

EVALUATION OF ANHYDROUS AMMONIA APPLICATIONS IN WINTER WHEAT

by

MATTHEW R. WYCKOFF

B. S., Kansas State University, 2009

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTERS OF SCIENCE

Department of Agronomy
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2012

Approved by:

Major Professor
David B. Mengel

Copyright

MATTHEW R. WYCKOFF

2012

Abstract

Research has shown that nitrogen fertilizer is needed most years to optimize winter wheat yields in Kansas. Anhydrous ammonia (AA) has long been a favorite N fertilizer of producers as it has proven to be a reliable and economical source of N. Anhydrous application methods and equipment have changed little over the past 70 years. Recently John Deere has developed their 2510 HSLD (2510H) anhydrous ammonia applicator designed to improve efficiency and performance in no-till systems. The 2510H is designed to be run at high speed with low soil disturbance and low draft. This is achieved by using a rolling coulter type injection unit, designed much like modern single disk opener grain drill units, to apply AA at relatively shallow depths. With this low soil disturbance design, topdress AA applications may also be possible.

Due to the environmental risks associated with wheat production, many Kansas producers prefer an N management system that consists of a “starter” application at planting with the majority of the N fertilizer applied in the spring. This approach makes certain that the crop survives the winter before the investment in N is made and eliminates the potential for fertilizer N being lost over the winter months. It has not been feasible to use AA for topdressing in the past due to the damage to the growing crop from application with traditional knife style applicators.

The first part of this research revisits traditional preplant AA application methods by evaluating proper unit spacing and the use of nitrification inhibitors as well as comparing these AA treatments to common topdress applications of N. Over three site years, few consistently significant advantages between unit spacing, use of nitrification inhibitor or N management method were found. Unit spacing did show a notable trend favoring 50 cm spacing.

The second part of this research was a two-year experiment conducted with the objective of assessing the feasibility of topdressing with AA using the 2510H as compared with topdressing with granular urea. A number of factors such as application direction in relation to crop row, speed of application and timing as a function of crop development were examined to minimize crop injury and maximize crop yield. The initial 2010 study was promising, showing no significant yield loss topdressing with AA compared to topdressing with urea. The experiment was repeated at two locations in 2011. Results were mixed, indicated that soil conditions and the

plants ability to recover from the AA application injury were important for the success of topdressing with AA.

Lastly, an economic evaluation of the production economics of preplant and topdress AA was compared to the traditional practice of topdressing winter wheat with urea. Through evaluation of the agronomic and economic factors affecting the feasibility of uses of AA and the 2510H, three main conclusions can be made: 1. Preplant application of AA has no agronomic advantage and only a small economic advantage over topdressing with urea when yields are the same. 2. Topdressing with AA is agronomically feasible but is at an economic disadvantage when compared to topdressing with urea, due to the yield reduction associated with the AA method. 3. Further research focused on reducing yield loss with topdress AA applications is needed before this N management strategy can be promoted on a large scale.

Table of Contents

List of Figures	viii
List of Tables	ix
Acknowledgements	xi
Dedication	xii
Chapter 1 - The History of Modern Nitrogen Management: A Review of Literature	1
The Transformation and Fates of Nitrogen in Soil	1
Soil Denitrification.....	2
Volatilization.....	2
Leaching.....	2
Immobilization	3
Plant Uptake and Nitrogen Use Efficiency	3
Anhydrous Ammonia as a Nitrogen Source	4
Anhydrous Ammonia Stabilization Products.....	5
Anhydrous Ammonia Application and Equipment	6
Anhydrous Ammonia Injection Unit Design	7
Anhydrous Ammonia Application Spacing	8
Nitrogen Application Timing and Topdressing with Anhydrous	10
Summary	11
References	12
Chapter 2 - Evaluation of Preplant Application of Anhydrous Ammonia in No-till Winter Wheat	
Production.....	16
Abstract.....	16
Introduction.....	16
Materials and Methods.....	18
Tissue Sampling and Analysis	23
Grain Yield and Analysis.....	23
Statistical Analysis.....	24

Results and Discussion	25
Manhattan 2010	25
Manhattan 2011	29
Rossville 2011	32
Combined Analysis	35
Conclusions	36
References	38
Chapter 3 - Evaluation of Topdressing Winter Wheat in Kansas with Anhydrous Ammonia	39
Abstract	39
Introduction	39
Materials and Methods	41
Tissue Sampling and Analysis	44
Grain Yield and Analysis	45
Statistical Analysis	45
Results and Discussion	46
Manhattan 2010	46
Manhattan 2011	50
Rossville 2011	54
Combined Analysis	56
Conclusions	59
Chapter 4 - An Economic Evaluation of Anhydrous Ammonia Applications in Winter Wheat ..	60
Abstract	60
Introduction	60
Materials and Methods	62
Field Research and Yield Data	62
Net Present Value Analysis	63
Partial Budget and Breakeven Analysis	66
Results and Discussion	66
Net Present Value Analysis Results	66
Partial Budget Results	70

Conclusions.....	75
References.....	77
Appendix A - Preplant Plot Data 2010-2011	78
Appendix B - Topdress Plot Data 2010-2011	88

List of Figures

Figure 1.1 Traditional Knife Applicator	8
Figure 1.2 John Deere 2510	8
Figure 2.1 Angled harvest pattern to capture a representative sample across the plot	23
Figure 2.2 Yield Response to Nitrogen.....	26
Figure 2.3 Grain Yield Response to Nitrogen	27
Figure 2.4 Grain Yield Response to Application Spacing.....	28
Figure 2.5 Manhattan 2011 grain yield response to application source, spacing and timing	31
Figure 2.6 50 cm Preplant AA @ 67 kg N ha ⁻¹	32
Figure 2.7 76 cm Preplant AA @ 67 kg N ha ⁻¹	32
Figure 2.8 Rossville 2011 grain yield response to application source, spacing and timing	34
Figure 3.1 Angled harvest pattern to capture a representative sample across the plot	45
Figure 3.2 Direction effect at Manhattan 2010	47
Figure 3.3 Across row treatments after application	47
Figure 3.4 With row treatments after application	47
Figure 3.5 Speed effect Manhattan 2010	48
Figure 3.6 Seriated closing disk.....	49
Figure 3.7 Topdressing with AA vs. Urea	50
Figure 3.8 Manhattan 2011, impact of application speed on yield at different growth stages	52
Figure 3.9 AA Treatment and N rate means	53
Figure 3.10 Treatment grain yield averages at Rossville 2011.....	55
Figure 3.11 Combine yield results urea vs. AA treatments	57

List of Tables

Table 1.1 Physical and Chemical Properties of Anhydrous Ammonia	6
Table 1.2 Effects of Anhydrous Ammonia Vapor on the Human Body.....	7
Table 2.1 Manhattan 2010 results as affected by N application source, timing and spacing.	25
Table 2.2 Weather Data	27
Table 2.3 Manhattan 2011 results as affected by N application source, timing and spacing.	30
Table 2.4 Rossville 2011 results as affected by N application source, timing and spacing.	33
Table 2.5 Combined data for all site years at the 67 kg/ha N rate	35
Table 2.6 Combined data for all site years at the 101 kg/ha N rate	35
Table 3.1 2009-2010 Treatments	41
Table 3.2 2010-2011 Treatments	43
Table 3.3 Key Cultural Practices	43
Table 3.4 Site Soil Information.....	44
Table 3.5 Site Application Dates	44
Table 3.6 Manhattan 2010 results as affected by N application source, speed and direction.	46
Table 3.7 Manhattan 2011 results as affected by N application source, speed and timing.	51
Table 3.8 Manhattan 2011 results as affected by N application source, speed and timing.	54
Table 3.9 Combined Yield Data	56
Table 4.1 Preplant Yield Treatment Averaged Across all Three Site Years	62
Table 4.2 Topdress Yield Treatment Averaged Across all Three Site Years	63
Table 4.3 Operation cost of the 2510H and 2510C	64
Table 4.4 General NPV Input Data over 1,000 Acres	65
Table 4.5 Yearly Cash Flow Results for the 2510C	68
Table 4.6 Yearly Cash Flow Results for the 2510H	69
Table 4.7 NPV Results.....	69
Table 4.8 Partial Budget Preplant AA vs. Topdressed Urea (current prices)	70
Table 4.9 Partial Budget Preplant AA vs. Topdressed Urea (higher N prices)	71
Table 4.10 Partial Budget Topdress AA vs. Topdressed Urea (current prices).....	72

Table 4.11 Partial Budget Topdress AA vs. Topdressed Urea (breakeven N price)	72
Table 4.12 Partial Budget Topdress AA vs. Topdressed Urea (breakeven yield)	73
Table A.1 Manhattan Preplant 2010	79
Table A.2 Manhattan Preplant 2011	81
Table A.3 Rossville Preplant 2011	84

Acknowledgements

Graduate school has been one of the best experiences of my life, in large part, because of the people that I have the opportunity to work with.

First, I would like to thank my major professor, Dr. Dave Mengel, for the opportunity to work on this project. Although we did not always agree, I could not have found a better mentor and advisor to work with. Doc always offered guidance but gave us enough flexibility to make mistakes and succeed on our own.

Second, I would like to thank all my fellow graduate students, most notably Jason Matz and Ray Azebado. Working with these guys made all the miles of traveling and painfully monotonous work fun. Grad school wouldn't have been the same without the friends that I went through it with.

I would like to recognize our research technician Garry Harter for all of his help and hard work. A special thanks to Dr. Jeff Williams for his help on the economic analysis. I would also like to acknowledge all the staff at the North Farm and other Research Stations I had the opportunity to work with at the.

Lastly, none of this would have been possible without the funding and technical support of the John Deere Company, Brian Ganske and Nate Meier.

Dedication

I dedicate this to my parents, Bob and Jane Wyckoff.

Mom and Dad, I cannot tell you “thank you” enough. Your old fashion parenting taught me the respect and discipline it took to finish this. I truly believe that the world would be a better place if there were more parents like you. I love you guys.

Chapter 1 - The History of Modern Nitrogen Management: A Review of Literature

The use of fertilizers go back as far as Greco-Roman times when some of the greatest philosophers such as Plato (428-348 B.C.) and Aristotle (384-322 B.C.) were among some of the first to document a simple understanding of the use of soil amendments, such as manure, to improve crop yields (International Fertilizer Development Center, 1998). These early understandings and practices remained virtually unchanged until the 1770's and the birth of modern chemistry, when scientist were first able to uncover the complex relationship between soil, water, atmosphere and plants at an elemental level. As this refined understanding developed, the importance of soil fertility and the ability of man to manipulate such in order to achieve higher crop yields to feed an ever growing world population, became even more apparent.

Scientists also recognized that nitrogen was most often the limiting nutrient in cereal grain production. Although our atmosphere is 73% N, it is in a form that is virtually unusable for plants. Throughout much of the second half of the 1800's, development of a source of synthetic N was at the forefront of science. In 1909, Fritz Haber successfully fixed atmospheric N to form ammonia and by 1913 Carl Bosch had developed the process on an industrial level (Smil, 2001). This important development is commonly referred to as the Haber - Bosch process and it changed agriculture and the world forever.

The Transformation and Fates of Nitrogen in Soil

Soil and plant nitrogen, both organic and synthetic, are subject to several different transformations and subsequent fates, making N management in wheat or any crop, a challenge. These potential fates include: soil denitrification, surface runoff, volatilization, leaching, plant uptake, immobilization and gaseous plant emissions (Ruan and Johnson 1999). Understanding these processes and what drives them is essential for efficient N management.

Soil Denitrification

The Soil Science Society of America (1979) defines denitrification as “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).”

There are two main factors that affect the rate of denitrification: oxygen supply and microorganisms in the soil. These factors are influenced by organic matter, water content, oxygen supply, temperature, nitrate levels and pH. Small amounts of denitrification happen all the time, but significant losses can be expected from warm soils that have been waterlogged for 36 hours or more (Killpack and Buchholz, 1993). Nitrogen losses in winter wheat due to denitrification can be as much as 9.5% (Aulakh et al., 1982).

Volatilization

Ammonia volatilization is the mass transfer of nitrogen as ammonia gas from the soil, plant, or liquid system to the atmosphere (Soil Science Society of America, 1979). Conditions promoting volatilization include high soil pH, increased temperature, increased soil moisture and unincorporated fertilizer. This is of particular concern with urea and/or urea containing fertilizers (Ernst, 1960). Volatilization losses from surface applied urea in no-till corn have been shown to exceed 30% (Keller and Mengel, 1985). Volatilization losses under cold weather conditions in winter wheat have generally been thought to be minimal, however recent work in Montana by Engel and co-workers have shown this is not necessarily the case. They have measured losses as high as 40% or more from urea surface applied to frozen soils (Engel and Wallander, 2011).

Leaching

All sources of nitrogen will eventually convert to nitrate (NO_3^-) which is not held tightly by soil particles and is subject to movement down through the soil profile and out of reach by plant roots (Nielsen, 2006). Factors affecting nitrate leaching are precipitation or irrigation levels, the amount of nitrate N present, soil texture and water movement rate through the soil profile (Baker, 1976). Management strategies that can help mediate leaching include applying N to coincide with plant uptake, using reasonable N rates, better application equipment, and

nitrification inhibitors to name a few (Dinnes et al., 2002). Although often overlooked, equipment that can place N accurately and in during the most effective time can be effective in reducing leaching potential.

Immobilization

Immobilization is a temporary tie up of N by microbes in the soil system. Soil microbes use ammonium and nitrate from the soil to break down high carbon plant residue. Once the residue is broken down, N is mineralized and released back into the soil. The duration of tie up for this process depends mostly on the amount of residue present, the C:N ratio of the residue, microbe population, soil moisture and temperature (Tisdale, 1985). Immobilization is especially a concern with surface applied fertilizers in no-till due to the amount of residue present at the soil surface. Rice and Smith (1984) found that as much as 21% of surface applied N can be immobilized in a no-till system. That was twice the immobilization found in a plowed tillage system. Placement of fertilizer can affect the amount of immobilization. Subsurface placement of N in no-till minimizes contact with residue and therefore reduces tie-up (Mengel et al., 1982). Nitrogen source can also have an effect on immobilization. Weber (2009) suggests that liquid urea ammonium nitrate (UAN) broadcast applied tends to be immobilized more than granular urea due to more of the liquid sticking directly to the residue rather than falling through the residue to the soil. Although N is not lost by immobilization, it can make N management challenging as when the N will be released back to the soil, and available for plant use, can be somewhat unpredictable.

Plant Uptake and Nitrogen Use Efficiency

Stewart (2005) estimates that 50% of U.S. grain yield today is due to the use of N fertilizers. From the discussion above it is obvious that the challenge lies in making sure that a high percentage of the N applied to the soil makes it to the plant. The percentage of fertilizer N that is recovered and utilized by the fertilized crop is referred to as nitrogen use efficiency (NUE). Worldwide, NUE is estimated to be about 33% (Raun and Johnsen, 1999). By improving NUE, more grain can be grown with less N while also reducing the potential environmental impact associated with applying excess N. There are several different management practices that

have proven to increase NUE, all of which reduce the potential for the losses discussed above. These practices include the use of controlled release fertilizers and nitrification inhibiting N products, application methods that prove to decrease loss and/or tie-up, applying N fertilizers in season when the crop will quickly take it up, and using precision application methods such as optical sensors and variable rate application (Randall et al., 2003; Malhi et al., 2001; Ruan and Johnson, 1999). Ruan and Johnson (1999) conclude that the right combination of management practices can result in NUE in excess of 85%.

Anhydrous Ammonia as a Nitrogen Source

The direct product of the Haber - Bosch process, anhydrous ammonia (AA), accounts for about 32% of the N fertilizers used in the U.S. (Terry and Kirby, 2006). Over the years, AA has proven to be a reliable and cost effective source of N. Nonetheless, some producers do not like to use AA, mainly due to the challenges and dangers of handling. As its name implies, AA is ammonia without water. This gives AA a strong affinity for water, and will immediately attach to a hydrogen molecule in water changing from ammonia (NH_3) to ammonium (NH_4^+). When AA is injected into the soil, a portion attaches to available soil water to form ammonium while the balance stays in the ammonia form. The amount and rate at which the ammonia is hydrogenised is related to AA rate, application method, cation exchange capacity of the soil, soil texture, and soil moisture. The toxicity of ammonia and subsequent rise in soil pH creates a “dead zone” around the injection point. Consequently, this “dead zone” effectively stops nitrification due to the absence of nitrifying microbes, leaving the N in ammonia and ammonium form which is fairly stable and less subject to loss. This is also referred to as the zone of retention. The breakdown of the zone of retention, which allows the ammonium to be converted to nitrite and nitrate is dependent on pH and osmotic potential as a product of ammonium concentration (Tisdale et al. 1985). AA’s self-inhibiting properties make it a relatively efficient source of N. Even so, there are products available to further reduce the potential for loss. One important group of loss preventive products for use with AA is nitrification inhibitors.

Anhydrous Ammonia Stabilization Products

In an attempt to increase NUE, several additives and coating products have been developed which decrease loss potential of applied N fertilizers. These products can be classified as nitrification inhibitors, urease inhibitors, slow release fertilizers, and poly-coated ureas (Frazen, 2010).

One of the oldest of these products, nitrapyrin (2-chloro-6-[trichloromethyl] pyridine), has been in use since the late 1960's and is classified as a nitrification inhibitor. Marketed as N-Serve, nitrapyrin is one of the only N loss preventive products intended for use with AA. N-Serve is toxic to nitrosomonas bacteria which oxidize ammonium into nitrite (Huber et. al., 1977). With the fertilizer N in the ammonium form, it is less subject to loss and theoretically can increase NUE. Studies support that N-Serve does slow the conversion to nitrite and increase ammonium-N in the soil as much as 100 days after AA application (Touchton et al., 1978; Touchton et al., 1979; Hendrickson et al., 1978). However, yield increases at normal N rates are somewhat inconsistent, primarily due to variations in rainfall patterns and soil types that are more or less conducive to loss (Touchton et al., 1978; Touchton et al., 1979; Hendrickson et al., 1978; Hergert and Weise, 1980). Consequently, although nitrapyrin is an effective nitrification inhibitor, yield increases may only be realized in situations where N loss potentials are significant.

Although N-Serve is a long-term, scientifically proven nitrification inhibitor, it has its shortcomings, primarily due to its volatility and corrosive nature. Nitrapyrin is volatile, and must be incorporated below the soil surface. Thus its effectiveness with surface applied N products such as urea or UAN solutions is limited. In addition, when mixed with AA, N-Serve will corrode nurse and application equipment to the point it jeopardizes reliability and safety if not constantly maintained and, therefore, makes retail dealers and producers reluctant to use it. Modern direct injection systems bypass many of the corrosion points in the applicator, making the use of N-Serve more user/equipment friendly, but its corrosive stigma still exists, and limits its use.

Anhydrous Ammonia Application and Equipment

To understand AA application and equipment we must first understand AA's physical and chemical properties. Table 1.1 lists some of the important chemical and physical properties of AA.

Table 1.1 Physical and Chemical Properties of Anhydrous Ammonia

Physical Form:	Gas (liquid under pressure)
Color:	Colorless gas and liquid, forms white vapor in contact with moisture
Odor:	Strong pungent penetrating odor, ammonia.
Boiling Point:	-28.1o F (-33o C) at 1 atm
Melting point:.....	-107.9o F (-78o C)
Ph:	Approximately 12.0 (neat)
Solubility:.....	510 - 530 g/L @ 20o C
Specific Gravity:	0.6818 @ -33.35o C and 1 atm
Vapor Density:	0.597 @ 0o C (0.60 @ 60o F)
Vapor Pressure:	7,600 mm Hg @ 25o C (93 psig @ 60o F)
% Volatile by Volume:	100
Molecular Weight:	17.03
Density:	0.696 g/L @ 20o C (5.14 lb./gal. @ 60o F)
Critical Temperature:	271o F (133o C)
Critical Pressure:	1636 psia

§ Anhydrous Ammonia Material Safety Data Sheet

Due to a -33° C boiling point and lethal vapor, handling and applying AA can be challenging. Anhydrous ammonia will stay in liquid form when stored under its own pressure which is dependent on temperature. At 21° C, AA will create a tank pressure of about 8 kilograms per square centimeter (Hanna, 2001). In traditional applicators, AA moves under its own pressure from the nurse tank, through some sort of mechanical or computerized metering system and into a distributor which send it to individual application row units. Most of the advancements to this type of delivery system over the years have been focused on mediating flow fluctuation due to pressure changes as a result of temperature change and improving distribution from one application unit to the next.

Physical features of AA discussed above also provide a basis for how it must be applied to the soil. AA must be injected directly into the soil and covered immediately to prevent ammonia gas escaping directly to the atmosphere and allowing reaction with the soil system for

retention. Factors affecting this direct loss of AA include application rate, application spacing, application depth, soil moisture and soil texture.

These same properties, which create problems for the application and storage of AA, also make it a very dangerous compound to use. Table 1.2 lists the impacts of various exposures to anhydrous ammonia vapor on the human body. The damage which can be caused by AA to the body at relatively low rates of exposure are another important reason many people choose not to use this product as an N source, even though it has important agronomic and economic advantages.

Table 1.2 Effects of Anhydrous Ammonia Vapor on the Human Body

PPM (parts per million)	Effects on the Human Body
5	Detectable by almost all persons. Some people complain of nose irritation after 5 minutes
134	Most people experience dryness and irritation of nose, throat and eyes.
700	Coughing. Severe eye irritation, if not treated, may lead to partial or total loss of sight.
1700	Serious lung damage, death unless treated.
2000	Burns and blisters skin after a few seconds of exposure.
5000	Death by suffocation within minutes.

§ Baker, 1993

Anhydrous Ammonia Injection Unit Design

Anhydrous ammonia injection unit design has changed little in the last 70 years. A typical unit consists of a large knife or shank with an injection tip behind it designed to place the AA 15-20 cm deep in the soil. An example of this type of unit is illustrated in Figure 1.1. Variations of knife and shank design have emerged over time producing varying levels of disturbance to the soil, but all of the current designs result in some tillage effect. Pulling this type of shank through the soil at these depths requires a substantial amount of power and can be very slow to use.

With ever increasing fuel prices, larger farm size and the growing popularity of no-till crop production systems, pressure to find a faster and less evasive application system for AA has led to the development of coulter type injection units. These units are made up of a single large opening disk or wheel, a depth gauge wheel, an injection boot and some sort of closing system. An example of this type of unit is shown in Figure 1.2. This design injects AA at a fairly shallow (5-12 cm) depth and allows for higher speeds, lower power requirements and less soil disturbance. Research by Hanna et al. (2005) found gaseous losses to be at an unacceptable level from a prototype unit of this kind. He attributed these losses to an inadequate closing system. John Deere has developed their 2510 HSLD (2510H) coulter type AA applicator which they market as being designed for high speed, low draft and low soil disturbance. The 2510H features a more robust closing system and improved injection boot than the prototype system used by Hanna et al. (2005). Work by Stamper and Mengel (2009) found losses from the 2510H to be comparable to a traditional knife system under ideal soil conditions. However, under excessively wet or dry conditions losses with this improved system could still exceed 10% of the applied N.



Figure 1.1 Traditional Knife Applicator



Figure 1.2 John Deere 2510

Anhydrous Ammonia Application Spacing

There are three important factors to evaluate when considering optimum AA application spacing. The first is that the application equipment and process must be feasible and efficient. As unit spacing gets closer, it effectively decreases the efficiency of the process as it takes more power to pull. The second consideration is the impact on the crop and grain yield due to less uniform distribution of N as spacing is reduced, especially at low N application rates. The third

issue is the ability of the plant roots to get to an N band if the spacing is too wide. Generally, plants planted in rows will not grow roots through the root system of an adjacent row to get to an ammonia band. Thus, a band must be present on one side of a row for efficient N uptake. Therefore, the ultimate goal is to find the balance between efficient application and tolerable impacts on uniformity and ultimately N uptake and yield.

The balance between efficient application and tolerable yield impacts may change from year-to-year and field-to-field as movement and retention of AA in the soil system is a dynamic process and can differ significantly with N rate, soil type and soil moisture. Furthermore, crop row spacing and root distribution plays a role in N uptake and utilization from the fertilizer band. Blue and Eno (1954) found the highest movement of AA in high moisture sandy soils. They attribute this increased movement to lower surface area for adsorption and greater water movement through the soil profile.

Anhydrous ammonia application equipment commonly used in small grains is typically spaced between 38 and 50 centimeters. Research by Maxwell et al. (1984) found no significant yield difference between 38 and 50 cm spacing but suggested this might not hold true in all soils and conditions. They also acknowledged noticeable waviness in plant growth associated with the wider spacing but these visible effects did not negatively affect yield. Work done in New Zealand documented a fairly linear decline in plant dry weight yield out to 20 cm from the fertilizer band where yields were similar to the zero N control in a fine sandy soil. This unevenness led to a 5% yield reduction for every 15 cm increment in application spacing from 15 up to 76 cm. Responses were not as consistent or dramatic in a heavier silt loam (MacMillan et al., 1971). Teal et al. (2007) found a slight advantage to 10 cm spacing over 46 cm in no-till soils but these results were somewhat inconsistent.

An experiment in Kansas found little yield response to application spacing from 15 to 102 cm at normal N rate (56-84 kg/ha). This work did document extremely uneven growth in the 56 kg N ha⁻¹ and 102 cm spacing but this variability did not result in significant yield differences (Swart, 1971).

Collectively, past research suggests that the traditional 38 to 50 cm spacing is probably sufficient for wheat under normal conditions. MacMillan et al. (1971) applied economics to their

agronomic findings and concluded that this range of 38 to 50 cm was also the most feasible from an economic standpoint.

Nitrogen Application Timing and Topdressing with Anhydrous

Winter wheat's long growing season and vernalization period lends producers an extended period of time in which N application can be made that is almost nine months long. In Kansas, preplant applications of AA commonly start as early as late July. Spring topdress N applications are common up to the beginning of reproductive growth in late March. This long period of application allows for many different theories on what might be the most efficient timing of N application from both an agronomic and economic standpoint.

Years of research has found that spring topdress applications of N tend to be consistently more efficient than fall applications from an agronomic standpoint (Lutcher and Mahler, 1988; Doll, 1962; Welch et al., 1966; Wuest and Cassman, 1992). Spring applications not only allow producers to evaluate crop health and yield potential after crop establishment and overwintering, but also eliminate the potential for N fertilizer loss over the winter months. Wuest and Cassman (1992) suggest N recovery of spring topdress applications may be as much as 25% higher than fall applications.

Spring topdressing applications may not result in higher yield in all years and situations. The advantage to spring topdressing over fall preplant applications is directly related to loss potentials over the winter months. High precipitation leads to N loss by denitrification and leaching. High temperatures can have mixed outcomes as they favor losses from denitrification and gains from mineralization of organic matter. Doll (1962) concludes that the most important loss factor over the winter months is precipitation. He suggests that 25 to 30 cm of precipitation over the winter months generally results in spring treatments being more efficient than fall applications. Economic advantages may also be realized in high loss situations by topdressing, as some have documented 1 kilogram of N topdressed being equivalent to as much as 1.5 kg N applied preplant (Welch et al., 1966).

Nonetheless, preplant applications may have advantages as well, most notably being the ability to use AA as an N source, as it is the cheapest N fertilizer. Gingrich and Smith (1953)

found little advantage to topdressing and concluded that preplant applications are more desirable from an economic and time management aspect.

The increasing price of N in recent years has sparked interest in topdressing with AA in order to capture the agronomic advantage of topdressing while also realizing the economic gain of using a lower cost N source. Applying AA into standing wheat has long been viewed as being impractical due to the amount of crop damage accrued by traditional AA application. With advancements in low disturbance applicator unit design, this application method may be feasible. Work by Oklahoma State University using a rolling coulter followed by a thin injection knife found this AA application method more effective than broadcast applications of liquid urea ammonium nitrate at the same time (Boman et al., 1995). If these results could be repeated routinely, this would translate to a substantial economic advantage to producers. However, little other research has been reported concerning this type of spring AA application.

Summary

Nitrogen is an essential component of modern agriculture and, ultimately, the ability to feed an ever growing world population. Increasing N use efficiency is imperative to the longevity of the environment and human race. Our understanding of N fertilization has come a long way over the last 150 years, but NUE is still surprisingly low. Nonetheless, continued research and development of increasingly efficient products and practices is improving NUE every year.

Anhydrous ammonia is one of the oldest and most widely used forms of N fertilizer. Although AA has lost popularity in recent years as it is not the safest or easiest fertilizer to use, it has proven to be an efficient and economical source of N. The development of improved and safer application methods could once again make AA the choice of N fertilizers for many producers.

References

- Aulakh, M.S., D.A. Rennie, and E.A. Pual. 1982. Gaseous nitrogen losses from cropped and summer fallow soils. *Can. J. Soil Sci.* 62:187-195.
- Baker, D.E. 1993. Using Agricultural Anhydrous Ammonia Safely. University of Missouri Extension. Publication GO1920.
- Baker, L., K. L. Campbell, H.P. Johnson, J.J. Hanway. 1976. Nitrate, Phosphorus and Sulfate in Subsurface Drainage Water. *J. Environ Qual.*, Vol. 4, no. 3.
- Blue, W.G., and C. F. Eno. 1954. Distribution and Retention of Anhydrous Ammonia in Sandy Soils. *Soil Sci. Soc. Am. Proc.* 18:420-424.
- Boman, R.K., R.L. Westerman, W.R. Raun, M.E. Jojola. 1995. Spring-Applied Nitrogen Fertilizer Influence on Winter Wheat and Residual Soil Nitrate. *J. Prod. Agric.* Vol. 8, no.4: 584-589.
- Dinnes, D.L., D.L. Karlen, D.B. Jaynes, T.C. Kaspar, J.L. Hatfield, T.S. Colvin, C. A. Cambardella. 2002. Nitrogen management strategies to reduce nitrate leaching in tile-drained Midwestern soils. *Agron. J.* 94:153–171.
- Doll, E.C.. 1962. Effects of Fall-Applied Nitrogen Fertilizer and Winter Rainfall on Yield of Wheat. *Agron. J.* 4: 471–473.
- Engel, R. J., C.R. Wallander. 2011. Ammonia Volatilization from Urea and Mitigation by NBPT following Surface Application to Cold Soils. *Soil Sci. Soc. Am. J.* 75: 2348–2357.
- Erisman, J.W., M.A. Sutton, J. Galloway, Z. Klimont, W. Winiwarter. 2008. How a century of ammonia synthesis changed the world. *Nature Geoscience* 1: 636-639.
- Ernst, J.W., H.F. Massey. 1960. The effects of several factors on volatilization of ammonia formed from urea in the soil. *Soil Sci. Soc. Proc.* 24:87-90 .

- Franzen D.W. 2010. Slow-Release Nitrogen Fertilizers and Nitrogen Additives for Field Crops. North Central Extension-Industry Soil Fertility Conference Proceedings. Vol. 26: 13-30.
- Gingrich, J.R., F.W. Smith. 1953. Investigation of Small Grain Response to Various Applications of Nitrogen, Phosphorus, and Potassium on Several Kansas Soils. Soil Sci. Soc. Am. J. 17: 383–386.
- Hanna, H M., P.M. Boyd, J.L. Baker, and TS. Colvin. 2005. Anhydrous ammonia losses using single disc and knife fertilizer injector. Tampa, FL. ASAE Paper No. 051060. ASAE. St. Joseph, MO.
- Hanna, M. 2001. Improving the uniformity of anhydrous ammonia application. Iowa State University Extension. PM 1875.
- Hendrickson, L.L., L.M. Walsh, and D.R. Keeney. 1978. Effectiveness of Nitrapyrin in Controlling Nitrification of Fall and Spring-Applied Anhydrous Ammonia. Agron. J. 70: 689-703.
- Hergert, G.W., R.A. Wiese. 1980. Performance of nitrification inhibitors in the Midwest (west). ASA Special Publication 1980. 38: 89-105.
- Huber, D.M., H.L. Warren, D.W. Nelson, C.Y. Tsai. 1977. Nitrification Inhibitors: New Tools for Food Production. BioScience Vol. 27 No. 8.
- International Fertilizer Development Center, United Nations Industrial Development Organization, Int'l Fertilizer Development Center . 1998. Fertilizer Manual: 46-59.
- Keller, G.D., D.B. Mengel. 1985. Ammonia Volatilization from Nitrogen Fertilizers Surface Applied to No-till Corn. Soil Sci. Soc. Am. J. 50: 1060–1063.
- Killpack, S.C., D. Buchholz. 1993. Nitrogen in the Environment: Denitrification. University of Missouri Extension. Pub. WQ255.
- Lutcher, L. K., R.L. Mahler. 1988. Sources and Timing of Spring Topdress Nitrogen on Winter Wheat in Idaho. Agron. J. 80: 648–654.

- MacMillan, R.H., J.J. Lorenzana, J.H. White. 1971. Effects of Non-uniform Distribution of Urea on Growth of Wheat. N.Z. Journal of Agricultural Research, 14: 821-827.
- Malhi, S.S., C.A. Grant, A.M. Johnston, K.S. Gill. 2001. Nitrogen fertilization management for no-till cereal production in the Canadian Great Plains: a review. Soil and Tillage Research, 2001 Volume 60: 101-122.
- Maxwell, T.M., D.E. Kissel, M.G. Waggoner, D.A. Whitney, M.L. Cabrera, H.C. Moser. 1984. Optimum Spacing of Preplant Bands of N and P Fertilizer for Winter Wheat. Agron. J. 76: 243-247.
- Mengel, D.B., D.W. Nelson, D.M. Huber. 1982. Placement of N fertilizers for no-till and conventional till corn. Agron. J 74: 515-518.
- Nielsen, R.L.. 2006. N Loss Mechanisms and Nitrogen Use Efficiency. Handout for 2006 Purdue Nitrogen Management Workshop.
<http://www.agry.purdue.edu/ext/pubs/2006NLossMechanisms.pdf>.
- Randall, G.W., J.A. Vetsch, J.R. Huffman. 2003. Corn Production on a Subsurface-Drained Mollisol as Affected by Time of Nitrogen Application and Nitrpyrin. Agron. J. 95: 1213-1219.
- Raun, W.R., and G.V. Johnson. 1999. Improving Nitrogen Use Efficiency for Cereal Production. Agron. J. 91: 357-363.
- Rice, C.W., M.S. Smith. 1984. Short-term immobilization of fertilizer nitrogen at the surface of no-till and plowed soils. Soil Sci. Soc. Am. J. 48:295-297.
- Smil, V. 2001. Enriching the Earth. P. xiii. Massachusetts Institute of Technology.
- Soil Science Society of America, Terminology Committees. 1979. Glossary of soil science terms. Rev. ed. Soil Sci. Soc. of Am., Madison, Wis.
- Stamper J.D. and D.B. Mengel. 2008. Effects of Nitrogen Rate, Timing, and Placement in Irrigated Corn Using Anhydrous Ammonia. Kansas Fertilizer Research, 2008.

- Stewart, W. M., Dibb, D. W., Johnston, A. E. & Smyth, T. J.. 2005. The Contribution of Commercial Fertilizer Nutrients to Food Production. *Agron. J.* 97, 1–6.
- Swart, C. L., L. S. Murphy, and C. W. Swallow. 1971. Retention Patterns and Effectiveness of Anhydrous Ammonia Applied with an Undercutting Blade. *Agron. J.* 63: 881–884.
- Teal, R.K., K.W. Freeman, K. Girma, D.B. Arnall, J.W. Lawles, K.L. Martin, R.W. Mullen and W.R. Raun. 2007. Effect of Tillage and Anhydrous Ammonia Application on Nitrogen Use Efficiency of Hard Red Winter Wheat. *Journal of Sustainable Agriculture.* 30:2, 51-67.
- Terry, D. L., and B. J. Kirby. 2006. Commercial fertilizers. Association of American Plant Control Officials Inc. and The Fertilizer Institute. Lexington, KY.
- Tisdale, S.L., W. L. Nelson, J. D. Beaton, 1985, *Soil Fertility and Fertilizers*, MacMillan Publishing Company, New York.
- Touchton, J.T., R.G. Hoeft, and L.F. Welch. 1978. Effect of Nitrapyrin on Nitrification of Fall and Spring-Applied Anhydrous Ammonia. *Agron. J.* 70: 805-810.
- 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. *Agron. J.* 71: 238-242.
- Weber H. S., D. B. Mengel. 2009. Use of Nitrogen management products and practices to enhance yield and nitrogen uptake in no-till corn and grain sorghum. *Kansas Fertilizer Research*, 2009.
- Welch, L.F., P.E. Johnson, J.W. Pendleton and L.B. Miller. 1966. Efficiency of Fall- Versus Spring-Applied Nitrogen for Winter Wheat. *Agron. J.* 58: 271-274.
- Wuest, S. B., Cassman, K. G. 1992 .Fertilizer-Nitrogen Use Efficiency of Irrigated Wheat: I. Uptake Efficiency of Preplant versus Late-Season Application. *Agron. J.* 84: 682–688.

Chapter 2 - Evaluation of Preplant Application of Anhydrous Ammonia in No-till Winter Wheat Production

Abstract

Research has reported that nitrogen fertilizer is needed most years to optimize winter wheat yields in Kansas. Anhydrous ammonia (AA) has long been a favorite N fertilizer of producers as it has proven to be a reliable and economical source of N. Anhydrous application methods and equipment have changed little over the past 70 years. Recently John Deere has developed their 2510 HSLD (2510H) anhydrous ammonia applicator designed to improve efficiency and performance in no-till systems. The 2510H is designed to be run at high speed with low soil disturbance and low draft. This is achieved by using a rolling coulter type injection unit, designed much like modern single disk opener grain drill units, to apply AA at relatively shallow depths. This experiment is intended to evaluate traditional preplant AA application methods by evaluating proper unit spacing and the use of nitrification inhibitors as well as comparing these AA treatments to common topdress applications of N. Over three site years, data showed few significant advantages between unit spacing, use of nitrification inhibitor or N management method.

Introduction

Anhydrous ammonia (AA) has long been a reliable and economical source of nitrogen fertilizer, which is essential to achieve maximum winter wheat yields in most years. Application equipment and methods have change little over the last 70 years. With agricultures transition to conservation and no-till systems in recent years, traditional knife AA applicators have come under scrutiny due to their substantial tillage effect. To answer this concern, John Deere has developed their 2510 HSLD (2510H), high speed, low draft AA applicator which is better suited for no-till systems. Low soil disturbance is achieved by using a large single disk opening system much like that used on modern single disk opener grain drills. This system injects AA at a relatively shallow, 10 to 12 cm, depth. Research by Stamper and Mengel (2009) found this

applicator and design to be an acceptable replacement for a traditional knife system when applying N rates less than 179 kg ha^{-1} and under good soil conditions.

Low soil disturbance AA application equipment is especially attractive in the semi-arid Midwestern wheat growing region where moisture conservation through no-till systems has proven to be imperative for long run profitability. Anhydrous has also been a long time favorite for wheat growers as it is an economical and effective source of N making it well suited for a relatively low input system. However, John Deere only offers the 2510H in 76 cm row spacings which is thought to be virtually useless in narrow seeded small grains such as wheat.

Optimum anhydrous ammonia spacing is a dynamic system. Movement and retention of AA in the soil system can differ significantly with N rate, soil type and water content at application and precipitation or irrigation management making optimum spacing vary greatly from year to year and field to field. Furthermore, crop row spacing and root distribution plays a key role in N uptake and utilization from the fertilizer band. Blue and Eno (1954) found the highest movement of AA in high moisture sandy soils. They attributed this increased movement to lower surface area for adsorption and more water movement through the soil profile.

Anhydrous ammonia application equipment commonly used in small grains is typically spaced between 38 and 50 cm. Research by Maxwell et al. (1984) suggested that spacing up to 50 cm may be adequate for most situations but 30 cm may be more favorable in certain soils and conditions. They also noted waviness in plant growth associated with the wider spacing but these visible effects did not negatively affect yield. Little work has been done on spacing in recent years as the theories and equipment available have not really changed in that time. There are also physical and economic considerations when evaluating spacing of AA application equipment. Narrower spacing requires more power per foot of applicator as you add more resistance from more row units. This translates to more power, time and fuel to complete the application process and, ultimately, increasing crop production cost.

One of the major drawbacks to preplant AA in winter wheat is the amount of time between when the N is applied and when the wheat will take it up. Although some N will be taken up in the fall, the majority will not be utilized until the wheat breaks dormancy and starts prostrate growth in the spring which can be six months or more after preplant application of AA. This leaves a significant amount of time in which N can be lost from the system. In an attempt to

decrease the potential for loss over this period, nitrapyrin may be used. Nitrapyrin (2-s-chloro-6-[trichloromethyl] pyridine), trade named N-Serve, was released in the 1960's and is classified as a nitrification inhibitor. N-Serve is specifically toxic to *Nitrosomonas* bacteria which oxidize ammonium into nitrite (Huber et al. 1977). With the fertilizer N in the ammonium form, it is less subject to loss and theoretically increases NUE. Studies support that N-Serve does slow the conversion to nitrite and increase ammonium-N in the soil as much as 100 days after AA application (Touchton et al., 1978; Touchton et al., 1979; Hendrickson et al., 1978). None the less, yield increases are somewhat inconstant primarily due to rainfall patterns and soil types that are more or less conducive to loss (Touchton et al., 1978; Touchton et al., 1979; Hendrickson et al., 1978; Hergert, 1980). Consequently, although nitrapyrin is an effective nitrification inhibitor, yield increases may only be realized in situations which loss potentials are significant.

The objective of this research is to evaluate effective AA application spacing with the 2510H in no-till systems to determine its optimum configuration for use in wheat production as well as compare preplant applications of AA to topdress applications of urea which is a common practice of Kansas farmers. An evaluation of N-Serve and its effect on N uptake efficiency with varying application widths was incorporated in the second year of research.

Materials and Methods

Field research was initiated in the fall of 2009 at one location on the KSU Agronomy North Farm in Manhattan, KS. Site information and key cultural practices are included in Tables 2.1, 2.2 and 2.3. Plots were arranged in the field using a randomized complete block design with four replications. Individual plots measured 3.04 meters wide by 24.38 meters long. Six meter alley ways were established between blocks to allow room to achieve the 12.87 kilometer per hour application speed recommended by John Deere. Anhydrous ammonia treatments were applied with a John Deere 2510H row units on an experimental tool bar. Row units were added, removed and shifted to achieve application spacings prescribed.

Table 2.1 Key Cultural Practices

Location	Manhattan 2009-2010	Manhattan 2010-2011	Rossville 2010-2011
Tillage	No-Till	No-Till	No-Till
Previous Crop	Soybeans	Soybeans	Soybeans
Wheat Variety	SantaFe	Everest	Everest
Seeding Rate	112 kg/ha	112 kg/ha	112 kg/ha
Starter	56 kg/ha 18-46-0 in furrow	56 kg/ha 18-46-0 in furrow	56 kg/ha 18-46-0 in furrow

Table 2.2 Site Soil Information

Location	Soil Series	Soil Description	pH	OM	Nitrate	P	K
				g kg ⁻¹	mg kg ⁻¹		
Manhattan 2009-2010	Ivan and Kennebec Silt Loams	Fine-silty alluvium, occasionally flooded.	7.1	2.4	2.6	77	400
Manhattan 2010-2011	Ivan and Kennebec Silt Loams	Fine-silty alluvium, occasionally flooded.	7.2	2.2	2.2	28	362
Rossville 2010-2011	Stonehouse-Eudora Complex	Course-silt, fine sand alluvium	6.5	1.1	2.8	18.2	124

Table 2.3 Key Dates

	Manhattan 2009-2011	Manhattan 2010-2011	Rossville 2010-2011
Preplant N App.	14-Oct-2009	18-Oct-2010	14-Oct-2010
Planting	20-Oct-2009	19-Oct-2010	17-Oct-2010
Topdress N App.	15-April-2010	24-March-2011	23-March-2011
Flag Leaf Sampling	7-May-2010	13-May-2011	11-May-2011
Harvest	25-June-2010	24-June-2011	23-June-2011

Preplant ammonia and spring topdress urea were compared at two N rates, 67 and 101 kg ha⁻¹. A control of no N was also included. Treatments used in 2009-2010 are listed in Table 2.4.

Table 2.4 2009-2010 Treatments

Treatment	Method	Time	Row Spacing (cm)	N Rate (kg/ha)
1	Control	na	na	0
2	Topdress urea	Feekes 4/5	na	22 Fall/ 45 Spring
3	Preplant AA	Preplant	38	67
4	Preplant AA	Preplant	50	67
5	Preplant AA	Preplant	76	67
6	Topdress urea	Feekes 4/5	na	22 Fall/ 78 Spring
7	Preplant AA	Preplant	38	101
8	Preplant AA	Preplant	50	101
9	Preplant AA	Preplant	76	101

Wheat was no-till drilled in 19 cm row spacings into soybean stubble at a rate of 112 kg ha⁻¹. Di-ammonium phosphate (18-46-0) was applied in furrow with the drill at a rate of 56 kg ha⁻¹. Thus, 10 kg ha⁻¹ of N and 26 kg ha⁻¹ P were applied as starter. Spring topdress treatments (treatment 2 and 6) were applied by hand when wheat had reached Feekes stage 4. Dates at which all field work was completed can be found in Table 2.3.

After evaluating results from the 2009-2010 study, modifications were made to the treatment list to include two additional N rates (34 and 135 kg N ha⁻¹) and the addition of nitrapyrin, a nitrification inhibitor for 2010-2011. The project was also expanded to include two additional sites, both a sandy site and a heavier silt loam site. This gave sites on two very different soils, differing in both degree and potential mechanism of N loss. At the irrigated, Kansas River Valley Field site, N loss potential would be relatively low, and primarily from leaching, while at the Agronomy Farm the loss potential would be higher, and primary due to

denitrification. Cultural practices used can be found in table 2.1 and site soil information can be found in table 2.2.

A similar randomized complete block design was used in 2011 but plot size at both locations was reduced to 15.24 m long due to space constraints. The same 2510H experimental applicator was used and a SideKick brand inline injection system was added to inject N-Serve (nitrpyrin) directly in the ammonia line prior to entering the distributor. N-serve was applied at the labeled rate of 2.34 l ha^{-1} . The treatments used at each location in 2010-2011 are listed in Table 2.5.

Table 2.5 2010-2011 Treatments

Treatment	Method	Time	Row	Inhibitor	Rate
			Spacing (cm)		(kg/ha)
1	Control	na	na	na	0
2	Topdress urea	Feekes 4/5	na	na	34
3	Topdress urea	Feekes 4/5	na	na	67
4	Topdress urea	Feekes 4/5	na	na	100
5	Topdress urea	Feekes 4/5	na	na	134
6	Preplant AA	Preplant	50	no	34
7	Preplant AA	Preplant	50	no	67
8	Preplant AA	Preplant	50	no	100
9	Preplant AA	Preplant	50	no	134
10	Preplant AA	Preplant	50	yes	34
11	Preplant AA	Preplant	50	yes	67
12	Preplant AA	Preplant	50	yes	100
13	Preplant AA	Preplant	50	yes	134
14	Preplant AA	Preplant	76	no	34
15	Preplant AA	Preplant	76	no	67
16	Preplant AA	Preplant	76	no	100
17	Preplant AA	Preplant	76	no	134
18	Preplant AA	Preplant	76	yes	34
19	Preplant AA	Preplant	76	yes	67
20	Preplant AA	Preplant	76	yes	100
21	Preplant AA	Preplant	76	yes	134

Drilling and fertilization was carried out the same as in 2009-2010. Dates of field operations can be found in Table 2.3.

Tissue Sampling and Analysis

Flag leaf samples were taken when wheat plants reached Feekes 9 by collecting uniformly, 30 random leaves from each plot. Samples were collected from the outer four to avoid harvest rows. All samples were dried at 60°C and ground to pass through a 0.5 mm stainless steel sieve. Concentrations of N were analyzed using a sulfuric acid-hydrogen peroxide digest and the extracted ammonia was analyzed by a colorimetric procedure (nitopruside-sodium hypochlorite) using RFA Methodology No. A303-S072, Total Kjeldahl Nitrogen.

Grain Yield and Analysis

The center 1.5 m of the every plot were machine harvested after physiological maturity. Harvesting technique was modified in 2011 as the harvester drove at an angle from the front corner of the plot to the opposite far corner in order to capture a more representative sample across the plot since there was noticeable wavy growth pattern in the wider spacing treatments. This way we would harvest an equal number of plants over the fertilizer band as between the band. Figure 2.1 illustrates how this was completed. Representative sub-samples were collected from the grain harvested from each plot to determine moisture and test weight. Yields were adjusted to 12% moisture. The subsamples were dried and ground to pass through a 0.5 mm sieve. Grain N content was analyze.



Figure 2.1 Angled harvest pattern to capture a representative sample across the plot

Statistical Analysis

All data were analyzed using SAS version 9.1. General plot leaf N, grain yield and grain protein were analyzed using proc GLM. Linear regression on grain yield was completed with PROC NLIN Quadratic Plateau. Combined site years data were analyzed using proc MIXED. All LSDs are calculated at a probability level of 0.05.

Results and Discussion

Manhattan 2010

The 2010 Manhattan experiment was relatively small but provided some very important information. A significant grain yield response to applied N was observed and is summarized in Figure 2.2. A summary of data is included in Table 2.6. Leaf N and grain protein showed a response to N rate but were unaffected by application spacing or by topdressing urea versus preplant applying ammonia.

Table 2.1 Manhattan 2010 results as affected by N application source, timing and spacing.

Treatment	Timing	Row Spacing	N Rate	Leaf N	Grain Yield	Grain Protein Content
		(cm)	(kg ha ⁻¹)	(% N)	(kg ha ⁻¹)	(%)
1. Control	na	na	0	1.99 d	1,340 e	11.2 a
2. Topdress Urea	Feekes 4	na	67	2.16 bcd	2,430 cd	10.4 ab
3. Preplant AA	Preplant	38	67	2.11 cd	2,290 d	10.0 b
4. Preplant AA	Preplant	50	67	2.38 abc	2,630 bc	10.6 ab
5. Preplant AA	Preplant	76	67	2.31 abc	2,320 d	9.9 b
6. Topdress Urea	Feekes 4	na	101	2.36 abc	2,940 a	10.7 ab
7. Preplant AA	Preplant	38	101	2.40 ab	2,790 ab	10.0 b
8. Preplant AA	Preplant	50	101	2.44 a	2,800 ab	10.6 ab
9. Preplant AA	Preplant	76	101	2.44 a	2,700 abc	10.8 ab
Pr>F				0.0152	<.001	0.199
CV				8.15	7.75	6.47
LSD(.05)				0.271	278	0.981
LSD(.10)				0.225	231	0.815

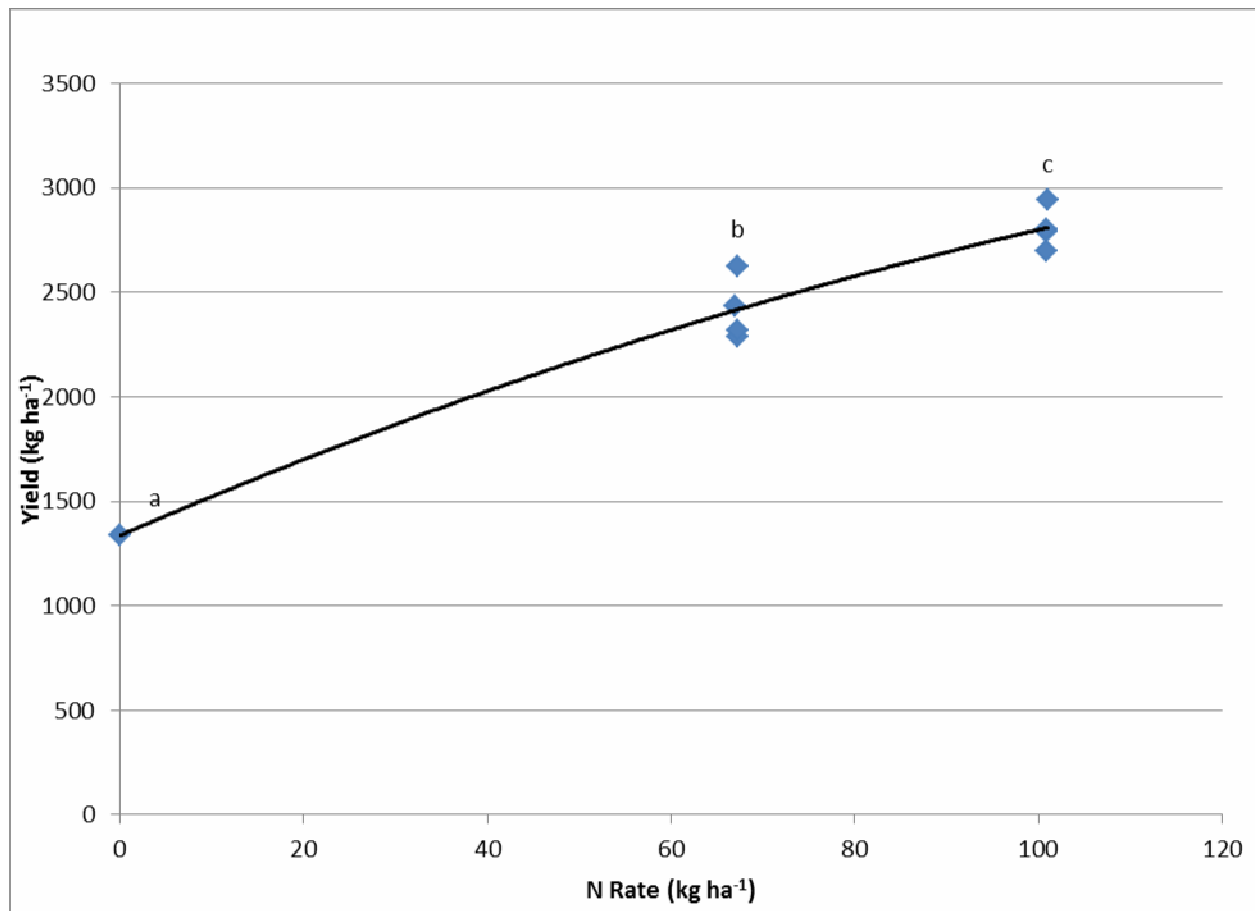


Figure 2.2 Yield Response to Nitrogen

Figure 2.3 shows no statistically significant yield difference was realized when comparing preplant AA treatments to topdressed urea at equal N rates. Although there was a slight trend for fall N applications to be less efficient than topdress, the AA was injected later in the fall when soil temperatures were cool and loss potentials were low. Weather data presented in Table 2.7 reports total precipitation between the fall application of AA and spring applications of topdress urea was about 19cm. These results concur with Doll's (1962) work, which concluded that one should only expect topdress treatments to be more efficient in years where precipitation through the winter months exceeded 25 to 30 cm.

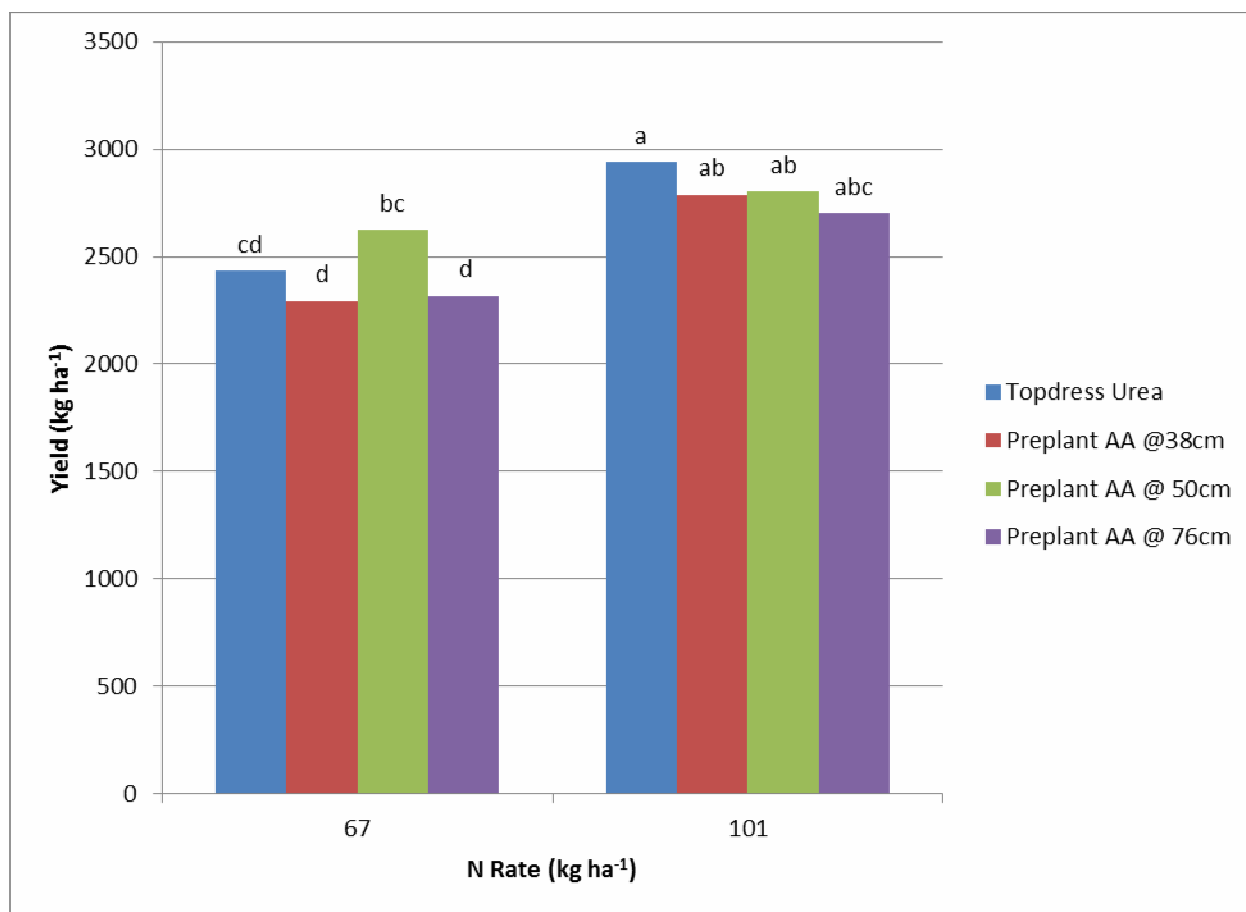


Figure 2.3 Grain Yield Response to Nitrogen

Table 2.2 Weather Data

	Total Precip.	Winter Precip.	10cm Soil Temp. Avg. Over 10°C	10cm Soil Temp. Avg. Over 15.5°C
	(cm)	(cm)	(Days)	(Days)
Manhattan 2009-2010	50.2	19.2	36	5
Manhattan 2010-2011	42.7	10.8	28	10
Rossville 2010-2011	31.9	11.6	29	16

* Winter precip. and soil temps. calculated from days between preplant and topdress applications.

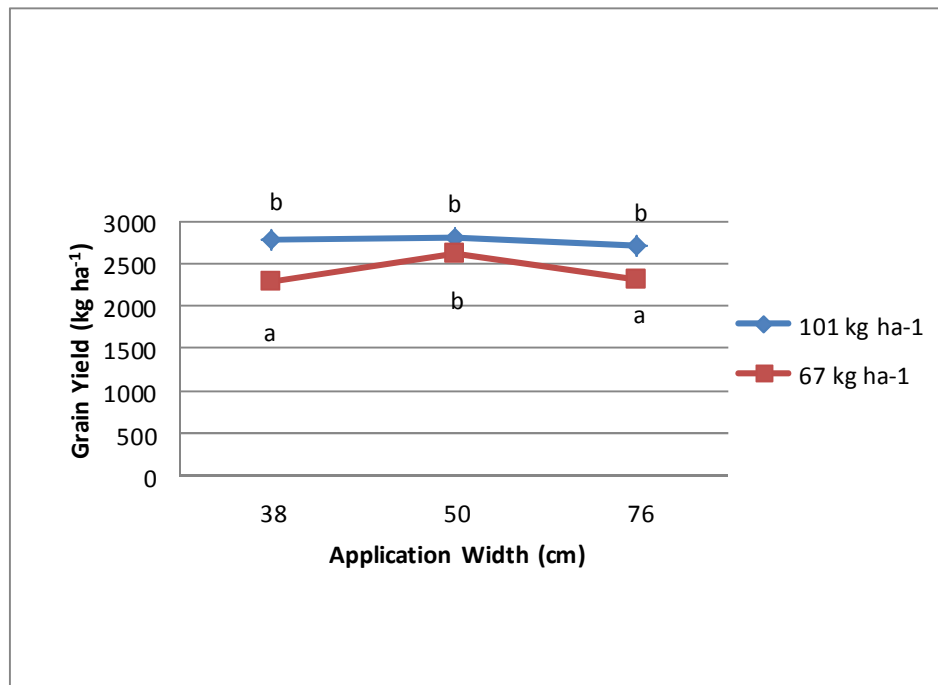


Figure 2.4 Grain Yield Response to Application Spacing

At the lower N rates, there was a small response to application spacing. The 50 cm spacing had a small advantage over the 38 and 76 cm spacings. We expected that the 76 cm spacing would be at a disadvantage due to the lack of N availability for those rows between the fertilizer band, especially early in the growing season when N was still in a tight band and root growth had not explored as much of the soil.

The small yield reduction observed at the 38 cm spacing is harder to explain as previous work shows an advantage to 38 cm spacings over 50 (Maxwell et al., 1984). Blue and Eno (1954) found that higher rate of AA in the application band tend to take longer to break down and ultimately increase N retention in the soil. This work would suggest that under the right conditions, the N in 38 cm spacing might not be retained as well and be subject to higher losses than the 50 cm since the concentration of N in the band at the narrower spacing would not be as great. Nonetheless, that type of conclusion could not be made from one site year a data. Furthermore, wider spacing can lead to uneven N-uptake which can reduce yield.

No significant yield differences between spacing treatments were found at the 101 kg ha⁻¹ N rate. This is most likely due to excess N masking the treatment differences.

This preliminary years worth of data on spacing confirms the common belief that 50 cm spacings are sufficient for wheat production but also suggest that 76 cm spacing may be an option under certain circumstances. Thus, research going forward was carried out using only the 50cm and 76 cm spacings.

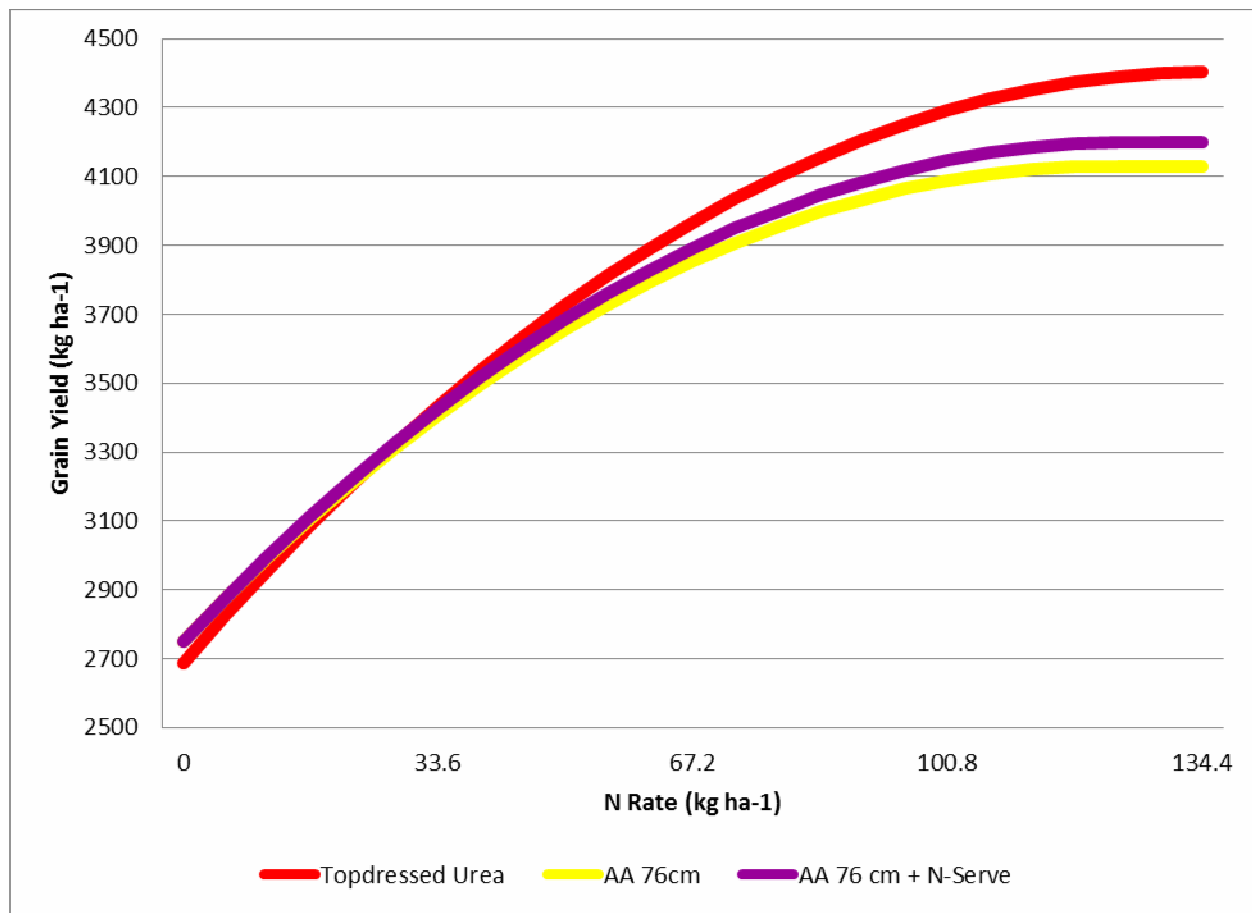
Manhattan 2011

The 2011 Manhattan experiment was substantially bigger than 2010 experiment. The location was within 100 meters of the 2010 plot area and on similar soils. The 38 cm spacing treatments were dropped from the experiment and an N-Serve treatment was added. A full N rate response curve was incorporated into each combination of treatments so regression analysis could be used to evaluate the data. The treatment means are summarized in Table 2.8.

Table 2.3 Manhattan 2011 results as affected by N application source, timing and spacing.

Treatment	Timing	Row Spacing	N Rate	N-Serve	Leaf N	Grain Yield	Grain Protein Content
		(cm)	(kg ha ⁻¹)		(% N)	(kg ha ⁻¹)	(%)
1. Control	na	na	0	na	2.16	2830	10.2
2. Topdress Urea	Feekes 4	na	34	na	2.29	3160	10.2
3. Topdress Urea	Feekes 4	na	67	na	2.42	4020	11.0
4. Topdress Urea	Feekes 4	na	100	na	2.50	4520	11.6
5. Topdress Urea	Feekes 4	na	134	na	2.72	4300	12.4
14. Preplant AA	Preplant	76	34	no	2.10	3220	10.5
15. Preplant AA	Preplant	76	67	no	2.56	3930	10.7
16. Preplant AA	Preplant	76	100	no	2.90	4220	12.1
17. Preplant AA	Preplant	76	134	no	2.85	4030	13.2
18. Preplant AA	Preplant	76	34	yes	2.22	3260	10.1
19. Preplant AA	Preplant	76	67	yes	2.53	3890	11.4
20. Preplant AA	Preplant	76	100	yes	2.95	4360	11.7
21. Preplant AA	Preplant	76	134	yes	2.78	4070	12.1
Pr>F					<.0001	<.0001	<.0001
CV					2.01	11.3	2
LSD(.10)					0.235	510	0.865
LSD(.05)					0.279	610	1.04

Results for the 2011 experiment at Manhattan were very similar to those obtained in 2010. A response to N was found for leaf N, grain yield and grain protein with topdress urea and preplant AA at 76 cm band spacing. However, mistakes during application with the 50 cm band spacing made those data useless. Some 50 cm application data was salvaged but is not included in this Chapter but can be found in Appendix A.



Treatment	Regression	R ²
Topdress Urea	$2688+0.4218N+-0.00174N^2$	0.838
AA 50 cm	$2749+0.2941N+-0.00104N^2$	0.739
AA 76 cm	$2749+0.3879N+-0.00174N^2$	0.706
AA 76 cm + N-Serve	$2751+0.3777N+-0.00174N^2$	0.522

Figure 2.5 Manhattan 2011 grain yield response to application source, spacing and timing

Figure 2.5 illustrates grain yield data after being fit to a quadratic regression model. Quadratic estimates of the 95% confidence intervals were also calculated for each treatment but not included in Figure 2.5. All of the confidence intervals overlapped; therefore, there were no statistical differences between any treatments. Although no statistical differences are present, the traditional urea treatment tends to yield a bit higher than the AA treatments. N-Serve treatments may also have a small advantage over no N-Serve at this site.

Rossville 2011

The 2011 Rossville experiment was on a much lighter and sandier soil than the Manhattan site. Effects of application spacing were more visually obvious as the growth was very even over the width of the plot in the 50 cm spacing while growth was very uneven throughout the spring growing season in the 76 cm spacing. These visual effects are documented in Figures 2.6 and 2.7. Darker green streaks over the fertilizer bands are apparent in Figure 2.7. Nonetheless, this uneven growth did not necessarily impact grain yield. Treatment means and letter groupings are included in Table 2.9.



Figure 2.6 50 cm Preplant AA @ 67 kg N ha⁻¹



Figure 2.7 76 cm Preplant AA @ 67 kg N ha⁻¹

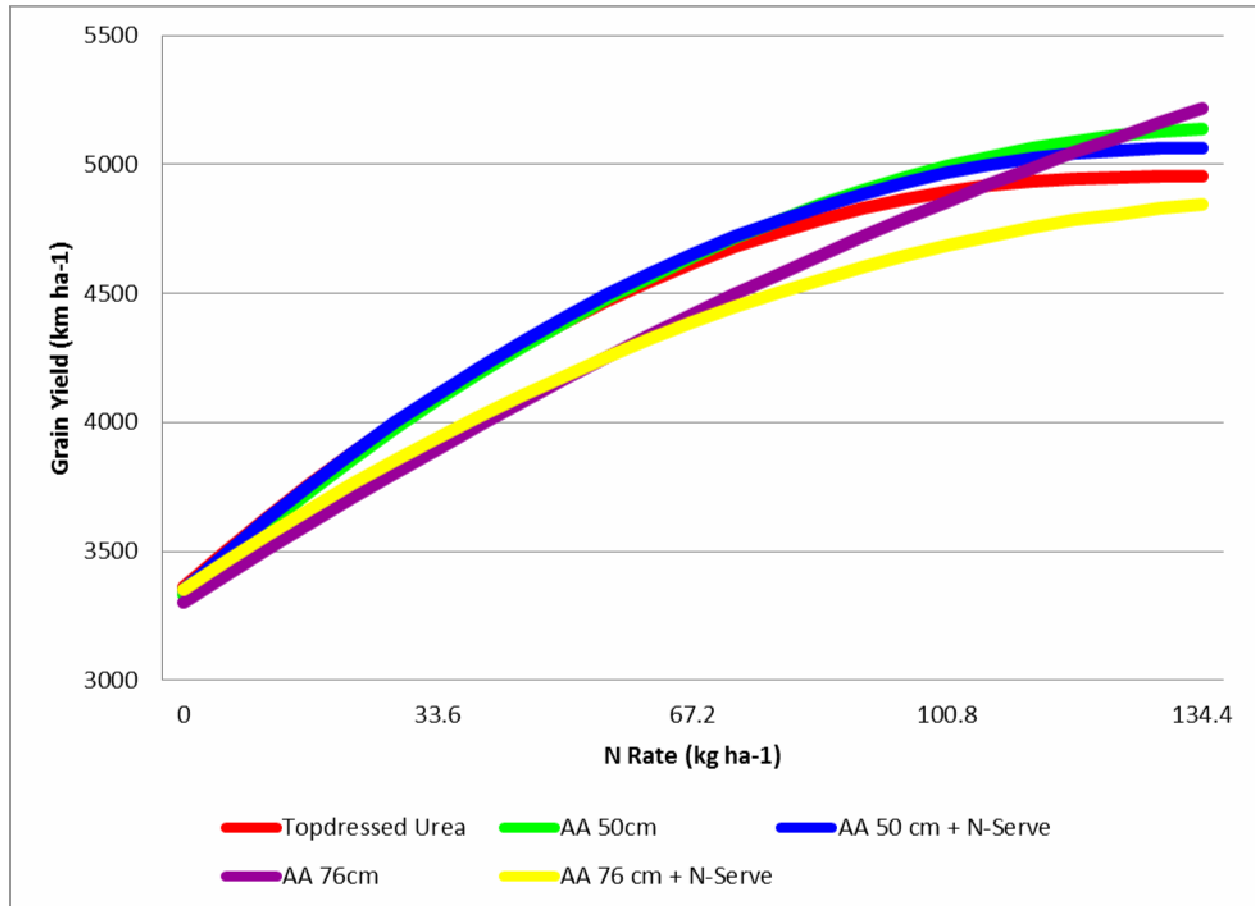
The data in Table 2.9 show a response to N rate for leaf N and grain yield but no statistical differences associated to treatment. Grain protein levels were above average and unaffected by N rate or treatment.

Table 2.4 Rossville 2011 results as affected by N application source, timing and spacing.

Treatment	Timing	Row Spacing	N Rate	N- Serve	Leaf N	Grain Yield	Grain Protein Content
		(cm)	(kg ha ⁻¹)		(% N)	(kg ha ⁻¹)	
1. Control	na	na	0	na	3.15	3,350	12.9
2. Topdress Urea	Feekes 4	na	34	na	3.27	4,120	12.7
3. Topdress Urea	Feekes 4	na	67	na	3.69	4,730	13.3
4. Topdress Urea	Feekes 4	na	100	na	3.68	4,720	13.0
5. Topdress Urea	Feekes 4	na	134	na	3.82	5,040	12.4
6. Preplant AA	Preplant	na	34	no	3.32	4,050	12.3
7. Preplant AA	Preplant	50	67	no	3.77	4,670	13.2
8. Preplant AA	Preplant	50	100	no	4.07	4,990	12.4
9. Preplant AA	Preplant	50	134	no	4.20	5,130	13.0
10. Preplant AA	Preplant	50	34	yes	3.40	4,160	12.5
11. Preplant AA	Preplant	50	67	yes	3.73	4,530	13.5
12. Preplant AA	Preplant	50	100	yes	3.92	5,080	13.3
13. Preplant AA	Preplant	50	134	yes	3.90	5,020	12.1
14. Preplant AA	Preplant	76	34	no	3.30	3,820	12.7
15. Preplant AA	Preplant	76	67	no	3.56	4,390	12.8
16. Preplant AA	Preplant	76	100	no	3.88	4,970	12.5
17. Preplant AA	Preplant	76	134	no	4.08	5,140	13.5
18. Preplant AA	Preplant	76	34	yes	3.42	3,970	13.2
19. Preplant AA	Preplant	76	67	yes	3.54	4,350	12.6
20. Preplant AA	Preplant	76	100	yes	4.12	4,710	13.2
21. Preplant AA	Preplant	76	134	yes	3.99	4,840	12.3
Pr>F					<.0001	<.0001	0.629
CV					8.89	6.29	7.14
LSD(.05)					0.466	405	1.29
LSD(.10)					0.390	340	1.07

Figure 2.8 represents the grain yield after being fitted to a quadratic plateau model. There is no statistical difference between any of the treatment regression lines. There does seem to be a

trend that the 76 cm spacing may be at a slight disadvantage. We would expect this to be worse in years that are extremely above or below average precipitation.



Treatment	Formula	R ²
Topdress Urea	$3360+0.4275N-0.00193N^2$	0.914
AA 50 cm	$3330+0.427N-0.00169N^2$	0.883
AA 50 cm + N-Serve	$3350+0.433N-0.00184N^2$	0.878
AA 76 cm	$3300+0.3167N-0.00066N^2$	0.838
AA 76 cm + N-Serve	$3350+0.3279N-0.00119N^2$	0.811

Figure 2.8 Rossville 2011 grain yield response to application source, spacing and timing

Combined Analysis

All like treatments for all sites and years at a given N rate, were included in the combined analyses. This included topdress urea, preplant AA at 50 cm spacing and preplant AA at 76 cm spacing treatments at the 67 and 101 kg N ha⁻¹ rates in three site years. This combined analysis was done using PROC MIXED with location and year as a main effect. These results are shown in Tables 2.10 and 2.11.

Table 2.5 Combined data for all site years at the 67 kg/ha N rate

Treatment	Timing	Row Spacing	N Rate	N-Serve	Grain Yield
		(cm)	(kg ha ⁻¹)		(kg ha ⁻¹)
1. Control	na	na	0	Na	2490 a
3. Topdress Urea	Feekes 4	na	67	Na	3720 b
7. Preplant AA	Preplant	50	67	No	3740 b
15. Preplant AA	Preplant	76	67	No	3530 b

*Letter designations indicate statistical significant at an alpha of .05.

Table 2.6 Combined data for all site years at the 101 kg/ha N rate

Treatment	Timing	Row Spacing	N Rate	N-Serve	Grain Yield
		(cm)	(kg ha ⁻¹)		(kg ha ⁻¹)
1. Control	na	Na	0	Na	2490 a
4. Topdress Urea	Feekes 4	Na	101	Na	4050 b
8. Preplant AA	Preplant	50	101	No	3980 b
16. Preplant AA	Preplant	76	101	No	3950 b

*Letter designations indicate statistical significant at an alpha of .05.

Tables 2.10 and 2.11 show that there is no statistical difference between N application methods at either the 67 or 101 kg N ha⁻¹ rates. However, there is a trend for slightly lower grain yields at the lower 67 kg N per hectare N rate with the wider applicator spacings.

Conclusions

A significant response to applied N was observed in all three experiments. However, no differences were observed between preplant or topdress N application treatments leaf N content, grain protein or grain yield. Topdressing had no advantage over preplant applications of N. This is most likely due to low precipitation and cool soil temperatures between the time of preplant N applications in the fall and topdressing applications, which significantly lowered N loss potential. While this is the norm in most of Kansas, on years with above average rainfall over the winter months, this would most likely not be the case.

Low loss potential would also explain the lack of response to N-Serve in these studies. A number of studies have shown that N-Serve is an effective nitrification inhibitor and works well when loss potentials are significant (Huber et al., 1977). Nonetheless, many researchers have found no advantages to using N-Serve when loss potentials were low as was the case with these experiments (Touchton et al., 1978; Touchton et al., 1979; Hendrickson et al., 1978; Hergert, 1980).

Although AA application spacing had no significant effect on yield in this study, the 50 cm spacing tended to have a slight advantage over 76 cm spacings. The clear waviness in growth observed at Rossville with the 76 cm spacing would suggest that in years that were very dry with limited N movement, or wet, with higher N loss, 50 cm spacing would likely have a more clear advantage. Growing conditions in all three site years were ideal for N uptake. There was enough soil moisture for good root development and lateral movement of N. This led to a natural distribution of fertilizer and uptake, which masked the application spacing effect. Above ground, conditions were also ideal for wheat growth and development. These ideal conditions allowed wheat plants over the fertilizer band to yield very well and compensate for those plants in between the fertilizer band that might have been stressed for N. In dry years the wheat crops would most likely have a harder time compensating. In wet years a combination of less root exploration of the soil profile and high rate of N leaching could make it much harder for plants farther from the fertilizer band to get N and therefore decrease yield. Though further research would be appropriate to verify these beliefs about wetter and dryer conditions, previous research suggest that narrower spacings are most efficient and effective in wheat production.

Even though this experiment found little agronomic advantages to specific N sources and application methods, there may still be economic and production advantages.

Topdressing N in the spring can reduce potential for loss over the winter as well as allow the producer to more accurately evaluate yield potential and market conditions, which is valuable information when deciding on appropriate N rates. On the other hand, anhydrous ammonia N has traditionally been around 30% less expensive per unit than urea N, which can substantially decrease production costs. Thus, there is more to consider than agronomic yield when making decisions in large scale production situations.

In closing, both preplant applications of AA and topdress applications of urea are viable N management strategies for winter wheat production in Kansas. Although this study found AA applied in 76 cm spacing acceptable, a significant body of previous work would suggest 50 cm spacing are desirable. N-Serve did not increase yield in this study, but that is not surprising since N loss over the winter months would have been minimal with the low winter precipitation and cool temperatures during the study years. However, previous research has clearly shown that it does work and should be considered in high potential loss environments. When considering between these N management strategies, production and economic factors, as opposed to agronomic, may ultimately be the most important consideration for most producers.

References

- Blue, W.G., and C. F. Eno. 1954. Distribution and Retention of Anhydrous Ammonia in Sandy Soils. Soil Sci. Soc. Am. Proc. 18:420-424.
- Doll, E.C.. 1962. Effects of Fall-Applied Nitrogen Fertilizer and Winter Rainfall on Yield of Wheat. Agron. J.4: 471–473.
- Hendrickson, L.L., L.M. Walsh, and D.R. Keeney. 1978. Effectiveness of Nitrapyrin in Controlling Nitrification of Fall and Spring-Applied Anhydrous Ammonia. Agron. J. 70: 689-703
- Hergert, G.W., R.A. Wiese. 1980. Performance of nitrification inhibitors in the Midwest (west). ASA Special Publication 1980. 38: 89-105.
- Huber, D.M., H.L. Warren, D.W. Nelson, C.Y. Tsai. 1977. Nitrification Inhibitors: New Tools for Food Production. BioScience Vol. 27 No. 8.
- Maxwell, T.M., D.E. Kissel, M.G. Wagger, D.A. Whitney, M.L. Cabrera, H.C. Moser. 1984. Optimum Spacing of Preplant Bands of N and P Fertilizer for Winter Wheat. Agron. J. 76: 243–247.
- Stamper J.D. and D.B. Mengel. 2008. Effects of Nitrogen Rate, Timing, and Placement in Irrigated Corn Using Anhydrous Ammonia. Kansas Fertilizer Research, 2008.
- Touchton, J.T., R.G. Hoeft, and L.F. Welch. 1978. Effect of Nitrapyrin on Nitrification of Fall and Spring-Applied Anhydrous Ammonia. Agron. J. 70: 805-810.
- 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 Agron. J. 71: 238-242.

Chapter 3 - Evaluation of Topdressing Winter Wheat in Kansas with Anhydrous Ammonia

Abstract

Anhydrous ammonia (AA) has proven to be a reliable and economical source of N for fall preplant application on winter wheat. However due to the environmental risks associated with wheat production, many Kansas producers prefer an N management system that consists of a “starter” application at planting with the majority of the N fertilizer applied in the spring. This approach makes sure the crop survives the winter before the investment in N is made and eliminates the potential for fertilizer N being lost over the winter months. It has not been feasible to use AA for topdressing in the past due to the damage to the growing crop from application with traditional knife style applicators. With the development of the John Deere 2510H high speed, low disturbance AA applicator, topdressing may now be feasible. This low disturbance is achieved using a coulter type opener instead of the conventional knife apparatus. A two-year experiment was conducted with the objective of assessing the feasibility of topdressing with AA using the 2510H as compared to topdressing with granular urea. A number of factors such as application direction in relation to crop row, speed of application and timing as a function of crop development were examined to minimize crop injury and maximize crop yield. The initial 2010 study was promising, showing no significant yield loss topdressing with AA compared to topdressing with urea. The experiment was repeated at two locations in 2011. Results were mixed, showing soil conditions and the plants ability to recover from the AA application injury was important for the success of topdressing with AA.

Introduction

Anhydrous ammonia (AA) has long been a reliable and economical source of nitrogen fertilizer which is essential to achieve maximum winter wheat yields in most years. Application equipment and methods have changed little over the last 70 years. With agricultures transition to conservation and no-till systems in more recent years, traditional knife AA applicators have

come under scrutiny due to their substantial tillage effect. To answer this concern, John Deere has developed their 2510 HSLD (2510H), low disturbance, high speed, low draft AA applicator specifically designed for no-till systems. Low soil disturbance is achieved by using a large single disk opening system much like that used on modern single disk opener grain drills. This system injects AA at a relatively shallow, 10 to 12 centimeter, depth. Research by Stamper and Mengel (2009) found this applicator design to be an acceptable substitute for a traditional knife system when used with N rates less than 179 kg ha^{-1} and good soil conditions. However under less than optimal conditions poor sealing can occur resulting in leakage and poor retention of ammonia.

Low soil disturbance AA application equipment is especially attractive in the semi-arid Great Plains wheat growing region where moisture conservation through no-till systems has proven to be important for optimum yield and profitability. Anhydrous ammonia has also been a long time favorite for wheat growers as it is an economical and effective source of N, making it well suited for a relatively low input system. Nonetheless, AA has not been an option in topdress N management systems commonly used in wheat production.

Traditional topdress N management systems consist of a minimal amount of N applied in the fall at planting to get the crop up and carry it through the winter. The balance of the N is applied as surface applied urea or UAN solutions in late winter or early spring. The advantages of this system are that it eliminates the potential for N fertilizer to be lost over the winter months, as well as lets the producer evaluate the crops agronomic and economic potential after the winter vernalization period and adjust N rates accordingly. Previously, this has eliminated AA as an N source as the application process is too invasive to be practical in standing wheat. With the recent advent of the 2510H and its low soil disturbance, topdressing with AA may be possible, which could save producers as much as 30% in fertilizer expenses.

Work by Oklahoma State University using a rolling coulter followed by a thin injection knife found this AA application method more effective than broadcast applications of liquid UAN at the same time (Boman et al., 1995). This could translate to a substantial economic advantage to producers. Little other research has been done concerning this type of spring AA application.

The objective of this study was to assess the feasibility of topdress with AA using the 2510H as well as evaluate application speed and timing of application in respect to crop development to minimize crop injury and maximize crop yield.

Materials and Methods

Field research was initiated in the fall of 2009 at one location on the KSU Agronomy North Farm in Manhattan, KS. Plots were arranged in randomized complete block design with four replications and measured 3.04 m wide by 24.38 m long. Six meter alley ways were established between blocks to allow room to achieve the 12.87 kilometer per hour application speed. Anhydrous treatments were applied with a John Deere 2510H experimental applicator with the application units set 50 cm on center apart. All plots received 22.4 kg ha⁻¹ at planting as urea to carry the crop through the winter. Treatments are listed in Table 3.1. Site information and key cultural practices are included in Table 3.3.

Table 3.1 2009-2010 Treatments

Treatment	Application Direction	Application Speed (km hr ⁻¹)	N Rate (kg ha ⁻¹)
1. Control	Na	Na	0
2. Topdress Urea	Na	Na	67
3. Topdress AA	With Row	6.4	67
4. Topdress AA	Across Row	6.4	67
5. Topdress AA	With Row	9.7	67
6. Topdress AA	Across Row	9.7	67
7. Topdress AA	With Row	12.9	67
8. Topdress AA	Across Row	12.9	67

Wheat was no-till drilled in 19 cm row spacings into soybean stubble at a rate of 112 kg ha⁻¹. Di-ammonium phosphate (18-46-0) was applied in furrow with the drill at a rate of 56 kg ha⁻¹. Thus, 10 kg ha⁻¹ of N and 26 kg ha⁻¹ P were applied as starter. Spring topdress urea treatments were applied by hand at growth stage Feekes 4. Across row treatments were applied at a 10° angle to the crop row. Dates at which all field work was completed can be found in Table 3.5.

After evaluating results from the 2009-2010 study, minor modifications were made to the treatment list but the research was carried out in much of the same way for the 2010-2011 growing season. Research was also expanded to have a site at the Kansas River Valley Experiment Field at Rossville, KS as well as another site on the KSU North Agronomy Farm in Manhattan, KS. This gave two sites on very different soils. Cultural practices can be found in Table 3.3 and site soil information can be found in Table 3.4 and.

Similar randomized complete block design was used in 2010 but plot size at both locations was reduced to 15.24 meters long due to space constraints. The same 2510H experimental applicator was used to apply all the AA treatments. Treatments are listed in Table 3.2.

Drilling and fertilization was carried out the same as 2009. Dates of field operations can be found in table 3.5.

Table 3.2 2010-2011 Treatments

Treatment	Timing	Application Speed	N Rate
		km hr ⁻¹	(kg ha ⁻¹)
1. Control	na	Na	0
2. Control B Urea	Preplant	Na	22
3. Topdress Urea	Feekes 4	Na	67
3. Topdress Urea	Feekes 4	Na	90
3. Topdress Urea	Feekes 4	Na	112
3. Topdress Urea	Feekes 4	Na	134
7. Topdress AA	Feekes 4	6.4	67
8. Topdress AA	Feekes 4	6.4	90
9. Topdress AA	Feekes 4	6.4	112
10. Topdress AA	Feekes 4	6.4	134
11. Topdress AA	Feekes 4	12.9	67
12. Topdress AA	Feekes 4	12.9	90
13. Topdress AA	Feekes 4	12.9	112
14. Topdress AA	Feekes 4	12.9	134
15. Topdress AA	Feekes 7	6.4	67
16. Topdress AA	Feekes 7	6.4	90
17. Topdress AA	Feekes 7	6.4	112
18. Topdress AA	Feekes 7	6.4	134
19. Topdress AA	Feekes 7	12.9	67
20. Topdress AA	Feekes 7	12.9	90
21. Topdress AA	Feekes 7	12.9	112
22. Topdress AA	Feekes 7	12.9	134

Table 3.3 Key Cultural Practices

Location	Manhattan 2009-2011	Manhattan 2010-2011	Rossville 2010-2011
Tillage	No-Till	No-Till	No-Till
Previous Crop	Soybeans	Soybeans	Soybeans
Wheat Variety	SantaFe	Everest	Everest
Seeding Rate	112 kg/ha	112 kg/ha	112 kg/ha
Starter	56 kg/ha 18-46-0 in furrow	56 kg/ha 18-46-0 in furrow	56 kg/ha 18-46-0 in furrow

Table 3.4 Site Soil Information

Location	Soil Series	Soil Description	pH	OM	Nitrate	P	K
				%	PPM		
Manhattan 2009-2010	Ivan and Kennebec Silt Loams	Fine-silty alluvium, occasionally flooded.	7.1	2.4	2.6	77	400
Manhattan 2010-2011	Ivan and Kennebec Silt Loams	Fine-silty alluvium, occasionally flooded.	7.2	2.2	2.5	28	362
Rossville 2010-2011	Stonehouse-Eudora Complex	Course-silt, fine sand alluvium	6.5	1.1	2.8	18.2	124

Table 3.5 Site Application Dates

	Manhattan 2009-2011	Manhattan 2010-2011	Rossville 2010-2011
Planting	20-Oct-2009	19-Oct-2010	17-Oct-2010
F4 Topdress N App.	15-April-2010	24-March-2011	23-March-2011
F7 Topdress N App.	Na	12-April-2011	11-April-2011
Flag Leaf Sampling	7-May-2010	13-May-2011	11-May-2011
Harvest	25-June-2010	24-June-2011	23-June-2011

Tissue Sampling and Analysis

Flag leaf samples were taken when wheat plants reached Feekes 9 by collecting 30 random leaves from the outer 0.75 m uniformly from each plot. All samples were dried at 60°C and ground to pass through a 0.05 mm stainless steel sieve. Concentrations of N were analyzed using a sulfuric acid-hydrogen peroxide digest and the extracted ammonia was analyzed by a colorimetric procedure (nitroprusside-sodium hypochlorite) using RFA Methodology No. A303-S072, Total Kjeldahl Nitrogen.

Grain Yield and Analysis

The center 1.5 m of each plot was machine harvested after physiological maturity. Harvesting technique was modified in 2011 as the harvester drove at an angle from the front corner of the plot to the opposite far corner in order to capture a more representative sample across the plot since there was noticeable wavy growth pattern in the wider spacing treatments. This way an equal number of plants were harvested over the fertilizer band as between the band. Figure 3.1 illustrates how this was completed. Representative samples were collected from each plot to run moisture and test weight. Yields were adjusted to 12% moisture. Subsamples were then dried and ground to pass through a 0.05 mm sieve. Grain N content was analyzed using the analytical methods given above.



Figure 3.1 Angled harvest pattern to capture a representative sample across the plot

Statistical Analysis

All data was analyzed using SAS version 9.1. General plot leaf N, grain yield and grain protein was analyzed using PROC GLM. Regression on grain yield was done with PROC NLIN Quadratic Plateau. Combined site years data was analyzed using PROC MIXED. All letter groupings are calculated at a probability level of 0.05.

Results and Discussion

Manhattan 2010

The 2010 Manhattan site was fairly small but yielded important preliminary information, most notably, that topdressing with the 2510H and AA is feasible. The data in Table 3.6 reveal no significant differences in leaf N, grain yield, or grain protein for any treatment other than the 0 N control.

Table 3.6 Manhattan 2010 results as affected by N application source, speed and direction.

Treatment	Application Direction	Application Speed	N Rate	Leaf N	Grain Yield	Grain Protein Content
		(km hr ⁻¹)	(kg ha ⁻¹)	(% N)	(kg ha ⁻¹)	(%)
1. Control	na	Na	0	2.33 d	2,040 b	11.9 abc
2. Topdress Urea	na	Na	67	2.48 cd	3,330 a	11.5 bc
3. Topdress AA	With Row	6.4	67	2.83 ab	3,100 a	11.3 c
4. Topdress AA	Across Row	6.4	67	2.64 ab	3,160 a	11.8 abc
5. Topdress AA	With Row	9.7	67	3.00 a	3,260 a	12.4 a
6. Topdress AA	Across Row	9.7	67	2.82 ab	3,180 a	11.3 c
7. Topdress AA	With Row	12.9	67	2.92 ab	2,940 a	12.1 ab
8. Topdress AA	Across Row	12.9	67	2.83 ab	2,960 a	11.5 c

*Values followed by the same letter are not statistically different at P=0.05.

As shown in Figure 3.2, there was no statistical yield difference between directional treatments when averaged across all application speeds. As shown in Figures 3.3 and 3.4, both treatments create similar crop damage. The across row treatment damaged the crop at the intersection where the applicator crossed the row. The with row treatments have large sections that are destroyed by the applicator running down the row while other rows are untouched. Visual observations revealed that although crop damage was similar, the across row treatments damaged more evenly across that plot area.

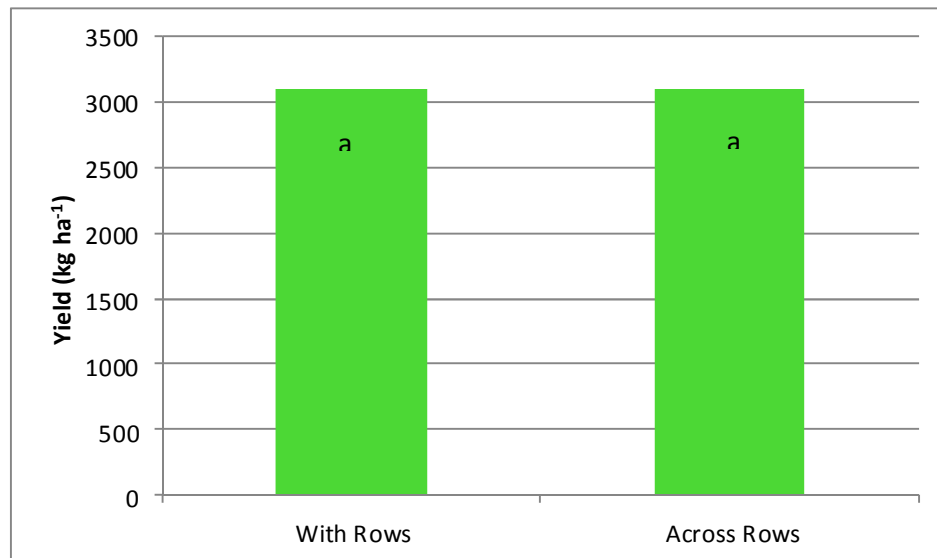


Figure 3.2 Direction effect at Manhattan 2010



Figure 3.3 Across row treatments after application



Figure 3.4 With row treatments after application

After this preliminary year, the directional treatments were dropped due to a lack of resources, mainly space and technology. The ability to run at a more extreme angle to the crop may decrease damage. Also, the ability to use RTK GPS technology to effectively address the growing wheat may also be a way to reduce crop damage. Further research using these techniques may help reduce crop damage and maximize yield.

Figure 3.5 shows that the only significant yield effect was between the 9.4 and 12.9 km hr⁻¹ treatments. We attribute this yield reduction at the 12.9 km hr⁻¹ to the increase in crop damage and soil disturbance at the higher speed. Visual observations during the application concluded that the seriated closing disk pictured in Figure 3.6 was to blame for much of the damage and soil disturbance. That seriated part of the closing disc was removed for topdressing applications after this first year.

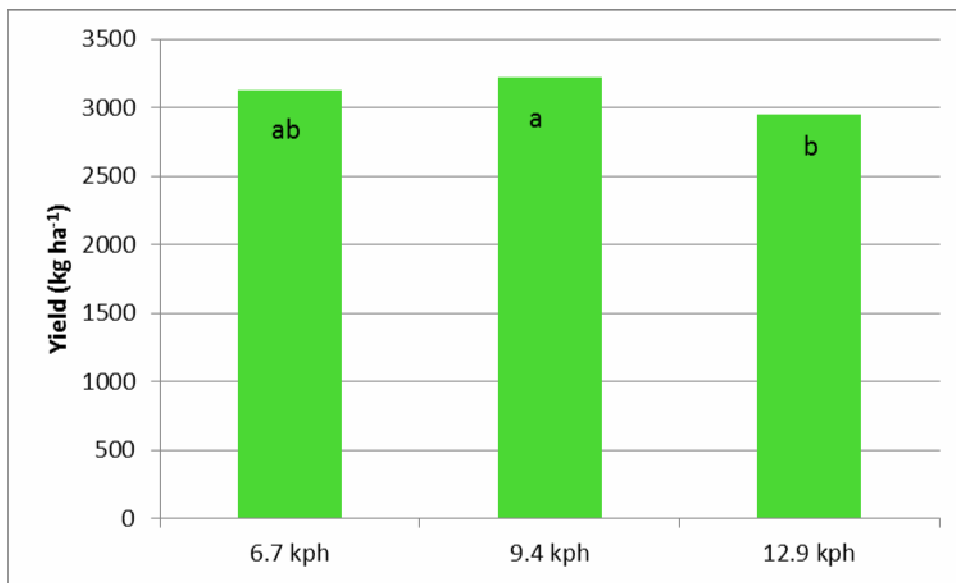


Figure 3.5 Speed effect Manhattan 2010



Figure 3.6 Seriated closing disk

The ultimate goal of this research is to evaluate whether topdressing with AA is a viable substitute for the traditional practice of topdressing with urea. Figure 3.7 shows no statistical yield difference between topdressing with AA compared to topdressing with urea. Conditions during and after topdressing were ideal for the crop recovery from damage due to the application process. Although topdressing with AA worked at this site and year, other years when conditions were less than ideal could result in significant reductions in yield.

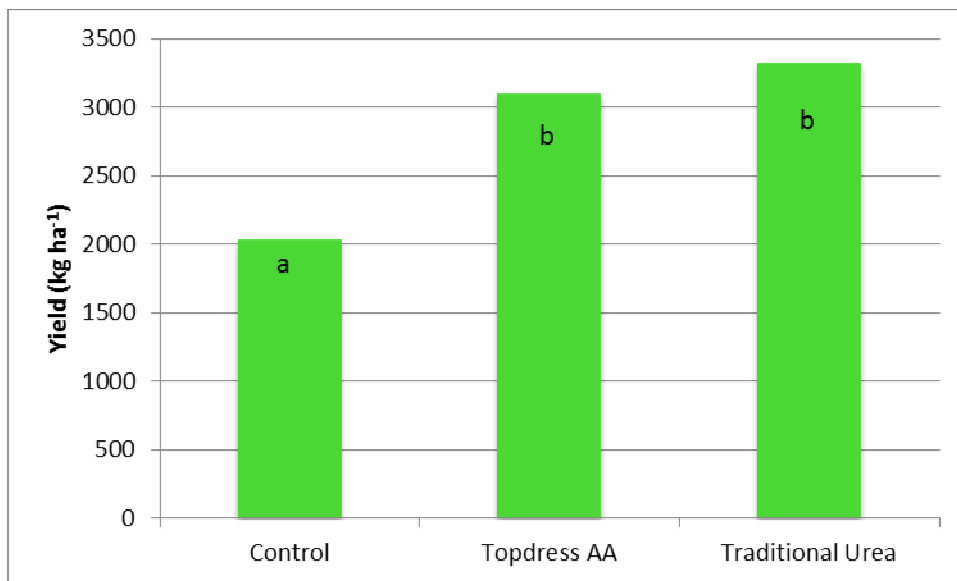


Figure 3.7 Topdressing with AA vs. Urea

Manhattan 2011

After the success of the Manhattan 2010 plots, the project was expanded substantially to include 22 treatments and two locations. The treatment list was modified by dropping the directional treatment and replacing them with a timing variable. The treatment list also included a full N response curve for every treatment.

Table 3.7 shows no significant differences between treatments other than N rate for leaf N, grain yield and grain protein. A trend of lower leaf N and protein, and higher yields are apparent for the topdress urea treatment. This is most likely attributed to differences in stress to the crop causing physiological growth and development differences between the urea treatments, which had little physical damage, and the AA treatments, which had significant physical damage. In further research, an AA applicator treatment with no N applied may be beneficial to account for this possibility. These results were not observed in any other site year.

Table 3.7 Manhattan 2011 results as affected by N application source, speed and timing.

Treatment	Timing	Application Speed	N Rate	Leaf N	Grain Yield	Grain Protein Content
		(km hr ⁻¹)	(kg ha ⁻¹)	(% N)	(kg ha ⁻¹)	(%)
1. Control	na	Na	0	2.19	2,960	9.9
2. Control B Urea	Preplant	Na	22	2.18	3,690	10.8
3. Topdress Urea	Feekes 4	Na	67	2.47	4,140	11.8
4. Topdress Urea	Feekes 4	Na	90	2.53	4,220	12.2
5. Topdress Urea	Feekes 4	Na	112	2.50	4,070	12.3
6. Topdress Urea	Feekes 4	Na	134	2.59	4,310	13.1
7. Topdress AA	Feekes 4	6.4	67	2.78	3,730	11.8
8. Topdress AA	Feekes 4	6.4	90	2.95	3,630	13.8
9. Topdress AA	Feekes 4	6.4	112	3.18	3,590	14.2
10. Topdress AA	Feekes 4	6.4	134	3.13	3,440	14.5
11. Topdress AA	Feekes 4	12.9	67	2.96	3,840	13.1
12. Topdress AA	Feekes 4	12.9	90	2.97	3,750	14.1
13. Topdress AA	Feekes 4	12.9	112	3.21	3,530	14.3
14. Topdress AA	Feekes 4	12.9	134	3.22	3,320	14.6
15. Topdress AA	Feekes 7	6.4	67	2.84	3,870	11.7
16. Topdress AA	Feekes 7	6.4	90	3.11	3,810	13.7
17. Topdress AA	Feekes 7	6.4	112	3.15	3,640	14.3
18. Topdress AA	Feekes 7	6.4	134	3.00	3,980	14.6
19. Topdress AA	Feekes 7	12.9	67	2.85	3,850	12.9
20. Topdress AA	Feekes 7	12.9	90	3.04	3,910	12.8
21. Topdress AA	Feekes 7	12.9	112	3.23	3,920	13.8
22. Topdress AA	Feekes 7	12.9	134	3.22	3,930	14.3
Pr>F				<.0001	<.0001	<.0001
LSD(.05)				0.23	451	1.16
LSD(.10)				0.20	377	0.97

Figure 3.8 shows statistical differences among the treatment averages. The most notable trend is the yield lag of the AA treatments when compared to the topdressed urea treatments. This difference is likely due to the substantial damage to the crop during the AA application process. Visual observations of extremely uneven maturity at harvest would support this theory.

No yield difference between application speed treatments were realized in this experiment after the seriated closing disk was removed in response to 2010 results.

When comparing timing treatments, an unexpected trend emerges. Feekes 7 treatments out yielded Feekes 4 treatments. As we damage the crop later in the growing season and after jointing, we would expect the crop would not yield as well. This thinking is confirmed with the Rossville 2011 data. These unexpended results are most likely explained by conditions at the time of application. Wet soils resulting in poor closure of the ammonia furrow and causing increased physical damage to the crop at the Feekes 4 application are likely to blame.

Data presented in Figure 3.9 supports this hypothesis. Yield appears is inversely related to N rate in the Feekes 4 treatments while yield tend to increase with N in the Feekes 7 treatments. This is characteristic of physical damage to the crop from ammonia burn which is expected in wet soil conditions resulting in poor furrow closure and increased gassing out. This data suggest that waiting on proper soil conditions may be more important than getting AA applications on early or before jointing.

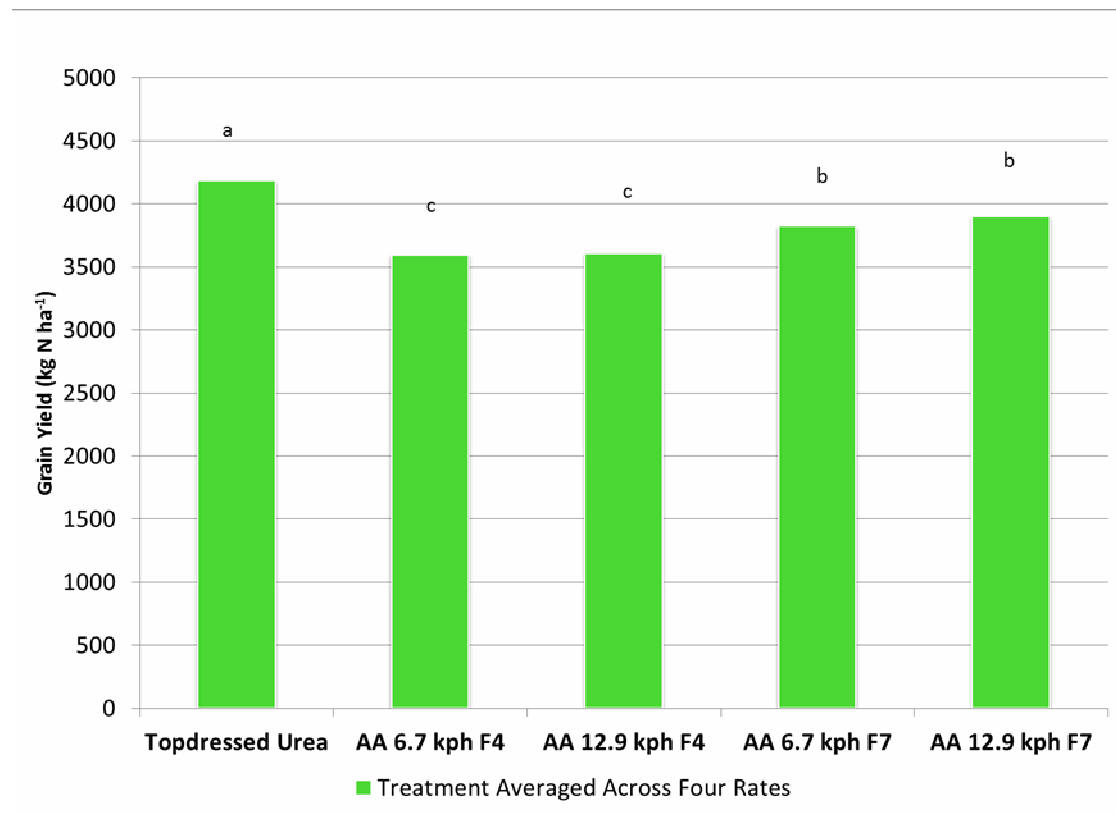


Figure 3.8 Manhattan 2011, impact of application speed on yield at different growth stages

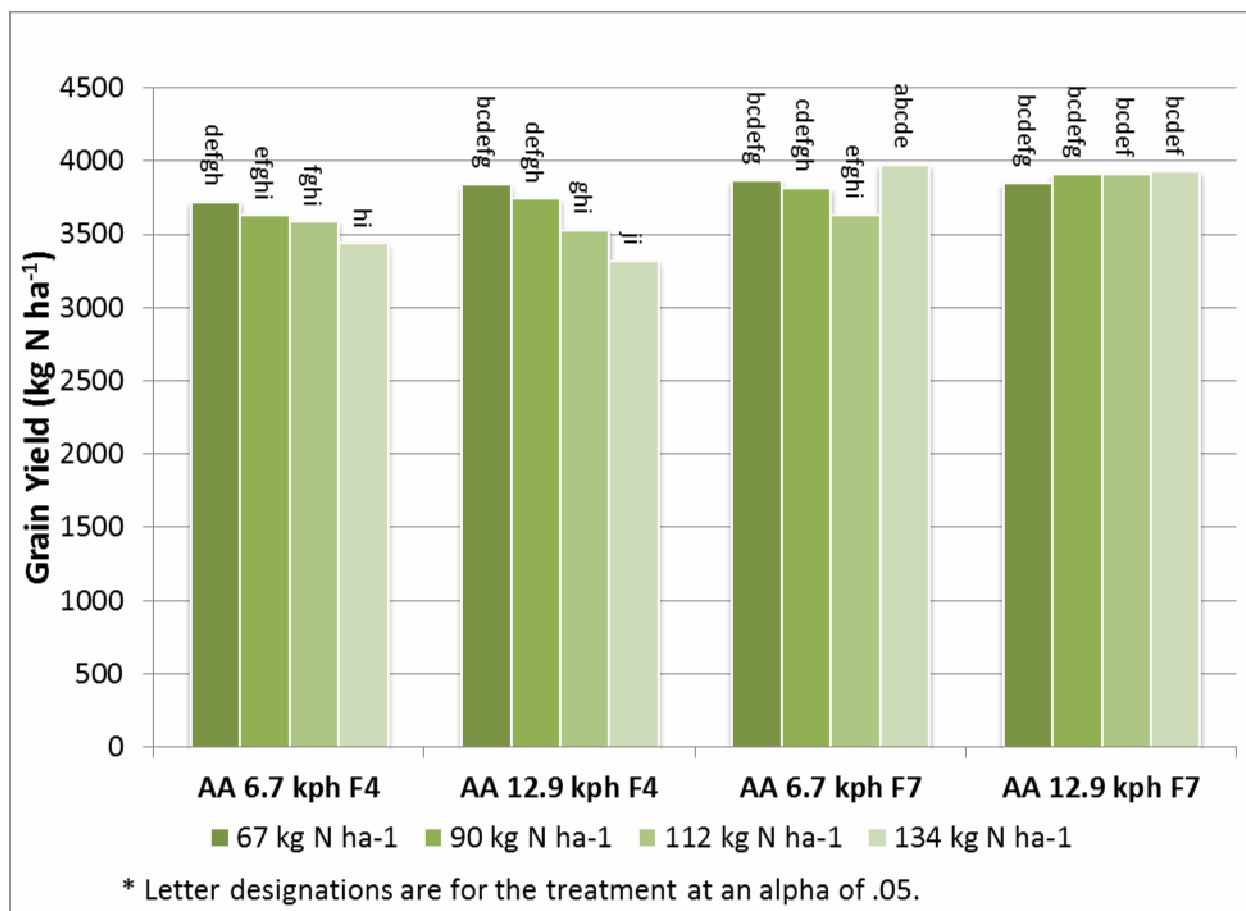


Figure 3.9 AA Treatment and N rate means

Rossville 2011

The lighter soils at the Rossville 2011 site provide a contrast to the heavier soils at the Manhattan sites but yielded similar results. Table 3.8 show no consistently significant treatment difference in response to anything but N rate for leaf N, grain yield or grain protein.

Table 3.8 Manhattan 2011 results as affected by N application source, speed and timing.

Treatment	Timing	Application Speed	N Rate	Leaf N	Grain Yield	Grain Protein Content
		km hr ⁻¹	(kg ha ⁻¹)	% N	(kg ha ⁻¹)	%
1. Control	na	Na	0	2.80	3,010	14.1
2. Control B Urea	Preplant	Na	22	3.09	3,490	13.7
3. Topdress Urea	Feekes 4	Na	67	3.25	3,980	14.8
4. Topdress Urea	Feekes 4	Na	90	3.28	4,490	14.8
5. Topdress Urea	Feekes 4	Na	112	3.29	4,470	13.7
6. Topdress Urea	Feekes 4	Na	134	3.50	4,890	14.8
7. Topdress AA	Feekes 4	6.4	67	3.44	3,940	14.2
8. Topdress AA	Feekes 4	6.4	90	3.83	4,470	15.1
9. Topdress AA	Feekes 4	6.4	112	4.11	4,020	14.2
10. Topdress AA	Feekes 4	6.4	134	4.22	4,250	13.0
11. Topdress AA	Feekes 4	12.9	67	3.99	4,230	13.8
12. Topdress AA	Feekes 4	12.9	90	3.89	4,180	13.7
13. Topdress AA	Feekes 4	12.9	112	3.96	4,540	15.3
14. Topdress AA	Feekes 4	12.9	134	3.94	4,030	14.3
15. Topdress AA	Feekes 7	6.4	67	3.67	3,540	15.5
16. Topdress AA	Feekes 7	6.4	90	3.74	3,200	15.1
17. Topdress AA	Feekes 7	6.4	112	3.74	3,390	15.5
18. Topdress AA	Feekes 7	6.4	134	3.64	3,560	14.1
19. Topdress AA	Feekes 7	12.9	67	3.69	3,660	15.0
20. Topdress AA	Feekes 7	12.9	90	3.81	3,770	14.9
21. Topdress AA	Feekes 7	12.9	112	3.82	3,630	14.8
22. Topdress AA	Feekes 7	12.9	134	3.89	3,680	14.7
Pr>F				<.0001	<.0001	0.0515
LSD(.05)				0.30	586	1.45
LSD(.10)				0.25	490	1.21

A visual depiction of yield results are presented in Figure 3.10. Topdressed urea yielded better than AA treatments.

Speed did not have an effect on yield in the Feekes 4 treatments but there was a small advantage at the 12.9 kph at the Feekes 7 timing. This is possibly due to increased ammonia burn from gassing out between the injection point and closing apparatus at the lower applications speed. This would have more adverse effects at the later timing as the crop is closer to maturity.

Unlike the Manhattan 2011 site, Feekes 4 AA application at Rossville tended to yield better than the Feekes 7. We would expect this to be true under normal soil conditions at time of applications as the crop typically has a harder time recovering from physical damage in later stages of growth and development.

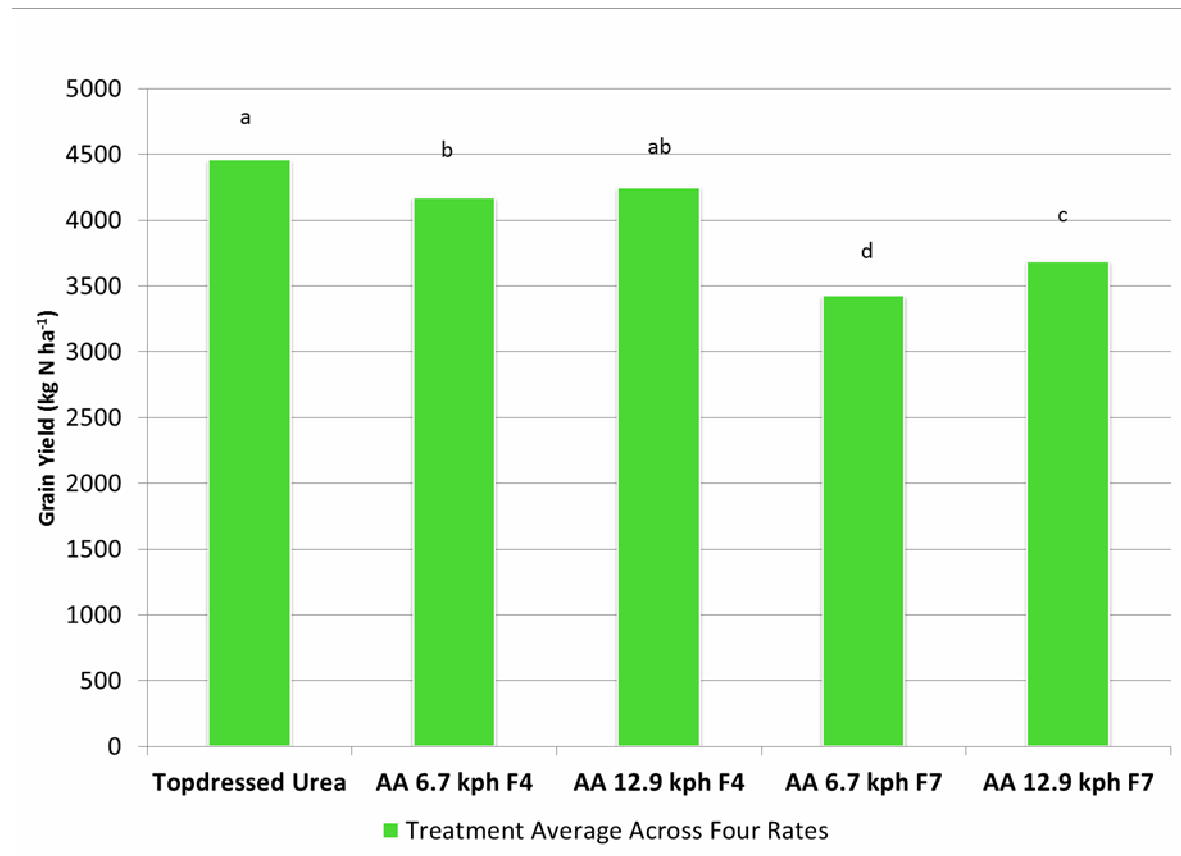


Figure 3.10 Treatment grain yield averages at Rossville 2011

Combined Analysis

Trends observed in individual site years hold true when combining the similar AA and urea treatments across all three site years. PRC MIXED was used to combine all three site years data in Table 3.9. Topdressing with urea tends to have a small, but not statistically significant, yield advantage over topdressing with AA and the 2510H, which is evident in Figure 3.11. This yield lag in the AA treatment is likely due to the physical damage to the growing wheat crop during the application process.

Table 3.9 Combined Yield Data

Treatment	Timing	App. Speed (km hr ⁻¹)	N Rate (kg ha ⁻¹)	Spacing (cm)	Grain Yield (kg ha ⁻¹)
1. Control	na	Na	Na	na	2660 a
3. Topdress Urea	Feekes 4	Na	67	na	3810 b
7. Topdress AA	Feekes 4	6.7	67	50	3610 b
11. Topdress AA	Feekes 4	12.9	67	50	3680 b

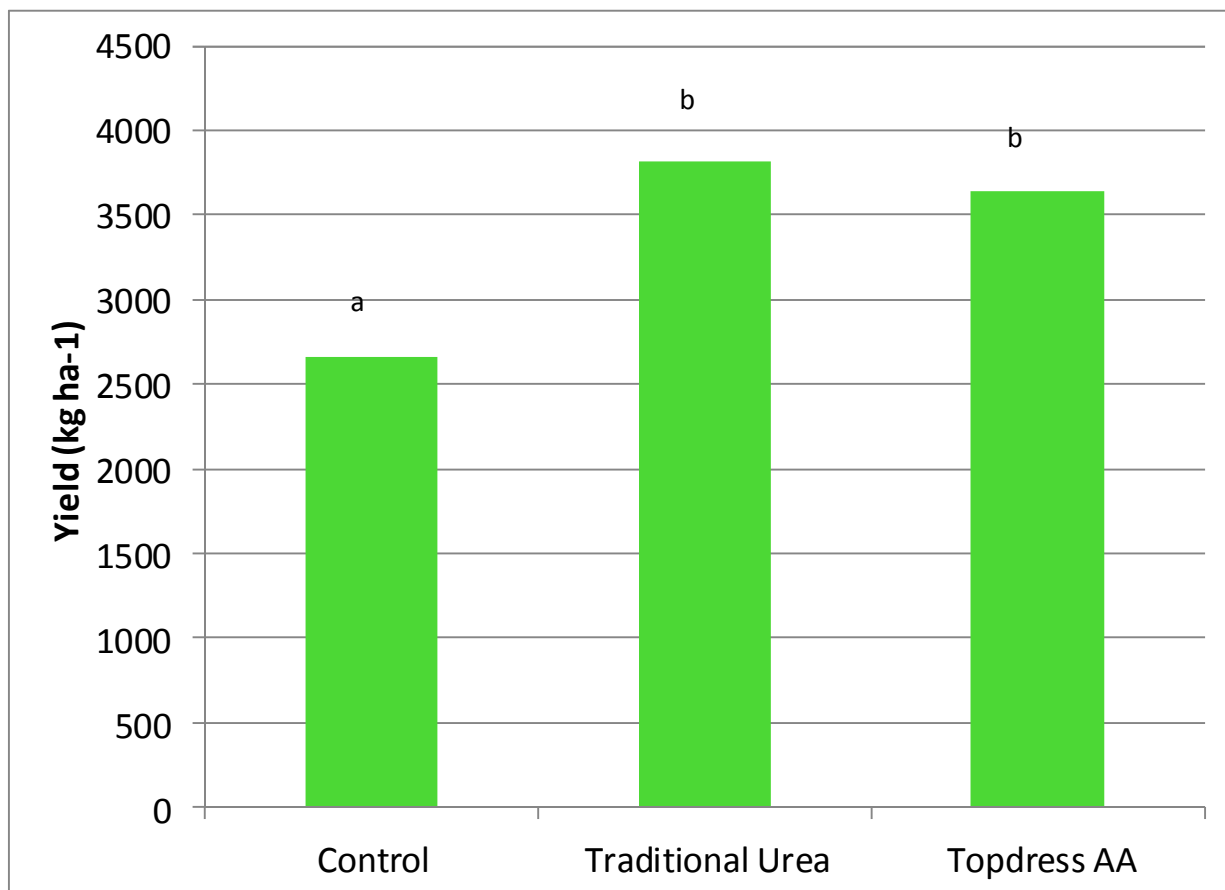


Figure 3.11 Combine yield results urea vs. AA treatments

Much like the combined data for urea vs. AA treatments, combined results in response to application speed were similar to individual site years. There was no yield response to application speed. These results are illustrated in Figure 3.12.

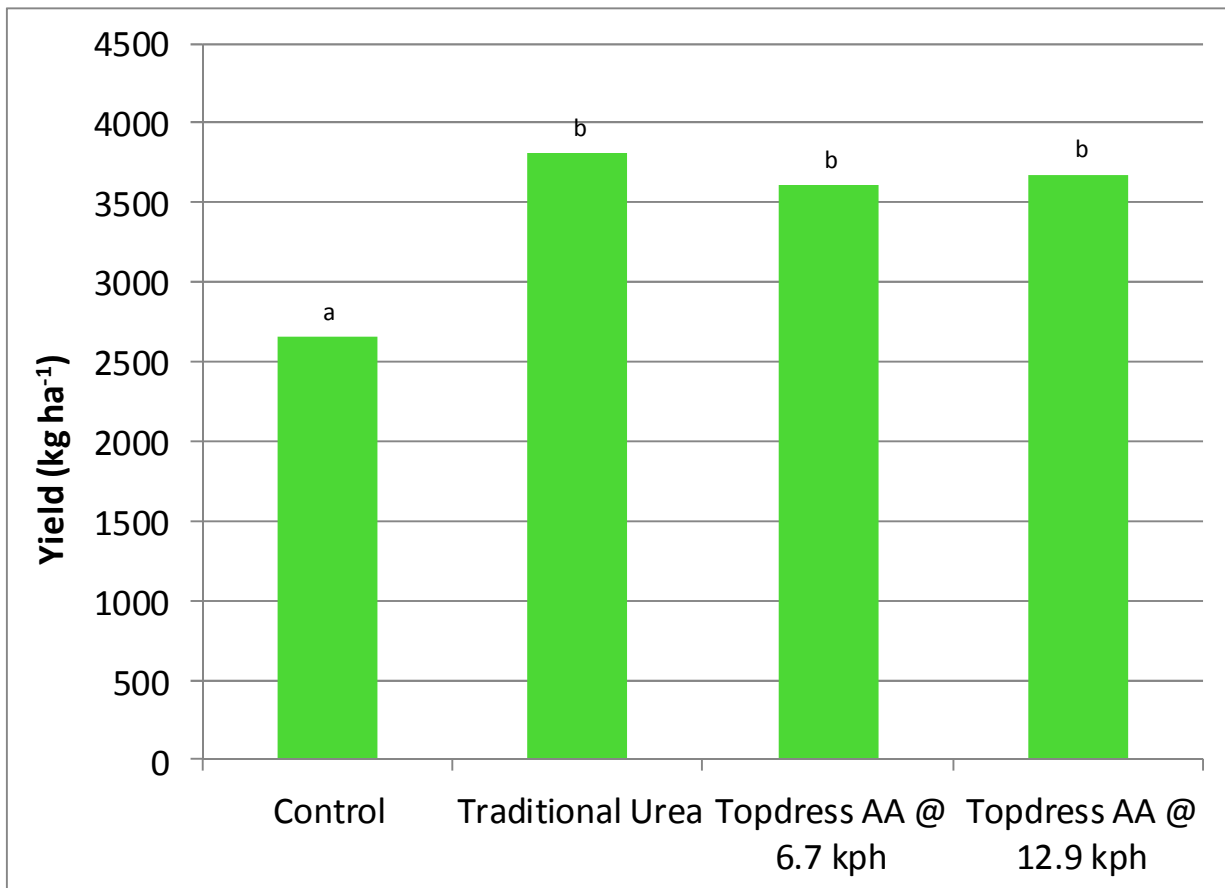


Figure 3.12 Combined yield response to application speed

Conclusions

Results from this research support that topdressing wheat in the spring using the John Deere 2510H to apply anhydrous ammonia is a viable N management strategy. Although there was never a statistical yield difference observed between topdressing with AA versus urea, AA treatments tended to yield 200 to 300 kg ha⁻¹ less. Nonetheless, even though AA does not tend to have an agronomic advantage, it may have an economic advantage over urea depending on application, fertilizer and grain prices.

There is more potential risk for yield loss associated with topdress with AA as opposed to urea. Favorable conditions for crop recovery after AA application were observed at all three sites year in this experiment. If the crop did not get adequate moisture after application to facilitate a quick recovery, topdressing with AA would most likely not yield favorable results.

Observations from this experiment also suggest that wet soils at application could have adverse effects associated with topdressing with AA. Wet soils result in higher gaseous ammonia losses and ultimately greater physical damage to the crop. Based on these results, it appears that waiting on proper soil conditions is more critical than particular timing or growth stage for application. Earlier Feekes 4 treatments are favorable, but applications delayed as late as Feekes 7 are acceptable in an attempt to apply in better soil conditions.

No yield response to application speed was observed after the seriated closing disc was removed. Application speeds between four and eight miles per hour are acceptable for at earlier application timing. At later application timings, higher application speeds are advisable.

Research should be continued to observe these N management strategies across differing climates and weather conditions. Further investigation into application direction is needed and may return promising results. A steeper across row treatment might work better. Taking more of a sidedressing approach using RTK GPS technology may eliminate physical damage from application.

Chapter 4 - An Economic Evaluation of Anhydrous Ammonia Applications in Winter Wheat

Abstract

Nitrogen (N) fertilizer is essential for wheat production in Kansas. Anhydrous ammonia (AA) has long been a reliable and economical source of nitrogen fertilizer. It is the lowest cost N source, since all other N fertilizers are derived from AA. Ammonia fertilizer application equipment and application methods have changed little over the last 70 years. With agriculture's transition to conservation and no-till systems in more recent years, the traditional knife AA applicators have come under scrutiny due to their substantial tillage effect. To address this concern, John Deere developed the 2510 HSLD (2510H), low disturbance, low draft, high speed AA applicator which is well suited for no-till systems. Due to the high application speed and lower power requirements of the 2510H, variable cost of operating this applicator are lower than conventional AA applicators. Furthermore, the low soil disturbance of the 2510H makes topdressing wheat with AA feasible. The objective of this study is to analyze the production economics of preplant and topdress AA when compared to the traditional practice of topdressing winter wheat with urea. Partial Net Present Value analysis revealed that the 2510H was of \$1.80 per hectare (\$0.73 per acre) lower cost to operate than a comparable conventional AA applicator. Partial Budgets of preplant applications of AA compared to traditional topdressed urea showed that AA applied with the 2510H has a small economic advantage. The economic evaluation of topdress AA versus traditional topdressed urea favored urea.

Introduction

Nitrogen (N) fertilizer is essential for wheat production in Kansas. Anhydrous ammonia (AA) has long been a reliable and economical source of nitrogen fertilizer. It is the lowest cost N source, since all other N fertilizers are derived from AA. Ammonia fertilizer application equipment and application methods have changed little over the last 70 years. With agriculture's transition to conservation and no-till systems in more recent years, the traditional knife AA

applicators have come under scrutiny due to their substantial tillage effect. To address this concern, John Deere developed the 2510 HSLD (2510H), low disturbance, low draft, high speed AA applicator which is well suited for no-till systems. Low soil disturbance is achieved by using a large single disk opening system much like that used on modern single disk opener grain drills. This system injects AA at a relatively shallow, 10 to 12 centimeter, depth. Research by Stamper and Mengel (2009) found this applicator and design to be an acceptable substitute for a traditional knife system when used with reasonable N rates and soil conditions.

Low soil disturbance AA application equipment is especially attractive in the semi-arid High Plain wheat growing region where moisture conservation through no-till systems has proven to be imperative for long run profitability. Anhydrous has also been a long time favorite for preplant application among wheat growers as it is a less expensive and effective source of N making it well suited for a relatively low input system. However, AA has not been an option in the topdress N management systems commonly used in wheat production due to the crop injury resulting from AA application.

Traditional topdress N management systems consist of a minimal amount of N applied in the fall at planting to get the crop up and carry it through the winter. The balance of N is applied as surface applied urea or UAN solutions in late winter or early spring. The advantages of this system is that it eliminates that potential for N fertilizer to be lost over the winter months as well as allows the producer evaluate the crops agronomic and economic potential after the winter vernalization period and adjust N rates accordingly. With the recent advent of the 2510H and its low soil disturbance, topdressing with AA may be possible, which could save producers as much as 30% in fertilizer expenses.

Previous chapters of this thesis have shown that AA applied with the 2510H is agronomically feasible in a variety of N management systems. Applications of AA with the 2510H and appropriate ammonia spacing prior to planting resulted in no significant yield difference when compared to topdressing with urea in the spring. Likewise, no significant yield difference was found when topdressing with AA and the 2510H versus the conventional method of topdressing with urea when soil conditions were sufficient to provide sealing and the plants had good conditions for regrowth.

With no agronomic difference between these two methods, it then becomes a question which method has the economic advantage for the producer. There are several variables to consider when analyzing the economics of these different N management strategies. Although AA is less expensive per unit of N, application cost is almost double that of urea due to the energy requirements of traditional AA application equipment. Anhydrous ammonia application also tends to require more time and labor than urea application which may make it logistically inefficient.

The objective of this study is to analyze the production economics of preplant and topdress AA when compared to the traditional practice of topdressing winter wheat with urea.

Materials and Methods

Field Research and Yield Data

Yield data from field research covered in the previous chapters were used in this economic analysis. Treatment grain yields were averaged across all three site years for the topdress urea treatment and the best AA application method in each of the preplant and topdress treatments. These treatments and yields are summarized in Tables 4.1 and 4.2.

Table 4.1 shows that there is no yield difference between traditionally topdressed urea and preplant AA. Table 4.2 indicates that traditionally topdress urea out yielded topdress AA by roughly 140 kg ha⁻¹, though this difference was not statistically significant at a 5% significance level. Nonetheless, we believe there is a yield reduction associated with topdress applications of AA and will treat this difference as if it is real for the economic analysis.

Table 4.1 Preplant Yield Treatment Averaged Across all Three Site Years

Treatment	Timing	Row Spacing	N Rate	Grain Yield
	(cm)	(kg ha ⁻¹)		(kg ha ⁻¹)
Topdress Urea	Feekes 4	na	67	3720
Preplant AA	Preplant	50	67	3740

Table 4.2 Topdress Yield Treatment Averaged Across all Three Site Years

Treatment	Timing	App. Speed (km hr ⁻¹)	N Rate	Spacing (cm)	Grain Yield (kg ha ⁻¹)
Topdress Urea	Feekes 4	na	67	na	3810
Topdress AA	Feekes 4	12.9	67	50	3680

Net Present Value Analysis

Custom fertilizer application rates for Kansas are published by Kansas State University on an annual basis (Dhuyvetter 2011). These rates are the basis for application cost in this analysis. Reported custom rates are for traditional knife AA application equipment and do not necessarily reflect the cost of operating the 2510H due to its higher operating speed and lower energy requirements. A net present value (NPV) analysis will be used to compare the 2510H to traditional knife applicator application cost. The results from the NPV analysis will then be used to adjust reported state custom rates to more accurately reflect the cost of operating the 2510H.

Net present value is the value of an investment that has a useful life over multiple years dimensioned in today's dollars. NPV takes into account the initial purchase price of an asset, any cost associated with its ownership, and expected returns. Investment, cost, and revenue values that occur in the future are discounted by the cost of money which is a combination of interest and risk. In this particular study, NPV analysis will be used to adjust the custom application rates, which reflect the cost of operating a conventional AA applicator. The John Deere 2510C (2510C) is the conventional knife style applicator used for comparison in the analysis. Values for the cost of operating the 2510H and 2510C are included in Table 4.3. The values used in the analysis and reported in Table 4.3 were acquired from an equipment manufacture. The difference column reflects the cost difference between the two applicators. Since NPV analysis is only used to adjust custom rates, the values in the difference column are used. This is also referred to as a partial net present value analysis since a full NPV analysis of owning and operating both applicators is not done.

Table 4.3 Operation cost of the 2510H and 2510C

	2510H	2510C	Difference
Purchase Price (\$)	86,217.00	65,961.00	20,256.00
Salvage Value (\$ after 10 years)	23,000.00	14,000.00	9,000.00
Width (18 units)	30ft	30ft	
Application Speed (mph)	9.25	6.5	2.75
Acres/hr	24	16	8
Tractor Cost (\$/hr)	60.00	60.00	-
Fuel Consumption (gal/hr)	12	12	
Fuel (\$/gal)	3.65	3.65	-
Cost of Operator (\$/hr)	20.00	20.00	-

Table 4.4 shows the assumptions used in the NPV analysis. NPV analysis assumes using the 2510H on a total of 1,010 hectares (2,500 acres), 400 hectares (1,000 acres) of which are wheat. This means the fixed cost (purchase price, taxes, insurance and depreciation) are spread across 1,010 hectares (2,500 acres) while variable cost associated with its use in wheat are incurred on 400 hectares (1,000 acres). This is assumed to be reflective of an average size farm that might be investing in this type of equipment.

Table 4.4 General NPV Input Data over 1,000 Acres

		2510C	2510H	Difference =H-C
Purchase price		\$ 26,384.40	\$ 34,486.80	\$ 8,102.40
Salvage value		\$ 5,600.00	\$ 9,200.00	\$ 3,600.00
Year sold	10			-
Interest rate	6.9%			-
Loan years	5			-
Downpayment	20.0%			-
Marginal tax rate	47.3%			-
Federal	28.0%			-
State	6.0%			-
Self employment	13.3%			-
Discount rate	3.64%			-
Section 179	0			-

Annual Variable Cost

	Growth Rate			
Tractor	3%	\$ 3,750.00	\$ 2,500.00	\$ (1,250.00)
Annual repairs	3%	\$ 140.00	\$ 580.00	\$ 440.00
Annual labor	3%	\$ 1,250.00	\$ 830.00	\$ (420.00)
Annual fuel and oil	3%	\$ 2,740.00	\$ 1,830.00	\$ (910.00)
Annual acres	3%	1,000	1,000	-

Partial Budget and Breakeven Analysis

Partial budgets are commonly used in agriculture as a simple decision making tool when comparing two alternatives. The budget is “partial” because only the cost and benefits that are different for the given alternatives are included in the analysis (Roth & Hyde, 2002). There are two set of alternatives to evaluate in this study. The first is to compare AA applied preplant, which is an alternative to the traditional method of topdressing with urea. The second is to compare topdressed AA, which is an alternative to traditional topdress urea. Both sets of alternatives have to consider the same three costs and benefits that are different; N price, grain yield and application cost. The net difference between the two alternatives shows which method is economically favorable.

Breakeven analysis typically refers to finding the point at which costs are equal to returns. In this analysis breakeven prices and yields are calculated to identify at what price or yield level the net returns after fertilizer expense of the alternatives are equal.

Results and Discussion

Net Present Value Analysis Results

Tables 4.5 and 4.6 show the yearly breakdown of the four variable costs for the two applicators. Although the 2510H is more expensive to purchase, variable costs of operating this machine are significantly less than those of the 2510C. This is due to efficiency gained by lower power requirements and higher operating speed.

The depreciation schedules shown in Table 4.5 and 4.6 come from the 2011 Farmers Tax Guide (IRS. 2011).

Table 4.7 summarizes the results of the NPV analysis for the 2510C and 2510H. The savings in fuel, tractor cost and labor due to being able to cover more acres per hour with less horsepower results in an advantage of \$1.12 per hectare (\$0.45 per acre) of wheat for the 2510H over the 2510C, even with the added purchase and maintenance cost. This means that \$1.12 per hectare (\$0.45 per acre) can be subtracted from the published custom AA application rate which

is \$27.47 per hectare (\$11.12 per acre). This estimated custom rate of \$26.35 per hectare (\$10.67 per acre) will be used for further partial budgets and breakeven analysis.

Table 4.5 Yearly Cash Flow Results for the 2510C

(1) Year	(2) Payment	(3) Tax depreciation	(4) Book value	(5) Salvage value	(6) Depreciation recapture	(7) Variable and fixed costs	(8) Tax reduction	(9) After-tax cash flow	(10) Present value (PV) factor	(11) PV of after-tax cash flow
0	\$26,384	\$0	\$26,384				\$0	(\$26,384)	1.0000	(\$26,384)
1		2,826	23,559			7,880	5,064	(2,816)	0.9649	(2,717)
2		5,047	18,511			8,116	6,226	(1,890)	0.9311	(1,760)
3		3,966	14,546			8,360	5,830	(2,530)	0.8984	(2,273)
4		3,232	11,314			8,611	5,602	(3,009)	0.8669	(2,608)
5		3,232	8,082			8,869	5,724	(3,145)	0.8365	(2,631)
6		3,232	4,849			9,135	5,850	(3,285)	0.8071	(2,652)
7		3,232	1,617			9,409	5,979	(3,430)	0.7788	(2,671)
8		1,617	0			9,691	5,349	(4,342)	0.7515	(3,263)
9			0			9,982			0.7251	
10			0	5,600	5,600	10,282			0.6997	
Total	\$26,384	\$26,384		\$5,600	\$5,600	\$90,335	\$45,624	(\$50,832)		(\$46,959)

Table 4.6 Yearly Cash Flow Results for the 2510H

(1) Year	(2) Payment	(3) Tax depreciation	(4) Book value	(5) Salvage value	(6) Depreciation recapture	(7) Variable and fixed costs	(8) Tax reduction	(9) After-tax cash flow	(10) Present value (PV) factor	(11) PV of after-tax cash flow
0	\$34,487	\$0	\$34,487				\$0	(\$34,487)	1.0000	(\$34,487)
1		3,694	30,793			5,740	4,462	(1,278)	0.9649	(1,233)
2		6,597	24,196			5,912	5,917	5	0.9311	4
3		5,183	19,013			6,090	5,332	(757)	0.8984	(681)
4		4,225	14,788			6,272	4,965	(1,307)	0.8669	(1,133)
5		4,225	10,563			6,460	5,054	(1,406)	0.8365	(1,176)
6		4,225	6,339			6,654	5,146	(1,509)	0.8071	(1,218)
7		4,225	2,114			6,854	5,240	(1,614)	0.7788	(1,257)
8		2,114	(0)			7,059	4,339	(2,720)	0.7515	(2,044)
9			(0)			7,271			0.7251	
10			(0)	9,200	9,200	7,489			0.6997	
Total	\$34,487	\$34,487		\$9,200	\$9,200	\$65,803	\$40,455	(\$45,074)		(\$43,224)

Table 4.7 NPV Results

	Total Cash Outlay	Total Tax Reduction	After-Tax P.V.	Annualized cost		
				total	per acre	per hectare
2510C	\$ 26,384.40	\$ 45,623.69	\$ 46,959.40	\$ (5,685.32)	\$ 5.69	\$ 14.04
2510H	\$ 34,486.80	\$ 40,455.13	\$ 43,224.05	\$ (5,233.09)	\$ 5.23	\$ 12.93
Diff (H - C)	\$ 8,102.40	\$ (5,168.57)	\$ (3,735.35)	\$ 452.23	\$ (0.45)	\$ (1.12)

Partial Budget Results

When considering a partial budget in this study, there are three variables that must be looked at; price of N per acre, application cost and return per acre from grain. The assumption is made that the yield differences from the field research in this study is real, the previous NPV analysis is accurate and there is a 30% spread in fertilizer source price.

Preplant AA vs. Topdress Urea

Table 4.8 shows a partial budget for applying N as preplant AA and applying N as topdressed urea. The bottom line reveals that preplant AA will return \$8.47 per hectare (\$3.45 per acre) more than topdressed urea.

Table 4.8 Partial Budget Preplant AA vs. Topdressed Urea (current prices)

Preplant AA With 2510H						Topdress with Urea					
Cost						Cost					
N Price		N Applied		Total		N Price		N Applied		Total	
(\$ kg ⁻¹)	(\$ lb ⁻¹)	(kg ha ⁻¹)	(lb ac ⁻¹)	(\$ ha ⁻¹)	(\$ ac ⁻¹)	(\$ kg ⁻¹)	(\$ lb ⁻¹)	(kg ha ⁻¹)	(lb ac ⁻¹)	(\$ ha ⁻¹)	(\$ ac ⁻¹)
\$ 1.10	\$ 0.50	67	60	\$ 73.92	\$ 30.00	\$ 1.43	\$ 0.65	67	60	\$ 96.10	\$ 39.00
Application Cost				\$ 26.35	\$ 10.67	Application Cost				\$ 12.65	\$ 5.12
Returns						Returns					
Yield		Grain Price				Yield		Grain Price			
(kg ha ⁻¹)	(bu ac ⁻¹)	(\$ kg ⁻¹)	(\$ bu ⁻¹)			(kg ha ⁻¹)	(bu ac ⁻¹)	(\$ kg ⁻¹)	(\$ bu ⁻¹)		
3695	55	\$ 0.25	\$ 6.80	\$ 921.40	\$ 374.00	3695	55	\$ 0.25	\$ 6.80	\$ 921.40	\$ 374.00
Return after Fertilizer cost				\$ 821.12	\$ 333.33	Return after Fertilizer cost				\$ 812.66	\$ 329.88

Table 4.9 creates a scenario where the price of N increases by 50% while keeping the same 30% spread between cost of AA and urea. This scenario results in the AA system being at a \$19.56 per hectare (\$7.95 per acre) advantage over the traditional urea system. This means that returns are increasing at a greater rate than fertilizer price. This leverage in fertilizer price means that as N price rises, the differential between the two systems will get larger at an even greater rate.

Table 4.9 Partial Budget Preplant AA vs. Topdressed Urea (higher N prices)

Preplant AA With 2510H						Topdressing with Urea					
Cost						Cost					
	N Price		N Applied		Total		N Price		N Applied		Total
	(\$ kg ⁻¹)	(\$ lb ⁻¹)	(kg ha ⁻¹)	(lb ac ⁻¹)	(\$ ha ⁻¹) (\$ ac ⁻¹)		(\$ kg ⁻¹)	(\$ lb ⁻¹)	(kg ha ⁻¹)	(lb ac ⁻¹)	(\$ ha ⁻¹) (\$ ac ⁻¹)
	\$ 1.65	\$ 0.75	67	60	\$ 110.88 \$ 45.00		\$ 2.15	\$ 0.98	67	60	\$ 144.14 \$ 58.50
Application Cost					\$ 26.35 \$ 10.67	Application Cost					\$ 12.65 \$ 5.12
Returns						Returns					
	Yield		Grain Price				Yield		Grain Price		
	(kg ha ⁻¹)	(bu ac ⁻¹)	(\$ kg ⁻¹)	(\$ bu ⁻¹)			(kg ha ⁻¹)	(bu ac ⁻¹)	(\$ kg ⁻¹)	(\$ bu ⁻¹)	
	3695	55	\$ 0.25	\$ 6.80	\$ 921.40 \$ 374.00		3695	55	\$ 0.25	\$ 6.80	\$ 921.40 \$ 374.00
Return after Fertilizer cost					\$ 784.16 \$ 318.33	Return after Fertilizer cost					\$ 764.61 \$ 310.38

As can be seen from the partial budgets in Tables 4.8 and 4.9, preplant AA has an economic advantage over traditional applications of topdress urea. This is under the assumption that both N management strategies result in the same grain yield. Based on previous research, this will probably not be true in all years. In the high N price scenario (Table 4.9), there is only enough of an advantage to the AA method to cover approximately one bushel per acre of yield loss. When this is taken into consideration, the differential is small enough that the deciding factor between these two strategies would come down to the producer's preference, which could include a host of concerns that have not been accounted for in this analysis (e.g., logistics, safety, timing of application).

Topdress AA vs. Topdressed Urea

Field research from this study found a two bushel reduction in grain yield when topdressing with AA versus urea. Although that yield difference was not statically significant, we assume it is real in these partial budgets. Table 4.10 shows that this 130 kg ha⁻¹ (two bushel) reduction in yield puts topdressed AA at an economic disadvantage at current prices. Topdress urea returned \$25.04 more per hectare (\$10.15 per acre) while paying 30% more for the fertilizer.

The next step in analyzing these practices is to do a breakeven analysis to see what fertilizer or grain price might result in AA and urea having similar returns.

Table 4.10 Partial Budget Topdress AA vs. Topdressed Urea (current prices)

Topdress AA With 2510H						Topdressing with Urea					
Cost						Cost					
N Price		N Applied		Total		N Price		N Applied		Total	
(\$ kg ⁻¹)	(\$ lb ⁻¹)	(kg ha ⁻¹)	(lb ac ⁻¹)	(\$ ha ⁻¹)	(\$ ac ⁻¹)	(\$ kg ⁻¹)	(\$ lb ⁻¹)	(kg ha ⁻¹)	(lb ac ⁻¹)	(\$ ha ⁻¹)	(\$ ac ⁻¹)
\$ 1.10	\$ 0.50	67	60	\$ 73.92	\$ 30.00	\$ 1.43	\$ 0.65	67	60	\$ 96.10	\$ 39.00
Application Cost				\$ 26.35	\$ 10.67	Application Cost				\$ 12.65	\$ 5.12
Returns						Returns					
Yield		Grain Price				Yield		Grain Price			
(kg ha ⁻¹)	(bu ac ⁻¹)	(\$ kg ⁻¹)	(\$ bu ⁻¹)			(kg ha ⁻¹)	(bu ac ⁻¹)	(\$ kg ⁻¹)	(\$ bu ⁻¹)		
3695	55	\$ 0.25	\$ 6.80	\$ 921.40	\$ 374.00	3830	57	\$ 0.25	\$ 6.80	\$ 954.90	\$ 387.60
Return after Fertilizer cost				\$ 821.12	\$ 333.33	Return after Fertilizer cost				\$ 846.16	\$ 343.48

Table 4.11 shows that fertilizer prices would have to go up by 100% from values used in the initial analysis to make the AA topdress method return the same as traditional urea when assuming a 30% price spread between the two sources, holding all else constant. Although there may be a potential for N prices to increase to this point, it is unlikely that grain prices would not rise in a similar way making this partial budget somewhat unrealistic.

Table 4.11 Partial Budget Topdress AA vs. Topdressed Urea (breakeven N price)

Topdress AA With 2510H						Topdressing with Urea					
Cost						Cost					
N Price		N Applied		Total		N Price		N Applied		Total	
(\$ kg ⁻¹)	(\$ lb ⁻¹)	(kg ha ⁻¹)	(lb ac ⁻¹)	(\$ ha ⁻¹)	(\$ ac ⁻¹)	(\$ kg ⁻¹)	(\$ lb ⁻¹)	(kg ha ⁻¹)	(lb ac ⁻¹)	(\$ ha ⁻¹)	(\$ ac ⁻¹)
\$ 2.33	\$ 1.06	67	60	\$ 156.71	\$ 63.60	\$ 3.03	\$ 1.38	67	60	\$ 203.72	\$ 82.68
Application Cost				\$ 26.35	\$ 10.67	Application Cost				\$ 12.65	\$ 5.12
Returns						Returns					
Yield		Grain Price				Yield		Grain Price			
(kg ha ⁻¹)	(bu ac ⁻¹)	(\$ kg ⁻¹)	(\$ bu ⁻¹)			(kg ha ⁻¹)	(bu ac ⁻¹)	(\$ kg ⁻¹)	(\$ bu ⁻¹)		
3695	55	\$ 0.25	\$ 6.80	\$ 921.40	\$ 374.00	3830	57	\$ 0.25	\$ 6.80	\$ 954.90	\$ 387.60
Return after Fertilizer cost				\$ 738.33	\$ 299.73	Return after Fertilizer cost				\$ 738.53	\$ 299.80

Breakeven analysis of grain prices that would result in equal returns from both methods yielded unrealistic results. It indicated that the breakeven grain price is around \$2 per bushel. It is highly unlikely that grain prices will get low enough to make up for the yield reduction associated with topdressing with AA.

If it is assumed that application costs are equal for both methods (i.e., urea topdressed and AA topdressed), traditional urea shows an advantage of \$5.68. However, assuming equal application cost is not likely accurate.

Information in the above partial budgets lead to the conclusion that the yield reduction associated with topdressing with AA is great enough that unrealistic prices for N, application cost, and grain price would have to occur to experience a breakeven situation between the two methods.

Table 4.12 shows that the breakeven yield difference is just over a half a bushel. This means if the yield reduction due to topdressing with AA can be improved, the two methods would be virtually equal from an economic standpoint. With more data and adjustments to topdressing with AA, this may be realistic. Nonetheless, there will always be more risk associated with topdressing with AA than the traditional urea method. When considering that, some yield disadvantage would likely be appropriate to account for the greater variability and risk associated with the AA method.

Table 4.12 Partial Budget Topdress AA vs. Topdressed Urea (breakeven yield)

Topdress AA With 2510H						Topdressing with Urea					
Cost						Cost					
N Price		N Applied		Total		N Price		N Applied		Total	
(\$ kg ⁻¹)	(\$ lb ⁻¹)	(kg ha ⁻¹)	(lb ac ⁻¹)	(\$ ha ⁻¹)	(\$ ac ⁻¹)	(\$ kg ⁻¹)	(\$ lb ⁻¹)	(kg ha ⁻¹)	(lb ac ⁻¹)	(\$ ha ⁻¹)	(\$ ac ⁻¹)
\$ 1.10	\$ 0.50	67	60	\$ 73.92	\$ 30.00	\$ 1.43	\$ 0.65	67	60	\$ 96.10	\$ 39.00
Application Cost				\$ 26.35	\$ 10.67	Application Cost				\$ 12.65	\$ 5.12
Returns						Returns					
Yield		Grain Price				Yield		Grain Price			
(kg ha ⁻¹)	(bu ac ⁻¹)	(\$ kg ⁻¹)	(\$ bu ⁻¹)			(kg ha ⁻¹)	(bu ac ⁻¹)	(\$ kg ⁻¹)	(\$ bu ⁻¹)		
3796	56.5	\$ 0.25	\$ 6.80	\$ 946.53	\$ 384.20	3830	57	\$ 0.25	\$ 6.80	\$ 954.90	\$ 387.60
Return after Fertilizer cost				\$ 846.25	\$ 343.53	Return after Fertilizer cost				\$ 846.16	\$ 343.48

A host of partial budgets with various combinations could be made that might make the AA method appear more feasible. Nonetheless, those combinations would likely depict special market circumstances and would not necessarily depict long-term feasibility of this practice. In general, the relationship between N, grain, and application prices are correlated and move at

similar rates. Although exceptions can be found that would differ from the partial budgets in this study, it is believed that the analysis done here reflects a realistic picture of the economic feasibility of topdressing with AA versus traditional methods to topdressing.

Conclusions

Results from partial NPV analysis of the 2510H revealed that it is about \$0.45 per acre lower cost to operate than a conventional applicator of similar size and type. Although the 2510H has a substantially higher initial cost, its increased productivity and lower horsepower requirements make it lower cost to operate in the long term.

Partial budget analysis of applying preplant ammonia opposed to topdressing with urea showed the AA preplant method to have an economic advantage over the urea topdress method. This is due primarily to the lower price per pound of N as AA compared to urea. Nonetheless, this difference was small and may not hold true in all years, especially during growing seasons when N loss is high over the winter months and yield is reduced as a result. The reverse could also be true, that N loss due to ammonia volatilization or immobilization could result in increased yields with preplant ammonia, especially in areas such as Western Kansas where over-winter N loss is low.

Topdressing with AA is at an economic disadvantage when compared to traditional topdressing methods using urea. Partial budgets reveal that an assumed yield loss of two bushel per acre when topdressing with AA is too large of an income loss to overcome the associated decreased input cost. Although combinations of N, application and grain prices can show an advantage to AA, these assumptions are not likely to occur over the long term.

Many of the values used in the analysis are assumptions or interpretations that are subject to interpretation and change. Nonetheless, although the actual values may not be perfect, the relationships are relative. Values and assumptions used in this analysis should not be viewed as fact, but as a basis for relative evaluation.

Through evaluation of the agronomic and economic factors affecting the feasibility of uses of AA and the 2510H, three main conclusions can be made:

1. Preplant application of AA has no agronomic advantage and only a small economic advantage over topdressing with urea when yields are the same.
2. Topdressing with AA is agronomically feasible but is at an economic

disadvantage when compared to topdressing with urea, due to the yield reduction associated with the AA method.

3. Further research focused on reducing yield loss with topdress AA applications is needed before this N management strategy can be promoted on a large scale.

References

- Dhuyvetter , Kevin C. (2011). Historical Custom Rates in Kansas and Projections for 2011. Kansas State University. Publication: *AM-KCD-2011.1*
- Roth, Sarah., & Jeffery Hyde. (2002). Partial Budgeting for Agricultural Businesses. Penn State Cooperative Extension. CAT UA366.
- Internal Revenue Service. (2011). Farmer's Tax Guide. United States Department of Treasury. Publication 225, pg 42-45.

Appendix A - Preplant Plot Data 2010-2011

Table A.1 Manhattan Preplant 2010

Plot	Treatment	N Source	Timing	Spacing	Inhibitor	Rate	Flag Leaf N	Grain Moisture	Test Weight	Grain Yield	Grain Protein
				(cm)		(kg ha ⁻¹)	(%)	(%)		(kg ha ⁻¹)	(%)
108	1	na	0	0	0	0	2.04	11.3	54.6	1619	11.4
203	1	na	0	0	0	0	1.88	11.2	54.9	1275	11.0
303	1	na	0	0	0	0	1.95	11.2	54.5	1324	11.3
406	1	na	0	0	0	0	2.08	11.3	54.5	1137	11.0
103	2	Urea	Topdress	0	0	67.2	2.11	11.3	55.4	2683	9.8
209	2	Urea	Topdress	0	0	67.2	2.20	11.6	53.9	2378	10.4
307	2	Urea	Topdress	0	0	67.2	2.15	11.7	55.3	2178	10.3
401	2	Urea	Topdress	0	0	67.2	2.19	11.5	55.9	2492	10.9
109	3	AA	Preplant	38	0	67.2	2.38	11.6	54.4	2292	9.8
205	3	AA	Preplant	38	0	67.2	2.07	11.2	53.0	2500	10.8
304	3	AA	Preplant	38	0	67.2	1.96	11.4	54.4	2321	9.2
405	3	AA	Preplant	38	0	67.2	2.04	11.7	54.6	2043	10.2
101	4	AA	Preplant	50	0	67.2	2.65	11.1	55.2	2850	10.1
204	4	AA	Preplant	50	0	67.2	2.23	11.4	52.8	2482	10.4
308	4	AA	Preplant	50	0	67.2	2.30	11.9	54.8	2664	10.8
407	4	AA	Preplant	50	0	67.2	2.32	11.4	54.0	2519	10.8
107	5	AA	Preplant	76	0	67.2	2.75	11.7	55.4	2375	10.2
207	5	AA	Preplant	76	0	67.2	2.25	11.3	53.7	2299	8.9
309	5	AA	Preplant	76	0	67.2	2.11	11.8	54.8	2360	10.0
404	5	AA	Preplant	76	0	67.2	2.15	11.4	53.9	2247	10.3
102	6	Urea	Topdress	0	0	100.8	2.72	11	55.1	3337	9.4
201	6	Urea	Topdress	0	0	100.8	2.28	11.1	56.1	2986	12.6

301	6	Urea	Topdress	0	0	100.8	2.24	11.1	55.6	2862	10.5
402	6	Urea	Topdress	0	0	100.8	2.19	11.2	55.4	2587	10.1
105	7	AA	Preplant	38	0	100.8	2.48	11.4	54.5	2902	9.8
202	7	AA	Preplant	38	0	100.8	2.39	11.2	55.5	2710	10.0
302	7	AA	Preplant	38	0	100.8	2.37	11.4	55.1	2927	10.7
408	7	AA	Preplant	38	0	100.8	2.36	11.4	54.7	2605	9.7
106	8	AA	Preplant	50	0	100.8	2.60	11.4	55.9	2741	10.6
206	8	AA	Preplant	50	0	100.8	2.43	11.4	54.4	2717	10.1
305	8	AA	Preplant	50	0	100.8	2.22	11.4	53.7	2791	11.2
403	8	AA	Preplant	50	0	100.8	2.51	11.4	55.0	2964	10.6
104	9	AA	Preplant	76	0	100.8	2.67	11.5	55.7	2788	10.1
208	9	AA	Preplant	76	0	100.8	2.27	11.7	54.8	2449	10.3
306	9	AA	Preplant	76	0	100.8	2.20	11.4	54.1	2630	11.9
409	9	AA	Preplant	76	0	100.8	2.62	11.6	54.9	2945	10.9

Table A.2 Manhattan Preplant 2011

Plot	Treatment	N Source	Timing	Spacing (cm)	Inhibitor	Rate (kg ha ⁻¹)	Flag Leaf N (%)	Grain Moisture (%)	Test Weight	Grain Yield (kg ha ⁻¹)	Grain Protein (%)
112	1	na	na	na	na	0	2.3	11.5	63.3	3394	10.6
208	1	na	na	na	na	0	2.1	13.9	57.7	2880	10.2
303	1	na	na	na	na	0	2.3	11.9	63.2	2574	10.4
413	1	na	na	na	na	0	1.9	11.0	59.2	2470	10.5
110	2	Urea	Topdress	na	na	34	2.4	12.2	60.9	4014	10.3
202	2	Urea	Topdress	na	na	34	2.3	12.6	60.2	3489	10.0
312	2	Urea	Topdress	na	na	34	2.5	13.8	57.0	2768	10.9
421	2	Urea	Topdress	na	na	34	2.0	12.6	57.2	2358	9.6
115	3	Urea	Topdress	na	na	67	2.4	12.6	59.3	3920	10.2
214	3	Urea	Topdress	na	na	67	2.5	13.4	55.8	4326	11.8
308	3	Urea	Topdress	na	na	67	2.4	12.9	58.8	3923	10.6
411	3	Urea	Topdress	na	na	67	2.3	11.0	58.5	3925	11.4
111	4	Urea	Topdress	na	na	101	2.4	14.9	57.0	4744	11.9
204	4	Urea	Topdress	na	na	101	2.6	13.4	59.0	4326	11.5
315	4	Urea	Topdress	na	na	101	2.4	13.4	58.8	4364	11.1
404	4	Urea	Topdress	na	na	101	2.6	15.0	56.5	4644	12.1
117	5	Urea	Topdress	na	na	134	2.7	15.1	55.8	4123	11.9
203	5	Urea	Topdress	na	na	134	2.6	11.8	63.6	4091	12.9
313	5	Urea	Topdress	na	na	134	2.7	16.5	59.2	4227	12.3
402	5	Urea	Topdress	na	na	134	2.9	14.9	56.9	4744	12.7
504	6	AA	Preplant	50	no	34	2.7	11.8	47.1	3846	12.6
507	6	AA	Preplant	50	no	34	2.8	19.0	52.1	3793	13.0
512	6	AA	Preplant	50	no	34	2.5	14.6	54.2	4171	11.7

515	6	AA	Preplant	50	no	34	3.0	16.7	50.6	4440	12.6
502	7	AA	Preplant	50	no	67	2.1	11.3	53.4	3582	9.7
508	7	AA	Preplant	50	no	67	2.1	12.2	54.6	3779	11.1
509	7	AA	Preplant	50	no	67	2.1	12.0	56.7	3650	10.4
513	7	AA	Preplant	50	no	67	2.2	12.3	57.6	4126	10.7
503	8	AA	Preplant	50	no	101	2.3	11.9	57.3	3558	10.6
505	8	AA	Preplant	50	no	101	2.6	13.2	56.4	4065	11.1
511	8	AA	Preplant	50	no	101	2.4	13.6	56.2	4200	11.2
514	8	AA	Preplant	50	no	101	2.9	14.0	55.7	4238	12.0
501	9	AA	Preplant	50	no	134	1.9	11.7	55.5	2757	10.4
506	9	AA	Preplant	50	no	134	2.2	11.9	57.7	3399	10.0
510	9	AA	Preplant	50	no	134	2.1	12.2	58.4	3133	9.9
516	9	AA	Preplant	50	no	134	1.9	12.1	56.3	3058	9.6
105	14	AA	Preplant	76	no	34	2.3	12.8	59.7	3539	10.3
219	14	AA	Preplant	76	no	34	1.9	12.2	58.6	3211	10.2
314	14	AA	Preplant	76	no	34	2.2	12.1	61.2	3058	10.8
409	14	AA	Preplant	76	no	34	2.0	11.5	59.9	3079	10.8
120	15	AA	Preplant	76	no	67	2.5	13.2	53.3	4000	12.1
207	15	AA	Preplant	76	no	67	2.8	12.0	61.1	4396	10.4
307	15	AA	Preplant	76	no	67	2.6	11.4	63.6	4228	10.5
418	15	AA	Preplant	76	no	67	2.3	12.9	56.4	3088	9.9
116	16	AA	Preplant	76	no	101	2.8	12.9	55.9	3453	11.5
211	16	AA	Preplant	76	no	101	2.8	13.4	57.9	4635	11.8
318	16	AA	Preplant	76	no	101	3.0	13.5	55.6	4263	12.3
403	16	AA	Preplant	76	no	101	3.0	14.5	54.2	4519	12.6
101	17	AA	Preplant	76	no	134	3.2	13.1	59.0	4612	12.5
217	17	AA	Preplant	76	no	134	2.5	17.2	51.5	3508	13.0
305	17	AA	Preplant	76	no	134	3.2	17.9	54.3	4650	13.2
410	17	AA	Preplant	76	no	134	2.6	16.9	56.6	3336	14.1

108	18	AA	Preplant	76	yes	34	2.4	12.5	57.2	3824	10.3
218	18	AA	Preplant	76	yes	34	2.1	12.2	58.2	2859	10.4
321	18	AA	Preplant	76	yes	34	2.0	12.8	56.6	2722	10.0
405	18	AA	Preplant	76	yes	34	2.3	13.6	56.7	3641	9.9
121	19	AA	Preplant	76	yes	67	2.3	12.2	55.9	3307	10.4
206	19	AA	Preplant	76	yes	67	2.8	11.8	62.3	4465	12.3
310	19	AA	Preplant	76	yes	67	2.8	12.6	60.2	4249	12.0
416	19	AA	Preplant	76	yes	67	2.3	11.7	56.2	3522	11.1
107	20	AA	Preplant	76	yes	101	3.2	12.8	59.5	4570	11.6
216	20	AA	Preplant	76	yes	101	2.6	12.7	56.9	4049	11.2
309	20	AA	Preplant	76	yes	101	3.1	12.9	59.2	4778	11.3
320	20	AA	Preplant	76	yes	101	2.9	13.3	54.0	4060	12.9
114	21	AA	Preplant	76	yes	134	2.7	18.0	56.5	4059	13.0
221	21	AA	Preplant	76	yes	134	2.7	15.0	53.0	3829	13.3
316	21	AA	Preplant	76	yes	134	2.9	12.1	57.5	4332	13.2
406	21	AA	Preplant	76	yes	134	2.8	14.4	55.8	4268	9.4

Table A.3 Rossville Preplant 2011

Plot	Treatment	N Source	Timing	Spacing (cm)	Inhibitor	Rate (kg ha ⁻¹)	Flag Leaf N (%)	Grain Moisture (%)	Test Weight	Grain Yield (kg ha ⁻¹)	Grain Protein (%)
112	1	na	na	na	na	0	2.6	10.6	63.1	3318	11.4
208	1	na	na	na	na	0	3.7	10.7	63.8	3533	13.4
303	1	na	na	na	na	0	3.3	10.8	63.3	3217	13.0
413	1	na	na	na	na	0	3.1	10.5	62.0	3315	13.8
110	2	Urea	Topdress	na	na	34	3.0	10.6	62.7	4069	13.6
202	2	Urea	Topdress	na	na	34	3.0	10.7	63.0	4261	13.9
312	2	Urea	Topdress	na	na	34	3.7	10.5	63.8	4030	11.3
421	2	Urea	Topdress	na	na	34	3.4	10.3	64.3	4108	12.0
115	3	Urea	Topdress	na	na	67	3.5	10.4	62.8	4896	13.6
214	3	Urea	Topdress	na	na	67	3.6	10.5	63.7	5007	12.6
308	3	Urea	Topdress	na	na	67	3.9	10.5	63.7	4009	13.2
411	3	Urea	Topdress	na	na	67	3.8	10.4	63.1	4998	13.9
111	4	Urea	Topdress	na	na	101	3.6	10.5	62.6	4325	12.4
204	4	Urea	Topdress	na	na	101	3.3	10.5	62.7	5056	12.3
315	4	Urea	Topdress	na	na	101	4.0	10.4	63.7	4590	13.8
404	4	Urea	Topdress	na	na	101	3.9	10.6	63.4	4907	13.6
117	5	Urea	Topdress	na	na	134	3.6	10.5	63.7	5119	12.5
203	5	Urea	Topdress	na	na	134	3.6	10.7	62.2	5168	10.9
313	5	Urea	Topdress	na	na	134	4.0	10.3	63.2	5032	12.8
402	5	Urea	Topdress	na	na	134	4.0	10.5	62.8	4857	13.5
109	6	AA	Preplant	50	no	34	2.8	10.7	62.7	4078	12.1
220	6	AA	Preplant	50	no	34	3.3	10.4	63.5	3920	12.1
301	6	AA	Preplant	50	no	34	4.0	10.6	63.2	4120	12.0

419	6	AA	Preplant	50	no	34	3.2	10.3	63.2	4071	13.0
102	7	AA	Preplant	50	no	67	3.3	10.7	63.0	4436	13.0
210	7	AA	Preplant	50	no	67	3.8	10.8	63.4	4560	13.3
306	7	AA	Preplant	50	no	67	4.1	10.6	63.5	4933	13.6
414	7	AA	Preplant	50	no	67	3.8	10.6	63.4	4754	12.8
106	8	AA	Preplant	50	no	101	4.2	10.5	61.9	4317	13.1
209	8	AA	Preplant	50	no	101	3.8	10.5	62.4	4839	11.3
320	8	AA	Preplant	50	no	101	4.2	10.5	63.0	5402	12.3
417	8	AA	Preplant	50	no	101	4.1	10.3	63.0	5415	12.9
118	9	AA	Preplant	50	no	134	4.0	10.4	63.9	5305	12.4
213	9	AA	Preplant	50	no	134	4.6	10.6	62.7	5206	13.0
317	9	AA	Preplant	50	no	134	3.9	10.3	62.9	5116	13.6
407	9	AA	Preplant	50	no	134	4.3	10.5	63.3	4887	13.1
104	10	AA	Preplant	50	yes	34	2.8	10.6	61.8	3990	12.7
212	10	AA	Preplant	50	yes	34	3.8	10.7	63.9	4083	11.6
304	10	AA	Preplant	50	yes	34	3.6	10.7	63.8	4220	12.9
412	10	AA	Preplant	50	yes	34	3.4	10.4	63.2	4353	12.8
103	11	AA	Preplant	50	yes	67	3.2	10.8	62.8	4636	13.1
201	11	AA	Preplant	50	yes	67	3.5	10.6	62.0	4852	13.0
311	11	AA	Preplant	50	yes	67	4.3	10.5	63.5	4414	13.4
408	11	AA	Preplant	50	yes	67	3.9	10.5	63.5	4218	14.7
113	12	AA	Preplant	50	yes	101	3.5	10.6	62.6	4691	11.8
215	12	AA	Preplant	50	yes	101	3.9	10.4	63.0	5091	12.4
302	12	AA	Preplant	50	yes	101	4.1	10.6	62.9	4937	14.5
415	12	AA	Preplant	50	yes	101	4.2	10.5	63.5	5613	14.4
119	13	AA	Preplant	50	yes	134	3.8	10.3	62.9	5021	13.8
205	13	AA	Preplant	50	yes	134	3.8	10.5	61.9	4968	10.6
319	13	AA	Preplant	50	yes	134	4.1	10.2	62.4	5340	12.3
401	13	AA	Preplant	50	yes	134	3.9	10.9	62.7	4754	11.9

105	14	AA	Preplant	67	no	34	2.7	10.7	62.9	3915	11.5
219	14	AA	Preplant	76	no	34	3.2	10.4	63.2	3378	13.2
314	14	AA	Preplant	76	no	34	3.6	10.6	64.1	3934	12.0
409	14	AA	Preplant	76	no	34	3.7	10.4	64.1	4053	14.1
120	15	AA	Preplant	76	no	67	3.1	10.4	63.6	4135	12.8
207	15	AA	Preplant	76	no	67	3.8	10.5	62.5	4495	13.4
307	15	AA	Preplant	76	no	67	3.8	10.6	63.4	4192	12.5
418	15	AA	Preplant	76	no	67	3.6	10.4	63.8	4733	12.6
116	16	AA	Preplant	76	no	101	3.5	10.4	62.2	4877	13.7
211	16	AA	Preplant	76	no	101	4.3	10.4	62.1	4908	12.9
318	16	AA	Preplant	76	no	101	3.8	10.3	63.0	5151	11.4
403	16	AA	Preplant	76	no	101	3.9	10.6	63.2	4955	12.0
101	17	AA	Preplant	76	no	134	3.9	10.7	61.1	5270	15.3
217	17	AA	Preplant	76	no	134	4.0	10.4	63.2	4812	12.6
305	17	AA	Preplant	76	no	134	4.1	10.4	62.8	5230	12.6
410	17	AA	Preplant	76	no	134	4.3	10.3	63.0	5319	13.4
108	18	AA	Preplant	76	yes	34	3.3	11.0	63.0	3864	13.2
218	18	AA	Preplant	76	yes	34	3.1	10.5	64.0	3985	12.3
321	18	AA	Preplant	76	yes	34	3.5	10.4	62.7	3843	13.3
405	18	AA	Preplant	76	yes	34	3.9	10.7	63.7	4177	14.2
121	19	AA	Preplant	76	yes	67	3.2	10.5	62.9	3719	11.5
206	19	AA	Preplant	76	yes	67	3.6	10.5	63.1	4787	12.8
310	19	AA	Preplant	76	yes	67	4.0	10.6	63.8	4098	14.0
416	19	AA	Preplant	76	yes	67	3.4	10.6	64.1	4795	12.0
107	20	AA	Preplant	76	yes	101	4.0	10.5	62.2	4574	13.8
216	20	AA	Preplant	76	yes	101	4.0	10.3	63.2	4822	14.1
309	20	AA	Preplant	76	yes	101	4.4	10.4	62.9	4372	12.8
420	20	AA	Preplant	76	yes	101	4.1	10.2	62.8	5083	12.3
114	21	AA	Preplant	76	yes	134	3.7	10.4	61.6	4902	12.1

221	21	AA	Preplant	76	yes	134	4.1	10.2	62.2	4575	11.7
316	21	AA	Preplant	76	yes	134	4.2	10.3	63.3	4987	12.1
406	21	AA	Preplant	76	yes	134	4.0	10.3	62.9	4902	13.2

Appendix B - Topdress Plot Data 2010-2011

Table B.1 Manhattan Topdress 2010

Plot	Treatment	N Source	Direction	Speed	Rate	Flag Leaf N	Grain Moisture	Test Weight	Grain Yield	Grain Protein
				(cm)	(kg ha ⁻¹)	(%)	(%)		(kg ha ⁻¹)	(%)
108	1	na	na	na	0	2.2	11.2	56.7	2339	11.97
205	1	na	na	na	0	2.4	11.5	56.4	1924	11.6
301	1	na	na	na	0	2.3	11.1	55.9	1772	11.7
402	1	na	na	na	0	2.4	11.4	56.8	2099	12.2
107	2	Urea	na	na	67.2	2.3	11.1	56.0	3321	10.7
204	2	Urea	na	na	67.2	2.8	11.3	57.2	3239	12.4
302	2	Urea	na	na	67.2	2.6	11.4	57.0	3099	11.4
401	2	Urea	na	na	67.2	2.2	11.6	56.9	3647	11.5
101	3	AA	angled	6.4	67.2	2.8	11.2	55.8	2562	10.4
202	3	AA	angled	6.4	67.2	2.6	11.4	56.8	3371	11.6
304	3	AA	angled	6.4	67.2	3.2	11.6	56.3	3068	11.7
407	3	AA	angled	6.4	67.2	2.8	11.6	57.1	3376	11.6
105	4	AA	with	6.4	67.2	2.7	11.5	57.0	2985	11.7
207	4	AA	with	6.4	67.2	2.4	11.4	56.5	3050	11.6
308	4	AA	with	6.4	67.2	2.7	11.3	57.0	3375	11.7
404	4	AA	with	6.4	67.2	2.7	11.5	56.7	3244	12.2
102	5	AA	angled	9.7	67.2	3.0	11.3	57.0	3016	12.6
203	5	AA	angled	9.7	67.2	2.9	11.6	56.9	3388	12.3
305	5	AA	angled	9.7	67.2	3.2	11.9	57.4	3008	12.3
406	5	AA	angled	9.7	67.2	2.8	11.7	57.6	3630	12.2
106	6	AA	with	9.7	67.2	2.9	11.4	57.2	2865	11.5
208	6	AA	with	9.7	67.2	2.7	11.6	57.3	3068	11.1
306	6	AA	with	9.7	67.2	2.8	11.4	57.2	3445	12.2

403	6	AA	with	9.7	67.2	2.9	11.8	56.6	3331	10.4
103	7	AA	angled	12.9	67.2	2.7	11.1	54.8	2689	12.2
201	7	AA	angled	12.9	67.2	2.7	11.3	56.9	3214	11.1
303	7	AA	angled	12.9	67.2	3.2	11.9	57.2	2591	12.7
408	7	AA	angled	12.9	67.2	3.0	11.6	57.1	3277	12.7
104	8	AA	with	12.9	67.2	2.8	11.6	56.8	2316	11.8
206	8	AA	with	12.9	67.2	2.6	11.7	57.4	3003	11.3
307	8	AA	with	12.9	67.2	3.2	11.3	56.6	3239	11.8
405	8	AA	with	12.9	67.2	2.7	11.5	56.5	3281	11.3

Table B.2 Manhattan Topdress 2011

Plot	Treatment	N Source	Time	Speed	Rate	Flag Leaf N	Grain Moisture	Test Weight	Grain Yield	Grain Protein
				(cm)	(kg ha ⁻¹)	(%)	(%)		(kg ha ⁻¹)	(%)
112	1	na	na	na	0	2.5	11.9	59.6	3124	10.1
208	1	na	na	na	0	2.3	12.4	59.1	3184	8.2
303	1	na	na	na	0	1.8	12.1	59.7	2509	8.4
413	1	na	na	na	0	2.1	12.0	58.9	3030	9.6
110	2	Urea	Preplant	na	34	2.3	12.0	59.6	4062	10.3
202	2	Urea	Preplant	na	34	2.2	11.9	60.3	3831	9.8
312	2	Urea	Preplant	na	34	2.0	12.1	59.7	3665	9.0
421	2	Urea	Preplant	na	34	2.1	11.7	57.3	3185	10.4
115	3	Urea	Feekes 4	na	67	2.9	12.1	60.6	4351	10.3
214	3	Urea	Feekes 4	na	67	2.4	14.2	57.1	4228	10.8
308	3	Urea	Feekes 4	na	67	2.3	13.1	57.1	4108	10.0
411	3	Urea	Feekes 4	na	67	2.3	12.5	57.4	3874	11.8
111	4	Urea	Feekes 4	na	90	2.6	12.6	59.7	4385	11.6
204	4	Urea	Feekes 4	na	90	2.5	14.6	58.2	4590	10.9
315	4	Urea	Feekes 4	na	90	2.6	14.5	56.7	3889	10.1
404	4	Urea	Feekes 4	na	90	2.5	14.1	55.9	4000	11.8
117	5	Urea	Feekes 4	na	112	2.8	12.5	60.1	4566	12.0
203	5	Urea	Feekes 4	na	112	2.5	14.0	57.0	4142	11.5
313	5	Urea	Feekes 4	na	112	2.3	17.9	53.8	3698	10.8
402	5	Urea	Feekes 4	na	112	2.3	14.0	57.3	3864	10.5
109	6	Urea	Feekes 4	na	134	2.5	15.4	57.5	4056	12.2
220	6	Urea	Feekes 4	na	134	2.7	15.4	54.4	4528	12.3
301	6	Urea	Feekes 4	na	134	2.5	15.2	57.6	4293	10.9

419	6	Urea	Feekes 4	na	134	2.6	15.4	49.1	4356	12.4
102	7	AA	Feekes 4	6.4	67	2.7	12.3	59.4	3480	11.1
210	7	AA	Feekes 4	6.4	67	2.8	15.8	56.7	4131	11.1
306	7	AA	Feekes 4	6.4	67	2.8	15.4	56.5	3641	10.6
414	7	AA	Feekes 4	6.4	67	2.8	18.7	53.0	3653	10.3
106	8	AA	Feekes 4	6.4	90	2.9	15.8	52.9	3812	12.2
209	8	AA	Feekes 4	6.4	90	3.2	19.0	52.2	3775	11.6
320	8	AA	Feekes 4	6.4	90	2.7	18.5	50.0	3071	13.3
417	8	AA	Feekes 4	6.4	90	2.9	19.3	46.0	3864	13.1
118	9	AA	Feekes 4	6.4	112	3.1	13.1	58.1	3973	12.2
213	9	AA	Feekes 4	6.4	112	3.2	20.3	51.3	3448	12.9
317	9	AA	Feekes 4	6.4	112	3.3	19.4	50.6	3595	12.9
407	9	AA	Feekes 4	6.4	112	3.2	18.5	43.6	3341	14.0
104	10	AA	Feekes 4	6.4	134	3.0	17.1	53.1	3512	13.5
212	10	AA	Feekes 4	6.4	134	2.9	17.6	52.4	3712	13.0
304	10	AA	Feekes 4	6.4	134	3.2	17.8	53.8	3703	12.4
412	10	AA	Feekes 4	6.4	134	3.3	19.7	44.2	2844	14.1
103	11	AA	Feekes 4	12.9	67	3.0	12.8	59.9	3928	12.1
201	11	AA	Feekes 4	12.9	67	2.7	16.1	54.5	4172	12.3
322	11	AA	Feekes 4	12.9	67	3.0	15.6	54.9	3595	11.1
408	11	AA	Feekes 4	12.9	67	3.0	17.1	53.1	3670	12.2
113	12	AA	Feekes 4	12.9	90	2.8	15.2	56.1	4141	12.9
215	12	AA	Feekes 4	12.9	90	3.0	18.8	53.5	3802	13.3
302	12	AA	Feekes 4	12.9	90	2.9	19.4	52.3	3900	12.7
415	12	AA	Feekes 4	12.9	90	3.1	21.6	46.7	3137	12.5
119	13	AA	Feekes 4	12.9	112	3.1	12.6	60.2	3956	13.3
205	13	AA	Feekes 4	12.9	112	3.3	21.7	48.5	3317	12.7
319	13	AA	Feekes 4	12.9	112	3.3	17.2	50.3	3656	13.1
401	13	AA	Feekes 4	12.9	112	3.2	18.5	50.3	3207	12.9

122	14	AA	Feekes 4	12.9	134	3.2	11.8	59.3	4170	13.1
219	14	AA	Feekes 4	12.9	134	3.1	18.2	54.0	3466	13.5
314	14	AA	Feekes 4	12.9	134	3.2	22.4	46.0	2630	12.8
409	14	AA	Feekes 4	12.9	134	3.4	17.9	48.6	3015	13.8
120	15	AA	Feekes 4	6.4	67	2.9	12.4	59.9	3848	11.0
207	15	AA	Feekes 4	6.4	67	2.8	12.7	59.0	3971	9.6
307	15	AA	Feekes 4	6.4	67	2.9	13.8	58.3	4017	10.3
418	15	AA	Feekes 4	6.4	67	2.8	14.6	53.4	3641	11.9
116	16	AA	Feekes 7	6.4	90	2.9	13.2	59.5	3910	12.2
211	16	AA	Feekes 7	6.4	90	2.8	15.6	55.7	3708	12.0
318	16	AA	Feekes 7	6.4	90	3.4	13.6	59.1	3718	11.5
403	16	AA	Feekes 7	6.4	90	3.3	16.4	49.0	3920	14.3
101	17	AA	Feekes 7	6.4	112	3.1	12.7	60.3	3407	12.7
217	17	AA	Feekes 7	6.4	112	2.9	14.3	57.0	4090	11.9
305	17	AA	Feekes 7	6.4	112	3.1	20.7	48.3	3395	12.7
410	17	AA	Feekes 7	6.4	112	3.4	14.3	54.6	3653	14.9
108	18	AA	Feekes 7	6.4	134	2.9	14.5	57.4	3985	13.3
222	18	AA	Feekes 7	6.4	134	3.0	12.2	64.3	4405	12.5
321	18	AA	Feekes 7	6.4	134	3.0	15.5	53.9	3561	13.4
405	18	AA	Feekes 7	6.4	134	3.2	14.5	55.1	3953	14.0
121	19	AA	Feekes 7	12.9	67	2.9	12.7	59.6	3621	11.8
206	19	AA	Feekes 7	12.9	67	2.8	14.7	57.5	4014	11.7
310	19	AA	Feekes 7	12.9	67	3.0	14.9	57.4	4118	11.3
416	19	AA	Feekes 7	12.9	67	2.8	14.9	56.7	3656	12.3
107	20	AA	Feekes 7	12.9	90	2.9	13.6	58.5	3988	11.9
216	20	AA	Feekes 7	12.9	90	3.1	17.1	54.8	4012	11.4
309	20	AA	Feekes 7	12.9	90	3.1	14.8	57.4	3952	10.8
420	20	AA	Feekes 7	12.9	90	3.0	14.7	54.4	3692	12.6
114	21	AA	Feekes 7	12.9	112	3.4	13.8	57.0	4094	13.1

221	21	AA	Feekes 7	12.9	112	2.8	16.1	56.9	3798	12.4
316	21	AA	Feekes 7	12.9	112	3.4	14.9	57.6	3757	11.9
422	21	AA	Feekes 7	12.9	112	3.3	13.1	56.4	4018	13.2
105	22	AA	Feekes 7	12.9	134	3.2	13.9	57.3	3917	13.0
218	22	AA	Feekes 7	12.9	134	3.2	16.1	53.7	4022	13.8
311	22	AA	Feekes 7	12.9	134	3.2	15.3	55.6	4099	12.2
406	22	AA	Feekes 7	12.9	134	3.3	13.7	57.6	3679	13.0

Table B.3 Rossville Topdress 2011

Plot	Treatment	N Source	Time	Speed	Rate	Flag Leaf N	Grain Moisture	Test Weight	Grain Yield	Grain Protein
				(cm)	(kg ha ⁻¹)	(%)	(%)		(kg ha ⁻¹)	(%)
113	1	na	na	na	0	2.9	13.0	63.5	3822	11.1
209	1	na	na	na	0	2.6	11.4	61.6	2810	13.7
304	1	na	na	na	0	2.9	12.0	61.7	2785	13.6
414	1	na	na	na	0	2.8	12.9	63.2	2602	13.0
111	2	Urea	Preplant	na	34	3.1	11.2	62.2	4349	12.2
203	2	Urea	Preplant	na	34	3.3	11.6	62.1	3067	11.6
313	2	Urea	Preplant	na	34	2.9	13.4	62.5	2998	12.9
422	2	Urea	Preplant	na	34	3.1	11.1	63.4	3537	13.3
116	3	Urea	Feekes 4	na	67	3.4	10.8	63.2	4297	13.4
215	3	Urea	Feekes 4	na	67	3.0	11.0	63.3	3655	14.3
309	3	Urea	Feekes 4	na	67	3.2	11.3	61.8	4071	11.8
412	3	Urea	Feekes 4	na	67	3.3	13.8	61.6	3876	14.5
112	4	Urea	Feekes 4	na	90	3.4	13.2	61.7	5285	14.5
205	4	Urea	Feekes 4	na	90	3.3	11.2	62.3	5020	13.2
316	4	Urea	Feekes 4	na	90	3.2	11.0	63.2	3965	12.6
405	4	Urea	Feekes 4	na	90	3.2	11.0	61.3	3672	13.7
118	5	Urea	Feekes 4	na	112	3.3	11.0	62.0	4212	13.9
204	5	Urea	Feekes 4	na	112	3.1	11.3	62.8	4868	11.6
314	5	Urea	Feekes 4	na	112	3.3	13.0	63.3	4156	12.3
403	5	Urea	Feekes 4	na	112	3.5	11.2	61.5	4632	12.3
110	6	Urea	Feekes 4	na	134	3.6	11.2	61.4	5387	13.7
221	6	Urea	Feekes 4	na	134	3.6	10.8	62.4	4828	12.5
302	6	Urea	Feekes 4	na	134	3.6	11.3	62.2	4732	14.0

420	6	Urea	Feekes 4	na	134	3.2	10.6	63.1	4629	13.6
103	7	AA	Feekes 4	6.4	67	3.5	11.7	60.6	3736	13.4
211	7	AA	Feekes 4	6.4	67	3.7	11.0	61.7	3501	10.8
307	7	AA	Feekes 4	6.4	67	3.3	11.2	62.3	4279	13.6
415	7	AA	Feekes 4	6.4	67	3.3	11.4	63.1	4257	14.1
107	8	AA	Feekes 4	6.4	90	3.9	11.4	62.0	5097	13.9
210	8	AA	Feekes 4	6.4	90	3.7	11.3	61.5	3903	15.2
321	8	AA	Feekes 4	6.4	90	3.9	10.3	62.4	4367	12.4
418	8	AA	Feekes 4	6.4	90	3.8	10.8	63.2	4502	13.6
119	9	AA	Feekes 4	6.4	112	4.5	10.3	62.2	3916	12.5
214	9	AA	Feekes 4	6.4	112	4.3	12.2	63.1	4022	12.7
318	9	AA	Feekes 4	6.4	112	4.0	10.8	62.7	3851	13.0
408	9	AA	Feekes 4	6.4	112	3.6	11.1	62.0	4293	13.8
105	10	AA	Feekes 4	6.4	134	4.3	11.1	61.6	4937	12.2
213	10	AA	Feekes 4	6.4	134	3.8	12.4	62.1	3702	10.7
305	10	AA	Feekes 4	6.4	134	4.4	11.0	61.9	4063	12.4
413	10	AA	Feekes 4	6.4	134	4.3	12.4	62.8	4278	12.0
104	11	AA	Feekes 4	12.9	67	3.8	11.2	62.2	4403	11.4
202	11	AA	Feekes 4	12.9	67	4.0	11.4	63.0	4068	12.8
301	11	AA	Feekes 4	12.9	67	4.0	12.3	62.0	4243	13.8
409	11	AA	Feekes 4	12.9	67	4.1	11.3	62.6	4211	12.2
114	12	AA	Feekes 4	12.9	90	4.3	12.7	61.5	4203	13.6
216	12	AA	Feekes 4	12.9	90	3.9	10.6	62.7	3861	12.8
303	12	AA	Feekes 4	12.9	90	3.8	11.3	61.8	4298	11.3
416	12	AA	Feekes 4	12.9	90	3.6	11.1	63.2	4361	12.2
120	13	AA	Feekes 4	12.9	112	3.7	10.5	62.0	4283	14.1
206	13	AA	Feekes 4	12.9	112	4.1	11.8	61.9	5024	15.3
320	13	AA	Feekes 4	12.9	112	4.1	10.5	63.3	4369	12.8
402	13	AA	Feekes 4	12.9	112	3.9	11.6	61.8	4490	13.5

101	14	AA	Feekes 4	12.9	134	3.9	11.5	61.2	3978	12.4
220	14	AA	Feekes 4	12.9	134	4.0	11.0	63.1	4261	13.9
315	14	AA	Feekes 4	12.9	134	3.9	10.8	62.2	4040	12.3
410	14	AA	Feekes 4	12.9	134	3.9	11.0	61.9	3835	13.4
121	15	AA	Feekes 4	6.4	67	4.0	12.1	60.1	3234	13.3
208	15	AA	Feekes 4	6.4	67	3.2	13.2	60.0	3695	14.5
308	15	AA	Feekes 4	6.4	67	3.7	13.7	58.0	3447	14.2
419	15	AA	Feekes 4	6.4	67	3.8	12.4	61.4	3786	14.6
117	16	AA	Feekes 7	6.4	90	4.0	12.7	59.6	3445	12.9
212	16	AA	Feekes 7	6.4	90	3.8	16.0	56.5	2976	15.1
319	16	AA	Feekes 7	6.4	90	3.6	13.7	57.6	3301	14.2
404	16	AA	Feekes 7	6.4	90	3.6	13.5	58.6	3065	12.9
102	17	AA	Feekes 7	6.4	112	4.0	13.0	60.9	3452	13.6
218	17	AA	Feekes 7	6.4	112	3.7	12.3	60.1	3606	14.6
306	17	AA	Feekes 7	6.4	112	3.9	14.4	56.3	3524	14.5
411	17	AA	Feekes 7	6.4	112	3.4	13.2	58.5	2983	14.0
109	18	AA	Feekes 7	6.4	134	3.5	11.8	60.8	4599	13.1
201	18	AA	Feekes 7	6.4	134	3.7	15.1	55.7	3301	13.3
322	18	AA	Feekes 7	6.4	134	3.5	12.3	60.1	3645	11.8
406	18	AA	Feekes 7	6.4	134	3.8	14.0	58.0	2699	13.2
122	19	AA	Feekes 7	12.9	67	4.0	12.7	59.6	3615	14.0
207	19	AA	Feekes 7	12.9	67	3.5	12.7	60.6	3717	13.4
311	19	AA	Feekes 7	12.9	67	3.8	13.2	58.2	3509	12.8
417	19	AA	Feekes 7	12.9	67	3.5	11.8	60.5	3786	14.3
108	20	AA	Feekes 7	12.9	90	3.5	11.6	61.5	4381	12.7
217	20	AA	Feekes 7	12.9	90	4.0	13.2	58.2	3345	13.7
310	20	AA	Feekes 7	12.9	90	3.8	13.1	58.8	3657	15.2
421	20	AA	Feekes 7	12.9	90	3.9	12.0	60.0	3692	12.8
115	21	AA	Feekes 7	12.9	112	4.1	12.1	60.8	3636	13.2

222	21	AA	Feekes 7	12.9	112	3.8	12.1	60.1	3934	14.1
317	21	AA	Feekes 7	12.9	112	3.8	13.3	58.3	3172	13.9
401	21	AA	Feekes 7	12.9	112	3.5	13.2	58.9	3779	12.5
106	22	AA	Feekes 7	12.9	134	3.7	12.5	61.2	4136	14.1
219	22	AA	Feekes 7	12.9	134	4.2	11.8	60.7	3800	14.1
312	22	AA	Feekes 7	12.9	134	3.8	15.5	57.6	3293	13.4
407	22	AA	Feekes 7	12.9	134	3.8	13.3	58.1	3503	12.1