8.8	11.3	6333.9	172.6	0.17	186.3	68.4	10.34
408	2	Fall	112	G77 (1)	60661	23.0	9.0	11.5	6945.5	186.0	0.28	199.1	69.8	10.70
407	3	Fall	112	G77 (2)	61092	26.8	9.5	12.4	6789.4	204.4	0.43	188.3	69.1	11.30
404	4	Fall	112	G77 (3)	60231	23.8	9.3	13.4	6019.1	186.3	0.28	170.3	70.9	9.73
410	5	Fall	112	N-Serve	62812	24.5	11.8	12.0	6550.7	217.1	0.53	189.4	69.0	11.67
401	6	Control	0		60231	21.6	7.9	13.0	6795.0	152.0	0.00	166.5	69.6	7.54
403	7	Spring	56		62382	24.1	7.6	12.8	5949.4	174.6	0.34	169.2	70.7	10.12
411	8	Spring	112		61092	25.8	10.5	12.3	6618.3	226.8	0.61	193.6	68.6	12.84
413	9	Spring	112	G77 (1)	65394	28.3	9.8	11.4	6800.9	200.6	0.40	175.8	70.0	11.80
412	10	Spring	112	G77 (2)	63673	25.3	11.2	12.1	7496.8	232.3	0.66	185.9	70.6	12.26
409	11	Spring	112	G77 (3)	63673	25.0	9.8	11.7	6726.1	211.3	0.49	179.5	70.6	12.44
405	12	Spring	112	N-Serve	62382	26.0	10.2	12.9	7971.0	240.7	0.73	178.6	71.0	12.28
402	13	Spring	168		62812	27.1	10.5	12.4	6677.2	235.4	0.47	177.1	70.9	13.28
406	14	Spring	224		63243	27.4	10.8	13.5	7430.2	254.8	0.44	183.1	70.6	12.92

Table B.3 Ottawa 2012 Corn Sampling Components

Plot	Trt.	Timing	N Rate kg ha^{-1}	Inhibitor	Plant Pop. pl ha^{-1}	Earleaf N g kg^{-1}	Stover N g kg^{-1}	Grain N g kg^{-1}	Stover DM kg ha^{-1}	Total N Uptake kg ha^{-1}	N Recovery kg kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield Mg ha^{-1}
112	1	Fall	112		52057	20.6								0.03
108	2	Fall	112	G77 (1)	55929	22.5								0.49
102	3	Fall	112	G77 (2)	60231	19.9								0.09
114	4	Fall	112	G77 (3)	58510	22.5								0.04

Table B.3 Ottawa 2012 Corn Continued

Plot	Trt.	Timing	N Rate	Inhibitor	Plant Pop.	Earleaf N	Stover N	Grain N	Stover DM	Total N Uptake	N Recovery	Moisture	Test Weight	Yield
			kg ha^{-1}		pl ha^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	kg ha^{-1}	kg ha^{-1}	kg kg^{-1}	g kg^{-1}	kg hL^{-1}	Mg ha^{-1}
105	5	Fall	112	N-Serve	57220	20.9								0.33
111	6	Control	0		49906	18.0								0.00
103	7	Spring	56		56359	20.1								0.16
113	8	Spring	112		52487	22.9								0.01
109	9	Spring	112	G77 (1)	55068	20.8								0.30
110	10	Spring	112	G77 (2)	55068	20.4								0.15
101	11	Spring	112	G77 (3)	58510	22.6								0.07
106	12	Spring	112	N-Serve	51627	22.4								0.33
104	13	Spring	168		55929	22.9								0.22
107	14	Spring	224		55929	21.1								0.46
203	1	Fall	112		55929	20.3								0.00
202	2	Fall	112	G77 (1)	54208	20.8								0.03
210	3	Fall	112	G77 (2)	53778	21.1								0.05
209	4	Fall	112	G77 (3)	56789	20.2								0.13
213	5	Fall	112	N-Serve	54638	22.3								0.00
205	6	Control	0		50336	17.4								0.05
212	7	Spring	56		46464	21.4								0.02
206	8	Spring	112		55929	19.4								0.11
211	9	Spring	112	G77 (1)	52057	21.0								0.00
204	10	Spring	112	G77 (2)	52917	20.9								0.06
208	11	Spring	112	G77 (3)	45604	23.6								0.24
201	12	Spring	112	N-Serve	58080	21.1								0.04
207	13	Spring	168		53348	21.2								0.08
214	14	Spring	224		51196	23.5								0.02
305	1	Fall	112		55499	20.2								0.01
306	2	Fall	112	G77 (1)	59371	20.9								0.03

Table B.3 Ottawa 2012 Corn Continued

Plot	Trt.	Timing	N Rate kg ha^{-1}	Inhibitor	Plant Pop. pl ha^{-1}	Earleaf N g kg^{-1}	Stover N g kg^{-1}	Grain N g kg^{-1}	Stover DM kg ha^{-1}	Total N Uptake kg ha^{-1}	N Recovery kg kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield Mg ha^{-1}
308	3	Fall	112	G77 (2)	51627	21.2								0.08
301	4	Fall	112	G77 (3)	58510	19.2								0.00
307	5	Fall	112	N-Serve	53348	21.2								0.00
313	6	Control	0		46894	17.8								0.00
310	7	Spring	56		49045	19.7								0.03
302	8	Spring	112		57650	21.7								0.00
303	9	Spring	112	G77 (1)	59371	21.4								0.00
309	10	Spring	112	G77 (2)	51627	21.3								0.00
304	11	Spring	112	G77 (3)	55068	20.5								0.01
311	12	Spring	112	N-Serve	58080	21.2								0.00
314	13	Spring	168		34418	21.8								0.05
312	14	Spring	224		49476	22.1								0.00
414	1	Fall	112		51196	21.7								0.01
408	2	Fall	112	G77 (1)	51627	21.9								0.01
407	3	Fall	112	G77 (2)	48615	22.9								0.03
404	4	Fall	112	G77 (3)	51627	20.1								0.02
410	5	Fall	112	N-Serve	48615	21.8								0.04
401	6	Control	0		55499	17.4								0.05
403	7	Spring	56		54638	18.6								0.00
411	8	Spring	112		51627	22.1								0.01
413	9	Spring	112	G77 (1)	49476	20.9								0.02
412	10	Spring	112	G77 (2)	36999	21.1								0.11
409	11	Spring	112	G77 (3)	44743	21.7								0.05
405	12	Spring	112	N-Serve	47324	22.0								0.03
402	13	Spring	168		52487	20.9								0.01
406	14	Spring	224		47755	22.2								0.05

Table B.4 Manhattan 2013 Corn Sampling Components

Plot	Trt.	Timing	N Rate	Inhibitor	Plant Pop.	Earleaf N	Stover N	Grain N	Stover DM	Total N Uptake	N Recovery	Moisture	Test Weight	Yield
			kg ha^{-1}		pl ha^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	kg ha^{-1}	kg ha^{-1}	kg kg^{-1}	g kg^{-1}	kg hL^{-1}	Mg ha^{-1}
110	1	Fall	112		63674	26.3	9.7	12.5	8295.2	254.6	0.62	215.0	68.3	13.96
108	2	Fall	112	G77 (1)	68835	25.7	8.6	12.7	7544.0	257.3	0.64	219.0	68.2	15.12
109	3	Fall	112	G77 (2)	64963	27.7	9.0	12.5	8229.2	273.4	0.77	215.0	68.3	16.00
102	4	Fall	112	G77 (3)	69267	26.7	8.4	12.4	8331.2	256.0	0.63	213.0	67.2	14.93
112	5	Fall	112	N-Serve	62383	27.4	9.0	11.3	8065.3	244.8	0.54	219.0	66.5	15.30
114	6	Control	0		64963	22.2	6.7	10.5	7672.8	178.9	0.00	202.0	69.2	12.11
103	7	Spring	56		66684	24.0	5.2	11.9	8925.3	215.4	0.55	207.0	69.1	14.18
106	8	Spring	112		66684	25.9	9.0	12.1	8408.3	251.0	0.59	220.0	67.6	14.56
113	9	Spring	112	G77 (1)	71417	24.4	7.7	12.5	7731.2	228.2	0.40	208.0	68.5	13.45
101	10	Spring	112	G77 (2)	72709	23.1	7.2	12.0	7556.4	230.9	0.43	208.0	70.1	14.76
117	11	Spring	112	G77 (3)	67114	28.0	9.6	13.3	8417.2	270.4	0.75	215.0	68.5	14.29
107	12	Spring	112	N-Serve	67975	26.6	9.5	12.0	8650.6	269.4	0.74	214.0	67.2	15.61
104	13	Spring	168		70556	27.2	6.3	12.4	7514.4	233.2	0.30	217.0	69.0	14.98
115	14	Spring	224		67114	27.0	10.5	12.7	8695.2	281.3	0.44	219.0	67.6	14.89
105	15	Fall	56		70126	25.6	7.6	11.8	8722.1	233.4	0.83	201.0	70.0	14.10
111	16	Fall	168		70988	25.2	10.7	12.7	7632.9	267.5	0.50	218.0	66.0	14.57
116	17	Fall	224		65825	29.2	10.3	13.5	7828.3	267.3	0.38	219.0	66.3	13.81
205	1	Fall	112		70126	26.0	8.1	13.1	6923.6	218.4	0.98	208.0	68.6	12.41
216	2	Fall	112	G77 (1)	70556	.	.	.	.	.	.	.	.	.
206	3	Fall	112	G77 (2)	67975	25.7	8.6	12.5	7794.8	225.3	1.04	206.0	69.5	12.60
204	4	Fall	112	G77 (3)	64104	24.1	9.8	12.2	7346.4	219.6	0.99	206.0	68.1	12.05
212	5	Fall	112	N-Serve	71847	21.4	6.2	12.7	8489.0	187.7	0.73	207.0	69.1	10.62
208	6	Control	0		68405	18.2	3.2	9.4	6843.0	98.4	0.00	179.0	72.0	8.12
213	7	Spring	56		68835	21.9	5.6	11.6	7319.0	157.6	0.90	198.0	70.7	10.08
211	8	Spring	112		70126	26.8	6.5	13.5	6556.5	192.1	0.77	213.0	68.2	11.03
207	9	Spring	112	G77 (1)	65393	29.1	6.5	12.3	7837.4	197.4	0.81	203.0	69.7	11.91

Table B.4 Manhattan 2013 Corn Continued

Plot	Trt.	Timing	N Rate	Inhibitor	Plant Pop.	Earleaf N	Stover N	Grain N	Stover DM	Total N Uptake	N Recovery	Moisture	Test Weight	Yield
			kg ha^{-1}		pl ha^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	kg ha^{-1}	kg ha^{-1}	kg kg^{-1}	g kg^{-1}	kg hL^{-1}	Mg ha^{-1}
215	10	Spring	112	G77 (2)	69267	.	.	.	.	.	.	.	.	.
201	11	Spring	112	G77 (3)	68835	28.6	7.7	13.5	9045.2	268.9	1.40	225.0	66.0	14.80
214	12	Spring	112	N-Serve	73998	.	.	.	.	.	.	.	.	.
202	13	Spring	168		67114	27.0	9.1	13.0	8984.7	261.0	0.91	219.0	67.2	13.73
217	14	Spring	224		62383	24.3	.	.	.	.	.	.	.	.
203	15	Fall	56		68405	25.7	7.1	11.3	7244.1	207.1	1.64	195.0	69.8	13.76
210	16	Fall	168		71847	24.3	.	.	.	.	.	.	.	.
209	17	Fall	224		69696	26.7	6.4	13.0	7558.1	210.3	0.48	221.0	72.7	12.46
302	1	Fall	112		72709	21.9	8.0	11.7	8059.7	235.1	0.89	207.0	68.8	14.54
315	2	Fall	112	G77 (1)	64533	20.4	9.0	12.5	8411.5	255.3	1.05	208.0	68.0	14.40
303	3	Fall	112	G77 (2)	68835	21.5	7.5	11.3	7862.6	239.8	0.93	208.0	68.6	15.94
316	4	Fall	112	G77 (3)	65825	22.5	8.1	11.1	8111.8	231.3	0.86	216.0	67.7	14.87
314	5	Fall	112	N-Serve	69696	23.7	7.2	11.8	7861.6	234.2	0.88	208.0	68.7	15.10
309	6	Control	0		67114	18.2	4.7	9.8	7399.8	126.6	0.00	195.0	70.2	9.43
310	7	Spring	56		66684	19.1	6.2	11.1	7902.6	191.9	0.99	197.0	71.7	12.85
305	8	Spring	112		67546	21.4	5.1	12.4	7973.5	220.0	0.77	212.0	67.5	14.43
306	9	Spring	112	G77 (1)	64963	23.3	8.4	12.6	6940.3	239.2	0.92	224.0	65.7	14.33
308	10	Spring	112	G77 (2)	67546	22.6	6.9	12.2	7575.1	225.0	0.81	208.0	68.7	14.11
304	11	Spring	112	G77 (3)	76580	22.4	7.5	12.3	8950.5	252.0	1.03	200.0	67.7	15.07
312	12	Spring	112	N-Serve	70126	22.2	6.9	11.8	8088.6	237.3	0.91	215.0	68.0	15.36
301	13	Spring	168		68405	23.4	7.3	12.8	7645.9	254.1	0.72	213.0	68.0	15.47
311	14	Spring	224		67114	23.7	9.4	13.2	8010.0	289.4	0.70	247.0	65.2	16.22
313	15	Fall	56		69267	20.8	7.5	11.5	8249.5	222.5	1.45	202.0	70.5	13.93
307	16	Fall	168		65825	22.5	6.2	12.7	7549.9	236.1	0.61	215.0	65.7	14.89
317	17	Fall	224		67546	23.8	9.6	12.4	7788.3	251.4	0.53	231.0	66.7	14.21
407	1	Fall	112		71417	23.1	6.0	11.8	7434.4	213.8	0.71	211.0	68.6	14.34

Table B.4 Manhattan 2013 Corn Continued

Plot	Trt.	Timing	N Rate	Inhibitor	Plant Pop.	Earleaf N	Stover N	Grain N	Stover DM	Total N Uptake	N Recovery	Moisture	Test Weight	Yield
			kg ha^{-1}		pl ha^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	kg ha^{-1}	kg ha^{-1}	kg kg^{-1}	g kg^{-1}	kg hL^{-1}	Mg ha^{-1}
401	2	Fall	112	G77 (1)	67975	22.9	7.6	12.1	7882.4	231.6	0.85	215.0	68.3	14.16
404	3	Fall	112	G77 (2)	61521	23.3	8.0	12.5	8543.8	242.0	0.94	222.0	68.7	13.96
402	4	Fall	112	G77 (3)	65825	24.7	7.7	12.1	7209.2	237.2	0.90	208.0	68.0	14.97
410	5	Fall	112	N-Serve	70126	24.1	9.5	12.3	7732.4	243.7	0.95	209.0	67.3	13.88
414	6	Control	0		64533	18.1	4.5	9.6	7977.4	127.6	0.00	194.0	68.5	9.54
413	7	Spring	56		63674	23.6	7.5	11.1	8897.1	214.8	1.32	188.0	69.2	13.29
408	8	Spring	112		66684	22.6	7.0	12.0	8014.4	231.9	0.85	227.0	65.1	14.69
415	9	Spring	112	G77 (1)	69267	22.5	6.0	11.8	8448.1	207.0	0.65	202.0	69.5	13.19
409	10	Spring	112	G77 (2)	70556	26.4	7.4	12.4	8229.5	230.4	0.84	217.0	68.0	13.72
411	11	Spring	112	G77 (3)	67546	26.7	7.4	12.6	7859.2	243.3	0.95	218.0	66.3	14.68
406	12	Spring	112	N-Serve	71847	27.7	6.6	12.9	7877.4	222.4	0.78	225.0	66.2	13.22
405	13	Spring	168		69696	27.9	10.2	12.7	7928.5	272.7	0.81	220.0	67.6	15.13
403	14	Spring	224		66684	24.3	8.5	13.1	8271.2	266.9	0.60	234.0	65.7	15.01
412	15	Fall	56		69267	24.5	6.4	10.5	7085.9	179.9	0.79	183.0	70.8	12.83
417	16	Fall	168		67975	24.3	7.1	12.3	8192.1	236.5	0.61	215.0	67.7	14.50
416	17	Fall	224		61953	22.3	6.9	12.7	8175.4	243.4	0.49	210.0	67.7	14.75

Table B.5 Rossville 2013 Corn Sampling Components

Plot	Trt.	Timing	N Rate	Inhibitor	Plant Pop.	Earleaf N	Stover N	Grain N	Stover DM	Total N Uptake	N Recovery	Moisture	Test Weight	Yield
			kg ha^{-1}		pl ha^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	kg ha^{-1}	kg ha^{-1}	kg kg^{-1}	g kg^{-1}	kg hL^{-1}	Mg ha^{-1}
110	1	Fall	112		76149	28.7	7.5	10.7	9122.6	218.9	0.38	195.3	68.2	14.10
108	2	Fall	112	G77 (1)	76580	23.5	9.3	10.9	7002.8	204.8	0.26	195.0	67.6	12.77
109	3	Fall	112	G77 (2)	75719	26.9	8.6	10.4	6903.1	200.9	0.23	189.3	68.5	13.61
102	4	Fall	112	G77 (3)	74859	26.3	8.9	11.2	8282.1	222.0	0.40	198.6	.	13.26

Table B.5 Rossville 2013 Corn Continued

Plot	Trt.	Timing	N Rate	Inhibitor	Plant Pop.	Earleaf N	Stover N	Grain N	Stover DM	Total N Uptake	N Recovery	Moisture	Test Weight	Yield
			kg ha^{-1}		pl ha^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	kg ha^{-1}	kg ha^{-1}	kg kg^{-1}	g kg^{-1}	kg hL^{-1}	Mg ha^{-1}
112	5	Fall	112	N-Serve	79591	31.7	8.5	12.1	7623.5	235.4	0.51	190.9	68.4	14.09
114	6	Control	0		76149	22.3	7.9	10.8	6400.3	173.1	0.00	196.7	67.0	11.31
103	7	Spring	56		74859	27.3	8.5	10.7	7015.2	178.3	0.08	196.8	67.0	11.10
106	8	Spring	112		75289	26.2	8.5	10.6	7731.3	215.3	0.35	195.6	67.8	14.13
113	9	Spring	112	G77 (1)	68836	27.0	8.1	10.8	8919.3	219.6	0.38	189.7	68.5	13.60
101	10	Spring	112	G77 (2)	73138	28.9	9.1	11.7	8817.5	236.4	0.52	193.5	68.2	13.33
117	11	Spring	112	G77 (3)	73998	27.8	12.2	11.1	8980.5	265.6	0.76	186.5	68.2	14.08
107	12	Spring	112	N-Serve	77010	26.3	8.3	10.8	7588.9	200.0	0.22	191.6	67.2	12.76
104	13	Spring	168		65394	25.3	8.6	10.9	9922.2	218.6	0.26	188.8	68.3	12.23
115	14	Spring	224		77010	28.8	9.9	10.8	8967.6	237.4	0.27	194.3	68.0	13.76
105	15	Fall	56		76149	19.1	6.4	10.6	6734.3	152.5	-0.31	193.8	68.0	10.27
111	16	Fall	168		77010	28.4	9.8	11.4	9220.2	248.8	0.42	189.0	68.4	13.82
116	17	Fall	224		73138	27.2	9.1	10.9	8246.4	224.5	0.22	190.4	68.2	13.69
205	1	Fall	112		77870	.	.	.	.	.	.	.	.	.
216	2	Fall	112	G77 (1)	73138	27.0	10.4	10.9	7097.0	213.6	0.93	192.9	67.8	12.75
206	3	Fall	112	G77 (2)	73138	.	.	.	.	.	.	.	.	.
204	4	Fall	112	G77 (3)	77010	.	.	.	.	.	.	.	.	.
212	5	Fall	112	N-Serve	75719	27.9	7.6	12.2	7356.3	234.0	1.10	187.2	68.7	14.63
208	6	Control	0		78300	16.1	5.5	9.8	5844.1	100.1	0.00	194.2	67.5	6.88
213	7	Spring	56		73138	28.6	7.5	11.6	7349.7	204.5	1.58	190.8	67.8	12.87
211	8	Spring	112		77440	28.6	7.7	11.7	9614.4	247.3	1.21	193.8	67.8	14.82
207	9	Spring	112	G77 (1)	75289	.	.	.	.	.	.	.	.	.
215	10	Spring	112	G77 (2)	72277	26.7	7.0	12.3	7582.6	226.8	1.04	189.5	68.7	14.15
201	11	Spring	112	G77 (3)	75719	30.2	8.4	11.0	9043.3	243.6	1.18	199.4	67.3	15.21
214	12	Spring	112	N-Serve	75289	29.6	9.1	12.4	8267.8	258.2	1.30	186.1	68.8	14.70
202	13	Spring	168		73138	30.5	6.9	11.5	8591.3	233.2	0.75	194.0	68.7	15.08

Table B.5 Rossville 2013 Corn Continued

Plot	Trt.	Timing	N Rate kg ha^{-1}	Inhibitor	Plant Pop. pl ha^{-1}	Earleaf N g kg^{-1}	Stover N g kg^{-1}	Grain N g kg^{-1}	Stover DM kg ha^{-1}	Total N Uptake kg ha^{-1}	N Recovery kg kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield Mg ha^{-1}
217	14	Spring	224		72277	30.9	10.4	11.9	9210.5	266.4	0.71	189.1	68.6	14.32
203	15	Fall	56		83893	27.1	4.8	11.0	7529.1	181.2	1.23	194.0	67.9	13.27
210	16	Fall	168		75289	29.5	9.0	11.3	8877.1	235.0	0.76	191.2	68.6	13.76
209	17	Fall	224		75289	24.8	7.7	11.2	7138.3	202.2	0.44	191.0	68.0	13.13
302	1	Fall	112		77870	29.1	11.0	11.3	8362.1	255.9	1.34	189.2	69.2	14.49
315	2	Fall	112	G77 (1)	77010	28.8	8.0	10.8	7264.9	202.5	0.90	192.8	68.2	13.37
303	3	Fall	112	G77 (2)	74859	27.5	8.7	10.2	8212.8	210.7	0.97	190.0	68.9	13.55
316	4	Fall	112	G77 (3)	73998	27.6	8.5	10.8	6766.5	199.5	0.88	189.4	68.5	13.24
314	5	Fall	112	N-Serve	75719	26.9	8.8	11.3	6916.7	198.6	0.87	191.8	68.8	12.25
309	6	Control	0		75289	19.4	4.8	11.3	5197.4	92.5	0.00	198.1	66.7	6.00
310	7	Spring	56		83463	20.4	4.5	10.8	5869.1	114.2	0.33	183.1	70.2	8.09
305	8	Spring	112		73998	29.6	6.7	11.0	8356.5	204.1	0.91	183.5	69.1	13.49
306	9	Spring	112	G77 (1)	73998	30.5	10.2	11.7	8473.3	244.2	1.24	192.0	68.2	13.47
308	10	Spring	112	G77 (2)	77440	25.1	6.3	11.0	7448.4	183.4	0.74	183.6	69.2	12.35
304	11	Spring	112	G77 (3)	75719	26.5	6.4	11.4	8009.4	200.7	0.89	185.1	69.2	13.13
312	12	Spring	112	N-Serve	65394	23.8	6.2	10.3	6741.6	155.9	0.52	179.3	69.4	11.03
301	13	Spring	168		78300	30.3	6.6	12.0	9271.5	233.9	0.79	189.9	68.6	14.37
311	14	Spring	224		75719	27.7	6.9	11.9	8178.9	200.4	0.46	180.0	70.1	12.13
313	15	Fall	56		70126	23.1	6.2	11.4	6101.2	166.1	1.11	188.9	68.4	11.26
307	16	Fall	168		77870	26.1	9.8	10.9	6859.5	212.1	0.67	188.5	68.5	13.28
317	17	Fall	224		68836	31.3	8.6	11.9	7757.1	212.8	0.51	184.1	69.4	12.34
407	1	Fall	112		77440	28.3	8.3	10.8	6627.4	201.4	1.17	204.2	66.4	13.57
401	2	Fall	112	G77 (1)	75719	26.8	7.8	11.3	8339.4	238.1	1.47	204.0	66.7	15.22
404	3	Fall	112	G77 (2)	79591	28.4	6.7	11.8	7243.6	206.9	1.21	194.2	68.8	13.39
402	4	Fall	112	G77 (3)	73998	27.4	7.8	12.1	8392.7	230.2	1.40	201.0	67.4	13.68
410	5	Fall	112	N-Serve	77440	27.4	10.6	12.1	7723.9	256.8	1.62	189.7	68.4	14.45

Table B.5 Rossville 2013 Corn Continued

Plot	Trt.	Timing	N Rate kg ha^{-1}	Inhibitor	Plant Pop. pl ha^{-1}	Earleaf N g kg^{-1}	Stover N g kg^{-1}	Grain N g kg^{-1}	Stover DM kg ha^{-1}	Total N Uptake kg ha^{-1}	N Recovery kg kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield Mg ha^{-1}
414	6	Control	0		75719	.	.	.	.	.	.	.	.	.
413	7	Spring	56		77010	21.0	4.2	10.7	5825.3	106.7	0.72	180.8	68.5	7.67
408	8	Spring	112		75719	26.7	6.9	10.9	9751.1	219.1	1.31	194.4	68.1	14.02
415	9	Spring	112	G77 (1)	69696	.	.	.	.	.	.	.	.	.
409	10	Spring	112	G77 (2)	76580	25.0	8.4	11.6	9554.1	254.0	1.60	189.5	68.7	14.97
411	11	Spring	112	G77 (3)	74859	28.0	6.1	11.5	7696.2	208.2	1.22	184.9	69.0	14.00
406	12	Spring	112	N-Serve	67975	26.4	7.6	11.6	7658.6	208.9	1.23	199.2	67.5	12.98
405	13	Spring	168		73998	25.9	6.1	11.2	7282.9	189.9	0.73	191.6	69.0	13.01
403	14	Spring	224		80882	29.9	6.0	12.0	9415.4	241.4	0.78	193.2	68.9	15.38
412	15	Fall	56		73138	.	.	.	.	.	.	.	.	.
417	16	Fall	168		73138	.	.	.	.	.	.	.	.	.
416	17	Fall	224		73568	.	.	.	.	.	.	.	.	.

Table B.6 Ottawa 2013 Corn Sampling Components

Plot	Trt.	Timing	N Rate kg ha^{-1}	Inhibitor	Plant Pop. pl ha^{-1}	Earleaf N g kg^{-1}	Stover N g kg^{-1}	Grain N g kg^{-1}	Stover DM kg ha^{-1}	Total N Uptake kg ha^{-1}	N Recovery kg kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield Mg ha^{-1}
110	1	Fall	112		67975	20.3	3.7	11.5	6618.3	95.4	0.37	195.4	66.0	6.14
108	2	Fall	112	G77 (1)	64964	20.7	4.5	11.5	6882.9	116.1	0.54	201.9	66.3	7.39
109	3	Fall	112	G77 (2)	62382	18.9	3.2	12.6	6396.2	108.2	0.48	195.5	66.4	6.95
102	4	Fall	112	G77 (3)	66684	17.1	3.9	12.1	5840.0	111.6	0.51	196.4	66.4	7.32
112	5	Fall	112	N-Serve	66684	19.9	4.0	13.1	5799.0	114.9	0.53	191.2	65.5	7.01
114	6	Control	0		67975	11.7	3.7	11.5	4623.6	49.6	0.00	195.3	66.3	2.80
103	7	Spring	56		66254	17.7	3.7	11.7	6011.5	78.8	0.44	195.0	67.1	4.84
106	8	Spring	112		67115	20.2	4.6	12.4	6691.1	117.7	0.56	196.6	66.6	7.02

Table B.6 Ottawa 2013 Corn Continued

Plot	Trt.	Timing	N Rate kg ha^{-1}	Inhibitor	Plant Pop. pl ha^{-1}	Earleaf N g kg^{-1}	Stover N g kg^{-1}	Grain N g kg^{-1}	Stover DM kg ha^{-1}	Total N Uptake kg ha^{-1}	N Recovery kg kg^{-1}	Moisture g kg^{-1}	Test Weight kg hL^{-1}	Yield Mg ha^{-1}
113	9	Spring	112	G77 (1)	62382	19.1	3.9	11.7	6165.4	94.8	0.37	193.0	66.7	6.06
101	10	Spring	112	G77 (2)	71847	22.2	4.4	13.0	7194.4	113.7	0.53	193.8	68.2	6.36
117	11	Spring	112	G77 (3)	65394	18.8	5.0	13.9	6020.7	120.8	0.58	192.0	68.2	6.50
107	12	Spring	112	N-Serve	67975	17.5	4.4	13.5	6010.6	139.2	0.73	198.7	66.6	8.34
104	13	Spring	168		69696	20.5	5.6	12.4	6371.6	134.7	0.48	201.4	66.4	7.99
115	14	Spring	224		69696	21.0	7.8	14.0	6353.0	146.9	0.42	195.7	67.1	6.93
105	15	Fall	56		67975	17.9	3.3	11.7	5191.9	77.6	0.42	199.2	65.2	5.14
111	16	Fall	168		68405	20.2	5.6	13.7	6760.6	134.0	0.47	195.5	65.5	7.05
116	17	Fall	224		69266	23.4	8.6	14.5	6564.3	152.3	0.44	196.1	67.6	6.61
205	1	Fall	112		60661	22.9	5.3	12.1	6401.1	113.9	0.51	200.9	66.4	6.62
216	2	Fall	112	G77 (1)	65394	19.0	4.6	12.9	5240.3	99.9	0.40	189.6	67.4	5.90
206	3	Fall	112	G77 (2)	63243	22.3	3.9	12.7	5553.8	115.3	0.52	197.3	66.8	7.39
204	4	Fall	112	G77 (3)	65824	20.5	4.0	13.1	6019.7	120.0	0.56	195.5	67.4	7.30
212	5	Fall	112	N-Serve	63673	20.2	4.6	13.3	6750.1	121.4	0.57	190.0	67.4	6.78
208	6	Control	0		63673	14.9	3.8	12.1	4934.8	51.4	0.00	195.9	65.1	2.70
213	7	Spring	56		67975	17.9	4.0	11.8	5620.1	73.3	0.33	199.1	69.2	4.29
211	8	Spring	112		63243	23.9	4.0	13.3	6282.8	126.0	0.61	197.7	66.4	7.58
207	9	Spring	112	G77 (1)	66254	20.8	4.0	12.7	6165.1	120.1	0.56	200.5	66.5	7.49
215	10	Spring	112	G77 (2)	71417	21.3	4.6	13.8	6714.9	114.8	0.52	186.9	67.6	6.09
201	11	Spring	112	G77 (3)	67975	22.7	3.8	13.5	5899.7	116.0	0.53	201.3	67.1	6.95
214	12	Spring	112	N-Serve	67115	18.9	6.5	13.0	5550.4	130.1	0.64	193.5	67.5	7.22
202	13	Spring	168		62382	25.1	5.6	12.6	7148.9	142.4	0.51	205.8	66.0	8.14
217	14	Spring	224		65824	22.4	6.7	14.5	5740.6	146.9	0.41	201.1	67.5	7.49
203	15	Fall	56		67545	19.4	3.6	12.4	4767.0	78.4	0.41	199.2	66.2	4.91
210	16	Fall	168		59801	22.8	5.2	12.6	5957.9	127.9	0.43	198.1	67.0	7.70
209	17	Fall	224		56359	23.1	5.4	12.4	7759.8	127.7	0.33	202.5	66.4	6.90

Table B.6 Ottawa 2013 Corn Continued

Plot	Trt.	Timing	N Rate	Inhibitor	Plant Pop.	Earleaf N	Stover N	Grain N	Stover DM	Total N Uptake	N Recovery	Moisture	Test Weight	Yield
			kg ha^{-1}		pl ha^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	kg ha^{-1}	kg ha^{-1}	kg kg^{-1}	g kg^{-1}	kg hL^{-1}	Mg ha^{-1}
302	1	Fall	112		65824	20.6	5.2	12.6	6845.5	119.4	0.51	205.2	66.6	6.68
315	2	Fall	112	G77 (1)	64533	19.4	4.9	11.9	5514.2	88.9	0.26	193.2	66.6	5.21
303	3	Fall	112	G77 (2)	65394	22.0	3.8	13.8	6417.0	90.4	0.27	202.6	66.6	4.79
316	4	Fall	112	G77 (3)	61522	22.7	5.4	13.8	5891.2	119.2	0.50	194.5	67.8	6.32
314	5	Fall	112	N-Serve	64103	22.3	4.2	13.2	5978.6	107.9	0.41	192.4	66.6	6.30
309	6	Control	0		62382	12.8	3.6	13.3	4059.5	57.7	0.00	201.1	64.5	3.24
310	7	Spring	56		65824	15.7	3.1	13.1	5940.5	84.3	0.40	192.6	67.0	5.02
305	8	Spring	112		65824	20.9	5.7	14.4	6546.1	104.5	0.38	202.9	72.2	4.67
306	9	Spring	112	G77 (1)	66254	20.4	4.7	13.5	6261.1	106.6	0.40	197.3	67.0	5.72
308	10	Spring	112	G77 (2)	62812	19.3	4.9	11.2	6684.1	92.0	0.28	202.1	66.1	5.31
304	11	Spring	112	G77 (3)	66254	20.7	5.0	12.2	6664.2	94.4	0.30	199.4	66.6	4.97
312	12	Spring	112	N-Serve	64964	22.2	4.0	14.4	6934.0	137.9	0.66	201.3	66.5	7.65
301	13	Spring	168		65394	20.3	5.3	14.2	5625.3	137.3	0.45	208.2	66.0	7.57
311	14	Spring	224		64964	22.9	6.9	15.3	7568.4	197.9	0.60	207.4	66.5	9.51
313	15	Fall	56		60661	19.4	3.1	12.6	5150.8	90.4	0.49	192.2	64.5	5.90
307	16	Fall	168		66254	24.1	5.1	12.8	7498.9	125.2	0.38	200.3	66.3	6.77
317	17	Fall	224		62382	25.8	7.2	15.3	6881.4	133.3	0.32	198.8	66.1	5.46
407	1	Fall	112		69696	17.6	4.9	12.2	5930.5	102.3	0.35	197.3	66.5	6.05
401	2	Fall	112	G77 (1)	64964	22.0	5.0	14.7	6452.6	125.5	0.54	198.3	66.5	6.36
404	3	Fall	112	G77 (2)	65394	20.5	4.8	14.2	5525.1	95.8	0.30	198.9	66.8	4.88
402	4	Fall	112	G77 (3)	64103	21.9	4.0	12.0	6359.1	102.2	0.35	199.3	67.0	6.37
410	5	Fall	112	N-Serve	67975	21.9	5.2	13.0	5476.0	100.2	0.34	188.3	68.1	5.53
414	6	Control	0		50336	13.8	5.5	10.6	5280.4	59.0	0.00	191.8	65.9	2.80
413	7	Spring	56		63673	15.5	3.4	11.7	4995.3	57.2	-0.03	188.9	67.7	3.45
408	8	Spring	112		68405	17.4	4.4	12.4	6173.0	98.6	0.32	197.2	66.6	5.76
415	9	Spring	112	G77 (1)	64964	19.9	3.3	15.3	4432.0	106.6	0.39	190.5	67.5	6.04

Table B.6 Ottawa 2013 Corn Continued

Plot	Trt.	Timing	N Rate	Inhibitor	Plant Pop.	Earleaf N	Stover N	Grain N	Stover DM	Total N Uptake	N Recovery	Moisture	Test Weight	Yield
			kg ha^{-1}		pl ha^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	kg ha^{-1}	kg ha^{-1}	kg kg^{-1}	g kg^{-1}	kg hL^{-1}	Mg ha^{-1}
409	10	Spring	112	G77 (2)	69266	21.4	5.2	13.7	6206.5	115.9	0.47	198.8	66.3	6.14
411	11	Spring	112	G77 (3)	67115	19.0	3.7	12.2	5825.3	98.5	0.32	195.4	66.9	6.28
406	12	Spring	112	N-Serve	65394	20.4	4.8	15.5	6456.2	136.2	0.63	196.7	67.0	6.81
405	13	Spring	168		67115	22.5	7.2	15.1	6812.0	149.3	0.51	200.8	66.4	6.63
403	14	Spring	224		66684	24.8	7.4	13.9	5893.2	131.8	0.31	213.7	65.9	6.35
412	15	Fall	56		69696	18.1	2.8	13.6	4199.0	86.5	0.42	189.2	67.1	5.48
417	16	Fall	168		64533	25.2	6.8	15.4	7560.9	155.2	0.54	200.0	65.9	6.76
416	17	Fall	224		65824	24.1	9.7	14.9	6824.8	172.3	0.48	196.3	66.3	7.12