USE OF NITROGEN MANAGEMENT PRODUCTS AND PRACTICES TO ENHANCE YIELD AND NITROGEN UPTAKE IN NO-TILL CORN AND GRAIN SORGHUM

by

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Abstract

Nitrogen fertilizers play an essential role in agricultural production in Kansas, particularly in row crops such as corn (*Zea mays* L.) and grain sorghum (*Sorghum bicolor* (L.) Moench). A good portion of the corn and grain sorghum grown in Kansas is typically grown using no-till production systems. These systems leave a large amount of surface residue on the soil surface, which can lead to ammonia volatilization losses from surface applied urea-containing fertilizers and immobilization of N fertilizers placed in contact with the residue. Leaching and denitrification can also be a problem on some soils. Current nitrogen prices, as well as concerns over environmental stewardship, are forcing producers to make smarter choices in the fertilizer products used as well as when and how the materials are applied, to optimize their nitrogen use efficiency. A common practice throughout Kansas is to apply N fertilizers prior to planting, sometimes up to 6 month prior to planting. What affect does this practice have on nitrogen availability to the growing crop?

Current Kansas State University (KSU) soil test fertilizer recommendations assume 50% nitrogen use efficiency. This means of every pound of nitrogen applied only half will be utilized by the plant and turned into valuable grain. Possible solutions to help increase nitrogen use efficiency are the use of nitrogen additives which are currently on the market and claim to reduce nitrogen loss through denitrification and volatilization as well as the use of timing and application of fertilizers to further increase nitrogen use efficiency.

The objective of this study is to evaluate different N fertilizer products, as well as additives and application practices and determine whether specific combinations can improve yield and N use efficiency of no-till corn and grain sorghum. The long-term goal of this study is to quantify some of these relationships to assist farmers in selecting specific combinations that could enhance yield and profitability. In this study five tools for preventing N loss were examined: fertilizer placement, or placing N below the soil surface or in bands on the residue-covered soil surface to reduce immobilization and/or volatilization; use of a urease inhibitor Agrotain (NBPT) that blocks the urease hydrolysis reaction that converts urea to ammonia and potentially could reduce ammonia volatilization; the use of a commercially available additive, Agrotain Plus, that contains both a nitrification inhibitor (DCD) and a urease inhibitor to slow

both urea hydrolysis and the rate of ammonium conversion to nitrate and subsequent denitrification or leaching loss; use of a commercial product NutriSphere-N, which claims urease and nitrification inhibition; and the use of a polyurethane plastic-coated urea to delay release of urea fertilizer until the crop can use it. The ultimate goal of using these practices or products is to increase N uptake by the plant and enhance yield.

An important measurement that was developed for this research was the use of a greenleaf firing index which used the number of green leaves below the ear at pollination as a key measurement in determining the effectiveness of fertilizer placement, application method, application timing and the use of nitrogen additives. If significant differences in lower leaf nitrogen stress are found, the potential exists to further develop this index and correlate differences observed with key parameters of nitrogen uptake such as ear-leaf nitrogen concentration, total nitrogen uptake and grain yield.

Results observed from this research show that the potential to increase nitrogen use efficiency and reduce nitrogen loss do exist with the use of certain nitrogen additives, application methods and application timing. When conditions are conducive for nitrogen loss the use of currently available tools to protect nitrogen from volatilization, immobilization and/or denitrification loss significantly increased yields in the corn experiments. Results from the grain sorghum research indicate that when N losses limit yield, the use of products and practices enhance yield. In locations where nitrogen loss is minimal or low yields limit nitrogen response, the use of these practices was not found to be helpful.

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Dedication

I would like to dedicate this work to my family. To Mom and Dad, thanks for your unending love and support.

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CHAPTER 1 - Literature Review

Introduction

Nitrogen is the most limiting nutrient for crop production in many of the world's agricultural areas and its effective use is important for the economic sustainability of cropping systems (Fageria and Baligar, 2005), they go on to state that low N recovery of N is not only responsible for higher cost of crop production, but also for environmental pollution. Hence, improving N use efficiency (NUE) is desirable to improve crop yields, reducing cost of production and maintaining environmental quality. To improve NUE in agriculture, integrated N management strategies that take into consideration improved fertilizers and fertilizer additives designed to reduce loss, along with soil and crop management practices are necessary. Of the 11.3 million hectares of crop land in Kansas, 1.13 million hectares were planted to grain sorghum and 1.6 million hectares were planted to corn in 2008. Grain sorghum is traditionally grown in the central and western portion of the state under dryland conditions where corn is not easily grown due to lack of sufficient moisture/irrigation or high nighttime temperatures during the growing season. Corn is grown in both the Eastern and Western portion of the state, in the east it is primarily grown under dryland conditions and in the west it is grown under both dryland and with irrigation. These two crops are extremely important to Kansas agriculture and are increasingly being grown using no-till practices to conserve both soil and water.

Nitrogen Use Efficiency

A key to increasing grain yields while decreasing or at least maintaining current nitrogen application rates is increasing the portion of the applied N that is recovered by plants. Nitrogen Use Efficiency (NUE) is defined as the percent of fertilizer N which is recovered or utilized by a fertilized crop {NUE= [(total cereal N removed)-(N coming from the soil+N deposited in the rainfall)]/ (fertilizer N applied to cereals)}. Worldwide, NUE is estimated to be only 33% (Raun and Johnson, 1999). The estimated 33% NUE worldwide, is far less than the 50% generally reported in the US (Hardy and Havelka, 1975).

While NUE is generally defined as a percent fertilizer N recovery, the concept of N use by plants can also be thought of in other ways. Moll et al. (1982) define N use efficiency as grain production per unit of N available in the soil from all sources. They define nitrogen use efficiency as Gw/Ns where Gw is grain weight and Ns is N supply expressed in the same units. They also describe two primary components of N use efficiency: (1) the efficiency of absorption (uptake), and (2) the efficiency with which the N absorbed is utilized to produce grain. The traditional fertilizer NUE would relate to the efficiency of absorption, while the efficiency of utilization is a physiological measure of how efficiently the plant utilizes N to produce grain.

Fertilizer N can be lost from crops and soils in many ways including: gaseous plant emission; soil denitrification; surface runoff; volatilization and leaching (Raun and Johnson 1999). Efficiency in uptake and utilization of N in the production of grain requires that those processes associated with absorption, translocation, assimilation, and redistribution of N operate effectively. Plant N losses, which are characterized as N released from plants predominantly as NH_3 following anthesis, have been estimated to account for 52 to 73% of the unaccounted for N in corn research (Francis et al.,1993)

Reported gaseous N losses due to denitrification from applied fertilizer N have been shown to be as high as 10% (conventional tillage) to 22% (no-till) in corn (Hilton et al., 1994). Fertilizer N losses in surface runoff range between 1% (Blevins et al., 1996) and 13% (Chichester and Richardson, 1992) of the total N applied, and are generally lower under no-tillage. When urea fertilizers are applied to the surface without incorporation, losses of fertilizer N as NH^3 can exceed 40% (Fowler and Brydon, 1989; Hargrove et al.,1977). Raun and Johnson (1999) state that the unaccounted 67% of N not take up by plants worldwide represents a \$15.9 billion annual loss of N fertilizer. They go on to state that based on present fertilizer use, a 1% increase in efficiency of N use for cereal production worldwide would lead to \$2.3million saving in fertilizer cost and an increase in NUE of 20% would result in a savings in excess of \$4.7 billion per year.

Loss Mechanisms

As stated above, soil denitrification and volatilization contribute to the loss of fertilizer N. The SSSA Glossary of Soil Science Terms (1979) defines denitrification as the "microbial reduction of nitrate or nitrite to gaseous nitrogen either as molecular nitrogen or as oxides of nitrogen.

To avoid confusion, a more explicit definition of denitrification seems advisable. Most microbiologists identify denitrification as a respiratory process present in a limited number of bacterial genera. In this process, N oxides serve as terminal electron acceptors for respiratory electron transport leading from a “reduced” electron donating substrate through numerous electron carriers to a more oxidized N oxide. Denitrifying bacteria can grow in the absence of molecular oxygen (O_2) while reducing NO_3^- or NO_2^- to $N_2O$and/or N_2. The reduction of the anion species to only gaseous products (dominantly N_2 and N_2O) and the quantity of gas produced are characteristics that distinguish denitrification from other types of microbial N metabolism (Firestone 1982).

Key factors in denitrification are soil moisture content and temperature. The denitrification process in agricultural soils is affected by NH_4^{+-}N and NO_3—N concentrations (De Klein and Van Logtestijn, 1994), water content (Davidson, 1992), available C content (Rolston, 1981), and temperature (Mancino et al., 1988). Denitrifications (emission of N_2O, NO, and N_2) is higher under neutral and alkaline soil conditions compared with acidic conditions (Fageria and Baligar, 2005). To simplify this process it can be said that certain soil bacteria that thrive in saturated (anaerobic) soil conditions will convert nitrate-N to oxygen and nitrogen gasses.

Volatilization of the nitrogen gas can result in N losses of as much as 5% of the available nitrate N per day (Hoeft 2004). Soils at greater risk to denitrification N loss are those that are naturally heavy textured and poorly drained, plus fields with significant levels of soil compaction that restrict natural drainage. (Nielsen 2006)

High soil moisture content affects denitrification indirectly by inhibiting the diffusion of oxygen, but in addition, exerts a very pronounced direct effect. Bremner and Shaw (1958b) observed increased losses of nitrogen as a function of moisture content up to 450% of moisture holding capacity, and noted that even when other conditions are very favorable for denitrification, little loss of nitrogen occurs if the moisture content is less that 60% of the water holding capacity. The direct effect of water has been confirmed by others (Jansson and Cark, 1952; Nommik, 1956). As is the case of other biological processes, denitrification exhibits a temperature dependence. The optimum temperature is surprisingly high, in the range 33-36°C as reported by Nommik (1956) and by Bremner and Shaw (1958b). The relative proportion of N_2O and N_2 in the denitrification gas varies with temperature; nitrous oxide being predominant at the lower temperatures but molecular nitrogen at the higher temperatures. This apparently reflects a higher temperature coefficient for the reduction of nitrous oxide than for the other steps in denitrification.

No-tillage systems, often characterized by an accumulation of crop residues on the soil surface, results in greater C, N, and water content in the upper 5-10 cm of soil compared with conventional tillage (Blevings et al., 1977; Doran, 1980) Consequently, facultative anaerobes and denitrifying bacteria are more numerous in no-tillage soils (Doran, 1980) and therefore, higher denitrification losses have been reported in no-tillage soils than plowed soils (Rice and Smith, 1982; Linn and Doran, 1984)

Ammonia volatilization is a process where urea is converted to NH_4^+ , and then into NH_3 gas, which is subject to loss. (Fageria and Baligar, 2005) When granular urea or urea-ammonium nitrate solutions (UAN) are applied to the soil surface, the urea is converted within a few days to NH_4CO_3 due to the action of urease enzymes that are present both in the soil and in plant residues. This conversion gives rise to both high NH_4^+ levels and elevated soil pH, conditions that are conducive to volatilization of NH_3. Because many agricultural systems favor the accumulation of plant residues at the soil surface, the NH_4^+ also may be made unavailable via immobilization, as soil microorganisms use the N to decompose the low N plant residues. Urease inhibitors temporarily reduce the activity of these urease enzymes, maintaining most of the applied N as urea for several days. Because urea is quite mobile in the soil, rainfall received within this period will move it more deeply in the soil, beyond the zone of residue accumulation, where it can hydrolyze normally with less opportunity for N losses via NH_3 volatilization or immobilization (Hendrickson 1992). In 1964, J.K.R. Gasser found evidence that ammonia may be lost by volatilization when urea is top-dressed on growing crops or on bare soil. Early results emphasize the importance of incorporating urea in the surface soil layer to minimize ammonia losses during hydrolysis. Among factors known to influence the rate of hydrolysis of urea and ammonia volatilization are soil organic matter content, cation exchange capacity, pH, soil water content, and temperature-humidity relations. (Ernst 1960; Gasser 1964; Terman and Hunt 1964; Terman, Parr and Allen 1968). The interactions of these factors on urea hydrolysis and ammonia loss from soil surfaces are exceedingly complex and unpredictable (Bandel et al 1980). Another factor affecting NH_3 volatilization is rainfall. In work done by Fox and Hoffman, 1981 and Fox et al., 1986, they noted that apparent ammonia volatilization loss from urea surface applied to no till corn is as high as 30%. They also noted that losses increased as the number of days increased between application and the time it took to get 0.4 in. (10 mm) of rain. In a later experiment Fox (1993), calculated the apparent ammonia volatilization losses from urea, assuming that there was no ammonia volatilization loss from ammonium nitrate, and that losses were best estimated with lower, sub-optimum N rates where N response was assured. Using these assumptions, the apparent ammonia volatilization losses from at-plant surface- applied urea in 1989, 1990, and 1991 were 28.7, 11.3 and 27.3%. The days after application until 10 mm. of rainfall for those three years were 4,1 and 4 days, respectively. These results confirm their earlier observations of apparent ammonia volatilization losses from urea of almost 30%, and that losses were greater when there were more than two or three rain free days following application.

The processes involved in urea hydrolysis can be classified generally into two categories: (1) the movement of urea toward the urease enzyme and (2) the hydrolysis reaction, i.e. the reaction of urea with the urease enzyme. The movement of urea to the urease enzyme results from molecular diffusion or movement with mass flow of water. The second process (reaction of urea with urease) depends on two factors: (a) the number of active urease molecules and (b) factors affecting the activity of the urease molecules (Kissel et al.,1988). According to Dick (1983), under no tillage urease activity is highest at the soil surface and decreases rapidly with increased depth, apparently because of the amount of decomposing crop residue at the soil surface. Keller and Mengel (1986) concluded that Broadcast applications of urea-based fertilizers on wet soils with high corn residue amounts can result in high N loss due to ammonia volatilization. Gasser (1964) states that rainfall during the week before and after urea application is considered to have an important bearing on susceptibility of urea to hydrolysis. Reynolds et al. (1985) found that greatest urea hydrolysis occurred at or near the soil surface. Volatilization of NH_3 is more likely if urea is applied to a moist soil rather than dry soil because as urea dissolves, it may subsequently be lost into the atmosphere as moisture on the soil surface evaporates. Moreover, if precipitation occurs shortly after application to dry soil, dissolution and downward movement of urea greatly lessens the likelihood of NH_3 loss. In fact some studies have shown that severe NH_3 losses can occur within hours of application if urea is applied to moist soils (Keller and Mengel 1986). Numerous studies have been done to summarize the impact that rainfall or irrigation after fertilizing N has on N loss. Fox et al.,(1981) noted that N losses increased as the number of days increased between application and the time it took to get 10 mm of rain. Mengel (1988) showed significant increases in N uptake and yield of rice as the time between urea application and irrigation water application was shortened. Heavy rain or irrigation may not result in significant infiltration of the urea in all cases (Raczkowski and Kissel, 1989), and even if the urea infiltrates to depths of several cm, it may return to the soil surface in response to evaporation, where it is again probe to NH_3 volatilization losses (Ferguson and Kissel, 1986; McInnes et al, 1986).

Urease Inhibitors

Due to the losses associated with denitrification and volatilization, extensive research has been done in an attempt to rectify this problem. One of the possible solutions that have been looked at are the use of different nitrogen additives to reduce N loss. The use of urease inhibitors, polymer coated N and nitrification inhibitors all offer potential solutions.

Randal et al., 1988, suggested one means of reducing ammonia volatilization loss from surface applied applications of urea containing fertilizers is to incorporate urease inhibitors as amendments in the fertilizer. It has been shown that, of the commonly tested urease inhibitors, N-(n-butyl) thiophosphoric triamide (NBPT), was the most effective at delaying urea hydrolysis. Consequently, it is the most effective in reducing ammonia volatilization loss from surface-applied urea containing fertilizers, even when applied at very low concentrations (Bremner and Chai, 1989; Beyrouty et al.,1988;Wang et al.,1991). NBPT, which is currently marketed under the name Agrotain®, claims to stabilize nitrogen by containing a urease inhibitor that minimizes the conversion of urea to NH_3. By keeping nitrogen in the urea form longer, nitrogen losses from volatilization are minimized and seedling injury when applied in close proximity to the urea is reduced. Schlegel et al. (1986) noted increased corn grain yields and N uptake when urease inhibitors were applied to a no-till system.

Several phosphoramide compounds have been studied for use as urease inhibitors (Martens and Bremner, 1984; Schlegel et al, 1986; O Connor and Hendrickson, 1987; Schlegel et al, 1987; Beyrouty et al., 1988; Bremner and Chai, 1989). McCarty et al. (1989) and Bremner et al. (1991) found NBPT to be the most effective and persistent of the phosphoramides in inhibiting urea hydrolysis in soils, attributing the primary inhibitory effect to the NBPT degradate N-(n-butyl) phosphoric triamide. Hendrickson et al. (1987) found that the urease inhibitor NBPT performed well when conditions were favorable for ammonia loss, and that immobilization and ammonia loss were reduced when the urease inhibitor was included. Schlegel (1991) reported that NBPT reduced the phytotoxic effects of surface applied urea fertilizers.

In a study done by Fox and Piekielek (1987) on the management and urease inhibitor effects on nitrogen use efficiency in no-till corn, found that apparent ammonium volatilization losses from dribble UAN were small compared with loss from broadcast sprayed UAN. In their study broadcast urea did not produce significantly different yield or N uptake than sprayed UAN, although ear-leaf N concentrations was slightly (.10 significance level) higher with sprayed UAN than with urea. This supports earlier observations (Fox and Hoffman, 1981; Bandel et al.,1980; Olson et al., 1964) that apparent ammonium volatilization losses from sprayed UAN are often as great as those from broadcast urea. In his study, Fox found that amending spray-applied UAN with NBPT did result in increases in all three N uptake efficiency parameters (grain yield, N uptake and ear-leaf N concentrations) over those obtained with unamended, sprayed UAN. NBPT did not significantly affect yield with UAN banded at planting or side dress. The only effect on N uptake with the banded UAN treatments was that NBPT caused a lower (.10 significance level) N uptake with the side-dress band treatment. NBPT did however increase ear leaf N concentrations with the at-planting band treatments indicating that the NBPT amendment had a small positive effect on N fertilizer efficiency of banded UAN at planting. The average ear leaf N concentration of the NBPT-amended side-dress band treatment was significantly (.01 level) lower than with the unamended banded UAN. This, combined with the lower N uptake in the NBPT side-dress band treatment, indicated that, for some reason, NBPT's ability to delay the hydrolysis of urea in UAN resulted in less of the fertilizer N being available for plant uptake.

Amending urea with 0.50% NBPT produced significantly greater N fertilizer use efficiency as measured by earleaf N, nitrogen uptake and grain yield with both the at-plant broadcast treatment and the side-dress band. Including NBPT with broadcast urea increased average grain yield by 880 kg ha^{-1} and N uptake by 17 kg ha^{-1}. These results concur with those of others (Bronson et al. 1990; Clay et al.,1990; Hendrickson, 1992) showing that NBPT can significantly increase the N fertilizer use efficiency of broadcast applications of urea to no-till corn.

Fox et al (1993) reported that urea- ammonium nitrate solution and urea make up 47 and 30%, respectively, of the N fertilizer used in the Mid-Atlantic area. Opportunities to incorporate these N fertilizers below the residue layer in reduced tillage systems are limited. Consequently, the most common N application methods used at that time in no-till systems were broadcasting of solid ammonium nitrate (AN) or urea or spraying urea-ammonium nitrate (UAN) solutions on the soil surface immediately before or after planting. However, significant N losses can occur through ammonia volatilization when ammonium N sources, particularly urea, are left on the soil surface and exposed to the atmosphere (Bandel et al., 1980; Ernst and Massey,1960; Hargrove et al., 1977;Terman, 1979; Volk, 1959)

In general, urease inhibitors will be of limited value in situations where urea or UAN can be easily and inexpensively incorporated into the soil during or immediately after applications. However when rapid incorporation is impossible due to the presence of a growing crop or undesirable due to the presence of soil or water conserving residue or time constraints, urease inhibitors offer one of the few technologies that can ensure full value of surface-applied urea and UAN. Even in those cropping systems where the applied N can be incorporated prior to planting, urease inhibitors will allow growers to apply N after the crop has been established, closer to the time of most rapid plant uptake. (Hendrickson 1992)

Hendrickson's 1992 paper summarizes the evaluation of NBPT in 78 trials from 1984-1989. All of these experiments were conducted by university scientists using replicated treatments. Most of the trials evaluated NBPT with both urea and UAN solutions, although the treatments varied considerably from trial to trial. The NBPT was generally dissolved in the UAN solutions just prior to application; but was introduced into the urea using a variety of impregnation and incorporation techniques. Additional N treatments such as anhydrous NH_3, NH_4NO_3, $(NH_4)2SO_4$, or subsurface applications of urea or UAN were generally employed as positive non-volatile nitrogen (NVN) controls to indicate the likelihood of significant N losses from surface applied urea or UAN. Because surface application of N is most widely practiced in reduced tillage, greatest emphasis was placed upon such systems. Approximately 45% of the trials were conducted on no-tillage, 45% on reduced tillage and 10% on conventional tillage systems.

When averaged over all years of study, NBPT increased grain yields by 270 kg $ha^{-1}$when applied with urea and by 100 kg ha^{-1} when applied with UAN. Both increases were highly significant. The responses to NBPT varied from year to year, probably reflecting prevailing environmental conditions. The most positive responses to NBPT were obtained in 1987 and 1989, years which with generally favorable growing conditions, as indicated by higher average grain yields. Less favorable responses to NBPT were obtained during years with more adverse growing conditions, such as the severe drought of 1988. Increases in excess of 10 bu/acre were obtained with 25% of the urea amended NBPT treatments and over 40% of the responses were in excess of 5 bu/acre. Similar increases for NBPT applied with UAN were observed in approximately 15 and 25% of the comparisons, respectively. Although both increases were highly significant, it should be noted that the NBPT response with UAN was actually greater than the response with urea in nearly 40% of the comparisons. The greater NBPT response with urea than with UAN was expected, as previous research has shown that urea is generally less efficient than UAN when surface-applied (Bandel et al., 1980; Touchton and Hargrove, 1982). According to Hendrickson, when surface applied urea is found to be less effective than a non-volatile nitrogen treatment (such as knifed UAN or ammonium nitrate), the difference is usually attributed to NH_3 volatilization or immobilization. He goes on to state that one might speculate that rapid urea hydrolysis at the soil surface may result in improved N efficiency due to temporary removal of the applied N from other loss mechanisms. For example, NH_4^+ formed at the soil surface following rapid urea hydrolysis may be temporarily fixed or immobilized, thereby reducing N losses via leaching or denitrification. Similarly, NH_4^+ formed near the soil surface may be nitrified more slowly than NH_4^+ from urea that is applied below the soil surface or urea that migrates into the soil following application to the soil surface with a urease inhibitor.

One aspect that Hendrickson addressed is nitrogen conservation, as he states, “at a time of increasing concern over groundwater pollution by NO_3^-, it may be more important to evaluate the ability of NBPT to enable maintenance of current grain yields using reduced inputs of N fertilizers”. In his analysis of numerous site years of data, Hendrickson found that in years of an absence of NBPT, the application of an additional 83 kg ha^{-1} nitrogen increased yields from 146 to 159 kg ha^{-1}. NBPT enabled attainment of that same yield without application of additional N. When NBPT was applied along with the additional N, yields were increased by an additional 376 kg ha^{-1}. This demonstrated that an average of 83 kg ha^{-1} of additional unamended urea-N would be required to overcome the apparently large losses of N that are prevented by NBPT. Undoubtedly, such losses do not occur at all locations every year, but as noted by Fowler and Brydon (1989), "the presence of conditions giving rise to large N losses are as unpredictable as the weather". If conditions leading to large yield losses are not present, NBPT will be an unnecessary input. Importantly, the additional N required when N losses do occur, would actually be greater than the 83 kg ha^{-1}average difference, because this average includes all of the sites where N losses were low or negligible. As stated by Fowler and Brydon (1989), the potential losses with broadcast urea cannot be corrected by simply increasing application rates to compensate for average losses. Similarly, basing the potential value of urease inhibitors upon the average yield differential between N sources with and without NBPT may greatly underestimate the value of the tool under conditions where N losses are severe. NBPT responses in these experiments were generally independent of rain received within the first 3 days following N application. Several of the individual experiments demonstrated a very marked response to NBPT, even when rain was received within 2 days after application. This suggests that losses of surface applied N and responses to urease inhibitors may be somewhat independent of rainfall patterns.

Control Release Fertilizers

Possible agronomic advantages of controlled release N fertilizers include (a) less toxicity to germinating seedlings, (b) less loss of N by leaching or denitrification, (c) more uniform growth of forage through the season without repeated N applications, (d) less volatilization loss of N, and (e) greater effectiveness per unit of applied N. A slow release N fertilizer would help solve some of the agronomic and environmental problems associated with fall application of N (Frye, 1977). Several investigations have demonstrated the slow release characteristic of sulfur coated urea (SCU) and its agronomic advantages over more soluble N sources for production of several crops (Mays and Terman, 1969; Allen and Mays, 1971; Dalal, 1974; Gascho and Snyder, 1976). Allen et al (1970) found that recovery was only 54% from a single application of urea on the surface, while recovery from sulfur coated urea or a split application of urea increased to 72-76% in common bermudagrass (*Cynodon dactylon*). With surface placement, yields were much less from urea, which apparently reflects large volatilization losses as NH_3 from urea. Thus, sulfur coated urea was effective in reducing losses of NH_3 to the atmosphere. Yield distribution was modified by split applications of ammonium nitrate or urea and by SCU-20, a heavier coated urea. In contrast, SCU-11 (a lighter coated urea) apparently released N too rapidly at high temperatures for expression of controlled- release effects. Allen and co-workers also found that SCU was effective in reducing luxury N uptake by early forage clippings, as compared to urea or ammonium nitrate. As a result, more residual N remained for later clippings and greater total yield resulted. Allen's study found that the rate of dissolution of SCU is very temperature dependent and heavier coatings plus microbicide may be required for tropical situations with mixed placement of N. Lighter coatings without microbicide may be preferred for turf application in cooler climates. The exceptional stability of SCU at 10° C suggests the possibility of fall and winter applications in southern states where this practice is not now recommended. A suitable formulation of SCU should offer protection from leaching and/or denitrification during the winter months, while N would become available for crop use when the soil warms in the spring.

Mays (1969), looking at sulfur coated urea vs. uncoated soluble nitrogen fertilizers for fescue forage observed that application date had little effect on yield percentage distribution among cuttings. Nitrogen responses were not seen on SCU fertilized plots until May regardless of the greatly different amounts of rain which had fallen on the SCU applied at different dates. Apparently granule breakdown was dependent on the high temperatures which arrive in northern Alabama in late May. Percentage of N in forage produced with SCU was lower in the first cutting but higher in the second cutting than that produced with soluble fertilizers. This reversal was apparently due to slow release of N from SCU and removal of much applied N from AN and urea fertilized plots by the early growth. (Mays and Terman, 1969)

The question of effect of temperature and coating thickness on release of urea from resin coated urea granules was addressed by Brown (1966), who observed that after 1 day, 94% of the N from non-coated urea was leached from the soil in a sand and soil leaching column whereas at the end of 4 weeks, 74% and 49% of the N from light and heavily coated urea fertilizers was recovered, respectively. Stability of resin in this experiment was shown by recovery of all capsules intact at both lighter and heavier thicknesses in sand and soil after 16 weeks.

Temperature markedly affected the release of urea from the heavy-coated fertilizer in sand. Although an initial period of rapid N release was seen at all temperatures, release rates were lower and tapered off more rapidly at lower temperatures. At one week, when the rates of release at all temperatures were relatively constant, there was an approximate doubling in the release rate for each 10-degree increase in temperature. Release rates decreased rapidly after 3 weeks at the 25 and 35C temperatures, presumably because of capsule depletion. At 5° C, only 70% of the urea had been released after 16 weeks of intermittent leaching.

Brown (1966) observed that in resin coated urea, the coating appears to act as a semi-permeable membrane. Osmotic pressure expands the resin capsule to a thinner more permeable membrane, and the dissolved fertilizer salts diffuse through. Rates of release are highest at this time, when the capsules are under a high internal pressure. Increased swelling of the capsules at higher temperatures was suggested by Oertli and Lunt (1962) as a modifying factor in release of salts through the resin membrane. A lighter resin coating or thinner capsule in itself permits a higher rate of diffusion. Fujita et al (1983) stated that when granular urea is coated with resin, water moves through the resin film by osmosis into the capsule. Nitrogen release occurs when the urea solution diffuses back. Nitrogen release can be controlled by using a surfactant that has a high affinity to water and the resin, and by controlling the added amounts of this surfactant. Hummel (1989) goes on to add that it is technically possible to produce products with release rates that range from 4 weeks to more than 1 year. Hummel also found that the uniform, delayed release of N from resin coated urea products may make them well suited for fertilizer programs that are based on one application per year in turf grass.

Nitrification Inhibitors

Nitrification inhibitors are chemicals that reduce the rate at which ammonium is converted to nitrate by killing or interfering with the metabolism of *Nitrosomonas* bacteria. The loss of N from the rooting zone can be minimized by maintaining applied N in the ammonium form during periods of excess rainfall prior to rapid N uptake by crops (Nelson and Huber, 1992). Schwab and Murdock (2005) state that depending on the soil conditions, some inhibitors can slow the conversion of ammonium nitrogen (NH_4-N) to nitrate nitrogen (NO_3-N) by a few weeks. This is important because nitrogen in the NH_4-N form is held tightly by the soil particles and is not subject to leaching or denitrification.

Dyciandiamide (DCD) is an efficient nitrification inhibitor (Hauck 1980; Rodgers and Ashworth 1982) and it is also one of the most convenient because it is non-volatile, nonhygroscopic, relatively water soluble (23 $g1^{-1}$ at 13°C), and chemically and physically stable (Prasad et al. 1971; Reidar and Michaud 1980). These properties allow DCD to be effectively formulated with a variety of fertilizers, including NH_4^+ salts and urea. A combined application of a nitrification and urease inhibitor with urea fertilizer can maintain N as NH_4^+ for a longer time with more chance of the fertilizer derived-N being taken up by the plant, fixed or immobilized by the organic or mineral component of the soil. Specific nitrification inhibitors are now commercially available as fertilizer additives that maintain the NH_4^+ form of N in the root/soil profile and reduce N losses from leaching and denitrification (Broadbent and Clark 1965). Rate required to inhibit nitrification vary with the inhibitor, soil type, source of N, method of application, organic matter content, temperature and moisture (Bundy and Bremner 1974, Goring 1962, Quastel 1965). Soliman and Abdel Monem (1996) and Xu et al. (2000), in pot experiments, found more fertilizer derived N recovery both in soil and in plants when DCD was used together with a urease inhibitor, hydroquinone or NBPT. With the advent of nitrification inhibitors, crop management programs can be easily adapted to see their potential to increase crop production, improve efficiency of fertilizer use, promote nitrogen and energy conservation, enhance food quality, improve disease control, and assist in pollution abatement. (Huber et al. 1977)

Timing

A production practice that has gained increased popularity in recent years is the application of fertilizer in the fall for crops to be grown the following spring/summer. The problem of limited time in the spring planting season has created interest in fall application of fertilizer. The practice offers several apparent advantages to fertilizer manufacturers, dealers, and farmers. These economic and logistical advantages include: better distribution of labor and equipment demands; time savings during the busy spring planting season; lower N costs in some years; and frequently more favorable soil conditions for field work (Bundy, 1986; Randal and Schmitt, 1998). Researchers generally agree that P and K can be applied any time of the year without loss of efficiency, except perhaps on coarse textured soils, provided precautions are taken to prevent erosion losses. But fall applications of N fertilizer have disadvantages for farmers that may, under some soil climatic conditions, negate all advantages (Frye, 1977). Of concern in determining the feasibility of fall-applied N are agronomic, economic, and environmental questions of sources, transformations, leaching losses, denitrification, immobilization, value of the crop, value of time saved, and cost of N fertilizers.

Responses to fall vs. spring applied N have been mixed, with more studies finding less efficient use of N from fall application. Pearson et al. (1961) found fall-applied N averaged 49% as effective in producing corn (*Zea mays* L.) as spring-applied N at seven locations in Alabama, Georgia, and Mississippi. Fall application (mid-November) produced lower corn grain yields than spring pre-plant application regardless of N rate in Ontario. One of the most interesting findings in this study is that they did not find a rate of nitrogen applied in the fall (maximum rate applied of 224 kg/ha) that would give the same yield as the optimum rate of 112 kg N ha^{-1} applied preplant or sidedress in the spring. (Stevenson and Baldwin, 1969). In a study by Vetsch and Randall (2004) it was observed that spring application of N was consistently superior to fall application for all production parameters. Spring application increased grain yield by 2.2 Mg ha^{-1} (36 bu acre), total N uptake by 52 kg ha^{-1} (47 lbs acre) and N recovery by 42% compared with fall application.

Boswell et al. (1974) however, observed no statistical difference in corn yields with fall-applied N as compared to spring application, and the use of a nitrification inhibitor with the fall application increased yields only one year out of three on a corn study conducted in Tennessee. Corn yields were not affected by time of application on a Davidson clay loam in Viginia, but spring- applied N treatments produced great yields than fall or winter applications on a Congaree silt loam (Frye and Hutcheson, 1971). Bundy (1986) concluded that fall N applications is an acceptable option on medium to fine textured soils where winter temperatures retard nitrification, however, under these conditions fall-applied N is usually 10 to 15% less effective than spring-applied N.

When considering the time of year fertilizer is being applied you must also take into account the crop and nitrogen product you are planning to use. Denitrification occurs primarily when the soil is water-saturated. Therefore, losses are usually highest for N applied in the fall or early in the spring in environments with heavy spring rainfall. Later, side-dress applications usually result in very little denitrification loss in these environments since plant driven water use would make soil saturation less likely. However in more monsoonal type climates, denitrification loss could occur more frequently after planting, during periods of heavy rainfall and high temperatures. Thus when periods of saturation or high rainfall occur, will have a large effect on when N loss through denitrification or leaching would occur, and the potential response to N timing.

Volatilization losses are highest when the soil is warm (above 15°C) and moist, experiencing high evaporation rates, and/or when soil pH is greater than 7. In most years, temperatures become high enough to cause concern in early May in Kansas and the mid-south. Polymer-coated urea, because of its slow release characteristics, offers farmers the option of early fertilizer application with a reduced risk of denitrification or leaching loss. There is still the potential for volatilization losses from this product because of its urea (Schwab and Murdock, 2005)

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CHAPTER 2 - Use of Nitrogen Management Products and Practices to Enhance Yield and Nitrogen Use Efficiency in No-Till Corn

Abstract

Long- term research has shown that nitrogen (N) fertilizer is usually needed to optimize corn (*Zea mays* L.) production in Kansas. Research has also shown differences in the response to various N fertilizers, products, and practices, particularly in the eastern portion of the state, where soil and climatic conditions can lead to N loss. A project was initiated in 2008 and continued in 2009 to quantify how a number of currently marketed products and commonly utilized management practices performed at supplying N to no-till corn. Conditions in 2008 and 2009 at these locations were conducive for N loss from ammonia volatilization, immobilization and denitrification. A significant response to N fertilizer as well as differences in performance among N fertilizers, enhancement products, and application practices was observed. Using currently available tools to protect N from volatilization, immobilization and/or denitrification loss significantly increased yields in these experiments

Introduction

In the production of corn (*Zea mays* L.), dentrification and leaching are major sources of N loss. In addition, ammonia volatilization and N-immobilization can play significant roles in some cropping systems. All applied N fertilizer sources are taken up by plants, incorporated into soil organic matter pools or eventually converted to nitrate-N. The nitrate form of nitrogen is not held tightly by the soil, and can be leached from the soil profile with excessive rains, especially on lighter-textured soils. Nitrate -containing fertilizers, including urea-ammonium nitrate solutions (UAN) and ammonium nitrate, are susceptible to leaching and denitrification as soon as they are applied to the soil. . Urea can convert to nitrate-N in less than two weeks in late spring; and thereafter is susceptible to leaching loss (Nielsen 2006).

Denitrification is a process where certain soil bacteria that thrive in saturated (anaerobic) soil conditions can convert nitrate-N to oxygen and nitrogen gasses. Volatilization of the produced nitrogen gas can result in N losses of as much as 5% of the available nitrate-N per day (Hoeft, 2004). Soils with the greatest risk of denitrification N loss are those that are heavy textured and poorly drained, plus fields with significant levels of soil compaction that restricts natural drainage. No-till production systems leave crop residues on the soil surface that can result in increased soil water content and reduced soil temperatures during the growing season. This can lead to increased N losses through leaching and denitrification (Thomas et al., 1973; Unger, 1978). This increased N loss through leaching and denitrification has been attributed to both increased soil water content, and an increased number of large pores contiguous to the soil surface which increase water movement through the soil (Thomas et al., 1973). Populations of denitrifying bacteria have also been shown to be higher in no-till systems (Doran, 1980).

Research has been conducted in an attempt to measure the effectiveness of different N fertilizer sources, fertilizer additives, application methods and times of application used in Kansas, with the goal of determining whether specific combinations could improve yield and N use efficiency in no-till corn. One such practice or type of N source widely studied has been controlled release fertilizers. Controlled release fertilizer products have been available for more than thirty years. Best known of these products is sulfur-coated urea (SCU). Unfortunately, SCU has not proven to be a useful agronomic tool, in part because the cost of coated urea is high relative to the benefits obtained. Recent advances in polymer technology have created a whole new type of controlled release fertilizer. A number of companies have introduced polymer coated urea products (PCU). The Agrium product ESN is priced more competitively in the agricultural market (Schwab and Murdock 2005). However, in order for this product to be agronomically useful, the producer must be able to confidently reduce the rate of applied nitrogen by the amount of N expected to be saved as a result of using this product. To be economical, the return from using the product, as compared to the return from a standard product, must exceed the increased price of the alternative product (Schwab and Murdock, 2005).

It is also critically important that farmers fully reduce N application rates to make improvements in environmental quality. Using products that increase the proportion of applied N which is utilized by the target crop and not adjusting N application rates accordingly will result in increased quantities of nitrate-N remaining in the soil after harvest, which can leach to groundwater, move through tile lines to surface waters, or be lost as N_20, an important greenhouse gas, to the atmosphere. Thus using more efficient practices or products and not making corresponding reductions in N application can actually enhance the potentially adverse impact of fertilization on water quality or the production of greenhouse gases such as N_2O.

Other fertilizer additives which could be of value to improve N use efficiency include the urease inhibitor NBPT ((n-butyl)thiophosphoric triamide) which is marketed under the trade name Agrotain; Agrotain Plus a product for use in N solutions that combines the urease inhibitor NBPT with DCD (dicyandiamide) a nitrification inhibitor, and a similar product Super U which cogranulates NBPT and DCD with urea; and Nutrisphere-N, a maleic-itaconic co-polymer who’s mode of action is not fully known, but is claimed “to work in the soil at the molecular level to prevent leaching and volatilization by creating an active shield that manages nitrogen in the soil. This shield prevents the action of urease in volatilization and slows nitrification reactions, which lead to nitrate leaching, and allows the plant better access to stable forms of nitrogen throughout the growing season.” (Specialty Fertilizer Products)

In a five year summary compiled by Hendrickson (1992), results from 21 trials employing multiple N rates showed that maximum grain yields could be obtained using an average of 82 kg less N ha^{-1} when NBPT was included in surface-applied urea. These results demonstrate that NBPT provides an effective alternative to the excessive rates of surface-applied urea that are currently used to ensure that N will not limit grain yields. Frye and co-workers found NBPT increased average corn grain yields by 880 kg ha^{-1} when used with urea and 380 kg ha^{-1} with UAN (Frye et al., 1990). When evaluating SuperU, the NBPT + DCD urea product, Schwab and Murdock (2005) found that at yield limiting rates of N, grain yield from Super U was significantly higher than the yield from urea alone.

Method of fertilizer application can also be used as a tool to reduce N loss, and there are several factors to consider when choosing application practices. The reduced or no-till production systems that are increasing popular in the central Great Plains leave a layer of crop residues on the soil surface that conserves moisture and can result in increased soil water content and reduces soil temperatures during the growing season, leading to increased N losses through leaching and denitrification (Thomas et al. 1973; Unger, 1978). The practice of applying nitrogen as broadcast UAN solutions or granular urea or ammonium nitrate can lead to nitrogen being made unavailable for plant uptake due to immobilization, or incorporation of the N by soil biomass during residue decomposition. R. H. Fox found that nitrogen fertilizer use efficiency of UAN applied to no-till corn was in the order: at-plant spray<at-plant surface band< sidedress surface band< sidedress inject (Fox, 1993).

The objective of applying nitrogen fertilizer is to increase N uptake by the plant and enhance yield. However the response obtained to different application practices can vary tremendously as shown in the research cited above. The long term goal of this research is to quantify some of these relationships, and assist farmers in selecting specific combinations of N fertilizer products and sources, additives and application techniques that can enhance yield and profitability on their farm, and minimize any potential adverse effects to the environment.

Materials and Methods

Field experiments were carried out at one location in 2008 and three locations in 2009 to evaluate the relative nitrogen use efficiency obtained with no-till corn using a number of different N fertilizer sources and products, application methods, products or additives to fertilizers claiming to enhance performance, and timing of nitrogen application. The locations used, soils present and soil test levels for each site are given in Table 2.1. Key cultural practices used at each location can be found in Table 2.2.

Table 2.1 Locations, description of soils present and soil test levels at corn nitrogen study sites.

Location and year	Soil Series	Soil pH	Mehlich-3 P	Exchangeable K	Organic Matter	NH_4-N	NO_3-N
			mg kg^{-1}	mg kg^{-1}	g kg^{-1}	mg kg^{-1}	mg kg^{-1}
2008 Agronomy North Farm, Manhattan	Ivan and Kennebec silt loam	6.9	35	249	24	4.8	2.9
2009, Agronomy North Farm, Manhattan	Smolan silt loam	5.8	15	266	20	6.4	5.4
2009, East Central Experiment Field, Ottawa	Woodson silt loam	6.5	12	102	17	2.7	5.6
2009, South Central Experiment Field, Hutchinson	Ost loam	6.7	42	180	13	7.9	2.9

Tillage and Previous Crops

In 2008 the study was conducted at the KSU Agronomy North Farm in Manhattan, KS (39°12’44.5824” N lat.; 96°35’40.5486” W long.). This experiment was no-tilled planted into grain sorghum (*Sorghum bicolor* L. Monech) stubble. Plots were 15.2 meters long and 3.04 meters (or 4 rows) wide arranged in a randomized complete block design with four replications. Starter fertilizer was applied to all treatments including the no N control using a coulter band applicator to allow using the control plots to calculate the NUE of the treatments only. Starter fertilizer was applied at a rate of 22.4 kg N ha $^{-1}$ N as UAN. The treatments used were:

1. Starter N only
2. Broadcast granular urea
3. Broadcast granular urea treated with Agrotain. (NBPT, N-butyl-thiophosporic triamide);
4. Broadcast granular urea/Super U co-granulated with a combination of NBPT and DCD (dicyandiamide);
5. Broadcast granular ESN urea (urea coated with polyurethane);
6. A 50/50 ESN/urea blend;
7. Broadcast sprayed UAN;
8. Broadcast sprayed UAN plus Agrotain Plus, a combination of NBPT and DCD;
9. Surface banded UAN;
10. Surface banded UAN with Agrotain Plus;
11. Coulter- banded UAN;
12. Coulter banded UAN with Agrotain Plus.

Starter fertilizer and coulter banded treatments were placed approximately 5 cm. below the soil surface in the row middles on 76.2 cm centers. All treatments were applied at the V-2 growth stage, at a rate of 90 kg N ha^{-1}for a total N application with starter of 112 kg N ha $^{-1}$. Application of nitrogen was delayed in the hopes of maximizing volatilization loss potential.

In 2009 the study continued at the Agronomy North Farm in Manhattan (39°12’30.6966” N lat.; 96°35’28.8852 W long.) and two additional locations, the KSU East Central Experiment Field near Ottawa (38°32’12.7242” N lat.; 95°14’38.7204” W long.) and the KSU South Central Experiment Field near Hutchinson (37°55’52.8522” N lat; 98°1’29.5674” N long.). The

Manhattan location was planted into double crop soybean (*Glycine max*) stubble following canola (*Brassica napus*), Ottawa was planted into double crop soybeans stubble following wheat (*Triticum aestivum*) and Hutchinson was planted into soybean stubble. All locations were no-till planted. Plots were 15.2 meters long and 3.04 meters (or 4 rows) wide at all locations except Manhattan which was 12.16 meters long and 3.04 (or 4 rows) wide because of space restrictions. All locations were arranged in a randomized complete block design with four replications. Starter fertilizer was applied to all treatments including the no N control at a rate of 22.4 kg ha^{-1} N as UAN. All N treatments were applied in 2009 at a rate of 67 kg N ha^{-1} unless otherwise noted, for a total N application rate of 101 kg N ha^{-1}. Specific treatments used in 2009 were:

1. Control, Starter N only
2. Broadcast granular urea applied in winter
3. Broadcast ESN applied in winter
4. Broadcast granular urea applied at planting
5. Broadcast granular urea treated with Agrotain. (NBPT, N-butyl-thiophosporic triamide);
6. Broadcast granular urea/Super U co-granulated with a combination of NBPT and DCD (dicyandiamide);
7. Broadcast granular ESN urea (urea coated with polyurethane);
8. A 50/50 ESN/urea blend;
9. Broadcast sprayed UAN;
10. Broadcast sprayed UAN plus Agrotain Plus, a combination of NBPT and DCD;
11. Broadcast sprayed UAN with Nutrisphere-N
12. Surface banded UAN;
13. Surface banded UAN with Agrotain Plus;
14. Surface banded UAN with Nutrisphere-N;
15. Coulter- banded UAN (Manhattan Only);
16. Broadcast prilled ammonium nitrate, a non-volatile N source (Ottawa and Hutchinson)
17. Broadcast granular urea at 101 kg N ha^{-1};
18. Broadcast granular urea at 134 kg N ha^{-1};
19. Broadcast granular urea at 168 kg N ha^{-1}.

At the Manhattan location the coulter banded UAN was placed approximately 5.0 cm below the soil surface in the row middles on 76.2 cm centers. At the Ottawa and Hutchinson locations, starter fertilizer was applied as UAN using a surface band application approximately 5 cm from the seed row. At Manhattan starter fertilizer was placed approximately 5 cm below and 5 cm to the side of the seed row. The winter broadcast urea and winter broadcast ESN was applied on February 4 in Manhattan; February 6 in Ottawa and February 27 in Hutchinson. The winter applications were applied to help quantify the efficiency of applying an application of nitrogen several months in advance of planting as this is a common production practice used in central KS to avoid ammonia volatilization. The 101, 134 and 168 kg ha^{-1} rate of broadcast urea were included in order to define a nitrogen response function at each location. All treatments (minus the winter treatments) were applied at the 4 leaf stage in Manhattan and at planting in Ottawa and Hutchinson. The coulter band treatment of UAN was used to represent a non-volatile N (NVN) source, and was used in both 2008 and 2009 at the Agronomy North Farm. At the Ottawa and Hutchinson locations, ammonium nitrate was used in place of coulter banded UAN as the NVN source.

Table 2.2 Key cultural practices used in conducting the experiments

Location	Manhattan 2008	Manhattan 2009	Ottawa 2009	Hutchinson 2009
Previous crop	Grain Sorghum	Double crop soybeans after canola	Double crop soybeans after wheat	Soybeans
Corn hybrid	RX785VT3	DKC52-59-VT3	DKC52-59-VT3	DKC50-44
Total N applied kg ha-1	112	90	90	90
Plant populations ha^{-1}	66,690	58,045	64,220	53,451
Planting date	23-Apr	23-Apr	20-May	21-May

Winter application	N/A	4-Feb	6-Feb	27-Feb
Spring application	16-May	18-May	20-May	21-May
Green leaves counted	24-Jul	24-Jul	22-Jul	4-Aug
Whole plant sampling	26-Aug	24-Aug	1-Sep	15-Sep
Harvest	22-Sep	14-Sep	7-Oct	15-Sep

Soil Sampling and Analysis

At each location the check plot in each replication was soil sampled to 15 cm for pH, available phosphorus (P), exchangeable potassium (K), soil organic matter (SOM) and a depth of 60 cm for profile nitrate at planting. Sampling was done using a hand probe, and samples consisted of 12 to 15 individual cores composited to form an individual composite sample. Values reported in Table 2.1 are the means of four composite samples. Analysis were done by the KSU Soil Testing lab using procedures described in Recommended Chemical Soil Testing Procedures for the North Central Region NCRR Publication no. 221 (1998)

Tissue Sampling and analysis

A number of measurements were made to document the relative effectiveness of each fertilizer treatment. Ear leaves were collected at the R1 growth stage (silking) to determine plant N content. Fifteen ear leaves were taken at random from the two center rows of the plot to form a uniform sample from the plot. All samples were dried to 60°C and ground to pass a 0.5-mm stainless steel sieve. Concentrations of N were analyzed using a sulfuric acid-hydrogen peroxide digest, and the extract containing ammonia was analyzed by a colorimetric procedure (nitropruside-sodium hypochlorite) using RFA Methodology No. A303-S072, Total Kjeldahl Nitrogen. Whole plant samples were taken at the R6 growth stage (black layer) to measure plant/stover N content at maturity. Ten plants were selected at random from the plot and cut off at ground level. Ears were removed, and the remaining vegetative portions of the plants were weighed and chopped, and a subsample was collected to determine N and dry matter content.

Grain Yield and Analysis

At the Manhattan location in both 2008 and 2009 and the Hutchinson location in 2009 plots were hand harvested by marking 5.3-m of plot and collecting all the ears in both rows of this area. Corn was then shelled using an Almaco mechanical sheller, a grain sample was collected for each plot to determine grain N content and grain moisture. The Ottawa location was mechanically harvested using a 2 row plot combine and grain samples were collected to determine individual plot moisture, test weight and N content. Yields from all locations were corrected to 155 g kg^{-1} moisture content. Nitrogen in the grain was determined by collecting a representative sub sample from each plot, drying, grinding, and analyzing for total N. Total N uptake was calculated as the total N content in stover and grain. This is a slight under estimate of total N uptake as it does not include the N content of the cob. Harvest index was calculated by dividing grain yield by total biomass produced (stover + grain). All plant analysis was done by the KSU Soil Testing Lab.

Statistical Analysis

Data for plant tissue, grain yield and treatment differences were analyzed using SAS version 9.1 with proc GLM at an alpha level of 0.05.

Results and Discussion

North Farm 2008

Treatments were applied when there was a forecasted window in which there was less than a 30% chance of precipitation for seven straight days in hopes of maximizing volatilization potential. In 2008 at the Agronomy North Farm, treatment application was delayed until May 16, when the corn was in the V-2 growth stage. Rainfall events occurred in the eight days following nitrogen application but all were less than the 10 mm (Table 2.3), the amount suggested as needed to incorporate broadcast applied urea and prevent volatilization (Fox and Hoffman, 1981 and Fox et al., 1986). Thus the potential for N loss through ammonia volatilization or immobilization loss of surface applied N was high because of moist soil at the time of application, frequent re-wetting from small rainfall events, good drying conditions and a large amount of low N content sorghum residue on the soil surface. In day 10-20 following nitrogen application there were three significant rainfall events with precipitation totaling 246 mm in that time period. Thus the potential for denitrification was also high for any materials which had significant amounts of N present as nitrate.

Table 2.3 Rainfall and temperature following nitrogen application on corn sites

	Manhattan 2008	Manhattan 2009	Ottawa 2009	Hutchinson 2009
Total rainfall 7 days after N application (mm)	3.05	0.00	7.87	0.76
Average Temp 7 days after N application (°C)	27.2°	29.1°	26.8°	27.9°

Source: KSU Weather Data Library

In 2008 surface application of granular urea and broadcast liquid UAN were significantly less effective at supplying N to the corn than other practices (Table 2.4). In this study conditions for ammonia volatilization were high for the 10 day period immediately after fertilizer application, with high levels of surface residue, moist soil surfaces, high temperatures and ET, and no significant rainfall to incorporate the fertilizer. The UAN was particularly affected, likely because it would have been prone to loss of N from both volatilization and immobilization when applied uniformly across the residue covered soil surface. Addition of the urease inhibitor NBPT as Agrotain or Agrotain Plus/Super U significantly improved performance of both products at this site, though less with UAN than urea. This is logical since only 50% of the UAN is urea, subject to volatilization. This is also likely because while the primary N loss from granular urea would have likely been due to volatilization, broadcast UAN would have been impacted by both immobilization and volatilization. Surface banding, which would have limited immobilization by reducing residue fertilizer contact, also increased performance of UAN. Addition of Agrotain Plus to the surface-banded UAN further improved performance, likely through urease inhibition and reducing ammonia volatilization. Coulter banding also provided good performance. Placing the UAN solutions below the residue would have limited both volatilization and immobilization, and the addition of Agrotain Plus urease inhibitor and nitrification inhibitor gave no improvement when UAN was coulter banded.

The broadcast polyurethane-coated ESN urea product provided excellent performance, particularly when used in combination with some immediately available urea.

Table 2.4 Manhattan 2008 results as affected by N product, timing, and method of application

Treatment	Earleaf N	Green leaves below ear	Total N Uptake	NUE	Grain Yield
	g kg^{-1}		kg N ha^{-1}	percent	Mg ha^{-1}
Control	15.67	1.75	55	na	4.91
Broadcast Urea	19.75	2.7	95	36	8.31
Broadcast Urea plus Agrotain	20.87	2.8	112	51	9.92
Broadcast Super U urea	19.04	3.45	116	55	10.26
Broadcast ESN	19.76	3.1	100	40	9.2
Broadcast 50/50 ESN/Urea	19.42	2.95	112	51	10.3
Broadcast UAN	17.76	2.2	88	30	7.3
Broadcast UAN + Agrotain Plus	18.19	2.35	96	36	8.32
Surface Banded UAN	21.3	2.6	94	35	8.49
Surface Banded UAN + Agrotain Plus	21.07	3.45	107	46	9.91
Coulter Banded UAN	22.3	3.2	103	43	9.46
Coulter Banded UAN+ Agrotain Plus	20.51	3	107	47	9.34
Pr>F	.0002	<.0001	<.0001	0.14	<.0001
CV	8.5	14.3	11.2	29.3	8.8
LSD (.05)	2.41	0.57	16	18	1.11
LSD (.10)	2.00	0.47	13	15	0.93

The combination of some starter followed by a blend of urea and ESN broadcast after planting is a simple application system that could provide some protection from leaching, denitrification, and volatilization. The all ESN treatment was less effective than the urea/ESN blend, likely a result of too slow release of N from the coated granule, re-enforcing that adequate available N must be present early in the season to optimize growth.

When evaluating the nitrogen use efficiency (total nitrogen taken up by the plant divided by the amount of nitrogen fertilizer applied) of treatments, it was observed that the broadcast urea, broadcast UAN, and surface band UAN treatments were not statistically different from each other at the alpha 0.05 level. When comparing broadcast urea nitrogen products, the broadcast Super U urea product resulted in an increase in nitrogen use efficiency that was statistically significant at the alpha 0.05 level. The broadcast urea+Agrotain (urease inhibitor alone) and broadcast ESN/Urea blend greatly improved nitrogen use efficiency when compared to the broadcast urea treatment, but not significantly at the alpha 0.05 level. The addition of Agrotain Plus to the broadcast UAN and surface band UAN both increased nitrogen use efficiency; however these increases were not significant. A strong correlation between nitrogen use efficiency and the number of green leaves below the ear leaf was also observed at the alpha 0.05 level (Can be found in chapter 4 Table 4.2).

Total nitrogen uptake showed similar results; there were no significant differences between the broadcast urea, broadcast UAN and surface band UAN treatments. The treatments of broadcast urea +Agrotain, broadcast Super U urea and broadcast ESN/Urea blend had total nitrogen uptake that was significantly higher than the broadcast urea treatment when an alpha 0.05 was used. The addition of Agrotain Plus to broadcast UAN and surface band UAN increased total nitrogen uptake when compared to broadcast UAN and surface band UAN without Agrotain Plus, however this increase was not statistically significant. A strong correlation ($r^2=0.66$) between total nitrogen uptake and the number of green leaves below the ear was also observed, at the alpha 0.05 level (Can be found in chapter 4 Table 4.2). The nitrogen use efficiency observed at this location in 2008 was well below the 50% nitrogen use efficiency estimate currently made by the Kansas State University Soil Testing Laboratory when making nitrogen recommendations with most treatments. It is possible that the weather observed in the 2008 growing season is the primary driver of the lower efficiency. In years when weather conditions result in lower nitrogen use efficiency, which may limit yield, a potential method to reduce loss of yield may be to develop a "side-dress" nitrogen application rate based on the number of green leaves below the ear.

North Farm 2009

As in 2008, spring treatments were applied when there was a forecast window in which there was less than 30% chance of precipitation for 10 days with hopes of maximizing the potential for volatilization. Nitrogen applications were made on May 18, 25 days after planting at approximately the V-3 growth stage. In 2009 at the Agronomy North Farm, there were fourteen days following nitrogen applications in which total rainfall was only 3.3 mm (Table 2.3). In the following 22 days, up to 36 days after nitrogen application there were four significant rainfall events with precipitation totaling 210 mm in that time period. The potential for N loss through ammonia volatilization or immobilization loss of surface applied N was high because of moist soil at the time of application, good drying conditions after application and a large amount of crop residue on the soil surface. The potential for denitrification was also high in this experiment because of the significant rainfall events which occurred after nitrification had likely occurred.

The results from this site are summarized in Table 2.5. In 2009 at Manhattan, corn responded to the highest N rate applied, 190 kg N ha^{-1} as granular urea plus starter applied in the spring. The broadcast treatment of 67 kg N ha^{-1} as urea applied in winter was significantly lower yielding than any of the spring applied urea treatments. While applying the nitrogen in February may have reduced ammonia volatilization potential due to cool temperatures and low ET, it provided a long window for nitrification and likely led to substantially more denitrification losses. Applying polymer coated urea in winter gave slightly better performance, but was still not as effective as delaying application until after planting.

The spring application of urea performed significantly better than when applied in winter, with little additional increase in yield observed by the use of additives such as urease or nitrification inhibitors, or the use of alternative fertilizer products such as ESN applied at planting. The broadcast application of a 50% urea/ESN blend and the urea with Agrotain Plus treatments were the highest yielding treatments at the Agronomy North Farm in 2009, though the differences were not significantly different from spring urea, using an alpha level of 0.05.

Granular urea was more effective than broadcast UAN at this site, likely due to the high level of surface residue capable of immobilizing the uniformly applied UAN. Surface banding, concentrating the UAN to increase movement through the residue, did not improve UAN performance compared to broadcasting. However coulter banding, physically placing the fertilizer below the residue, did show improvement. No benefit was seen to adding Nutrisphere N to broadcast or surface banded UAN at this site.

Table 2.5 Manhattan 2009 results as affected by N product, timing, and method of application

Treatment	Earleaf N	Green leaves below ear	Total N Uptake	NUE	Grain Yield
	g kg^{-1}		kg N ha^{-1}	percent	Mg ha^{-1}
Control	21.03	3.15	74	na	6.54
Broadcast Winter Urea	23.23	4.00	100	30	8.64
Broadcast Winter ESN	23.27	4.10	110	41	9.67
Broadcast Urea	25.30	5.15	128	61	10.36
Broadcast Urea plus Agrotain	25.63	5.75	131	63	10.60
Broadcast Super U urea	23.83	4.80	127	60	10.86
Broadcast ESN	23.55	5.55	124	56	10.49
Broadcast 50/50 ESN/Urea	23.95	5.20	124	57	10.91
Broadcast UAN	23.65	4.30	113	44	9.28
Broadcast UAN + Agrotain Plus	23.63	4.50	104	34	8.88
Broadcast UAN+ Nutra-sphere	23.43	3.65	91	20	8.04
Surface Banded UAN	22.78	4.30	103	33	9.28
Surface Banded UAN + Agrotain Plus	24.43	5.05	112	43	9.82
Surface Banded UAN+ Nutra-sphere	23.90	4.15	103	33	9.27
Coulter Banded UAN	23.45	5.35	119	46	10.16
Broadcast 101 kg Urea	26.10	5.45	146	55	11.36
Broadcast 134 kg Urea	26.05	6.10	144	42	11.21
Broadcast 168 kg Urea	26.15	6.00	167	47	12.29
Pr>F	<.0001	<.0001	<.0001	.0086	<.0001
CV	5.5	9.27	11.2	36	10.6
LSD (.05)	1.88	0.97	19	23	1.41
LSD (.10)	1.57	0.81	16	19	1.23

In 2009 three additional higher rates of N were applied in order to define the N response function. This response curve was used to predict the equivalent urea rate that would need to be applied to achieve similar yields as were obtained from different N products and application methods (Figure 2.1)

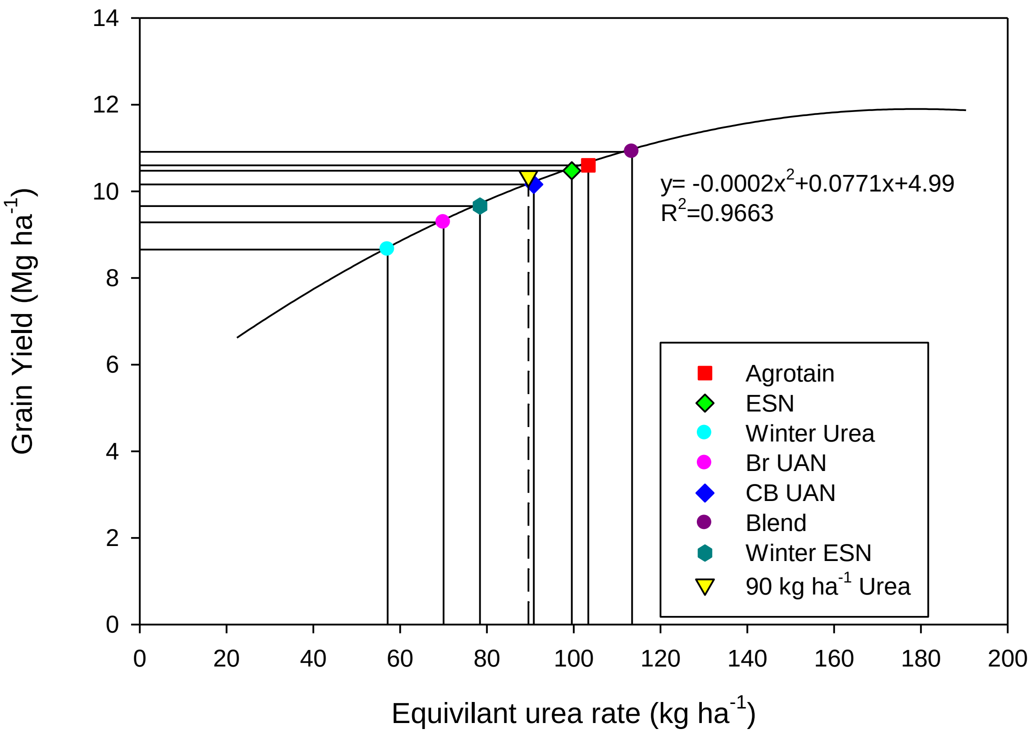

Figure 2-1 Impact of N products and practices on corn yields at Manhattan, 2009

In Figure 2.1 yields of all different N treatments can be compared to the spring broadcast application of urea. All treatments compared were applied at a total rate of 90 kg N ha^{-1}. The standard urea treatment is indicated by a dashed vertical line. Any treatment to the right of the dashed line produced higher yields than urea with the same rate of applied N, indicating a more effective N application method. Those to the left of urea were less effective. The application of an ESN/urea blend at 90 kg N ha^{-1} produced a yield equivalent to that obtained from applying 113 kg N ha^{-1} broadcast urea. Broadcast urea with Agrotain was equivalent to applying 103 kg N ha^{-1} broadcast urea and broadcast ESN was equivalent to applying 100 kg N ha^{-1} broadcast urea. In a time of such volatility with N prices, being able to effectively gain an additional 22 kg ha^{-1} of N as urea, could prove to be very beneficial.

Similarly the application of Winter ESN was equivalent to applying 78 kg N ha^{-1} as spring broadcast urea, broadcast UAN was equivalent to applying 70 kg N ha^{-1}, and urea broadcast in the winter was equivalent to only applying 57 kg N ha^{-1} in the spring. This loss of N is important to consider when evaluating how and when to apply N. If you are applying 90 kg ha^{-1} of N and only recovering 57 to 78 kg N ha^{-1} it would be beneficial to use a more efficient product or practice to reduce N loss.

Comparing the nitrogen use efficiency of different methods of application (Table 2.5), the broadcast urea and broadcast UAN treatment s were not significantly different. The surface band UAN treatment, however, was significantly lower than the broadcast urea treatment. Applying the N in the winter resulted in reduced nitrogen use efficiency, as the broadcast winter urea and broadcast winter ESN both resulted in significantly lower NUE than the broadcast urea in the spring. The broadcast urea+Agrotain, broadcast urea+Super U, broadcast ESN and broadcast ESN/urea blend all gave similar nitrogen use efficiencies as compared to broadcast urea in 2009 at this location. The addition of Agrotain Plus to broadcast and surface banded UAN did not significantly affect the nitrogen use efficiency when compared to broadcast and surface band UAN alone, although the addition of Nutrisphere-N to broadcast UAN did significantly decrease the nitrogen use efficiency in comparison to the broadcast UAN treatment.

Total nitrogen uptake obtained from broadcast urea was significantly higher than the surface banded UAN but not the broadcast UAN (Table2.5). The winter application of broadcast urea resulted in a significantly lower total N uptake compared to spring broadcast urea, but the winter ESN treatment was not significantly different than spring urea. Addition of Agrotain Plus and Nutrisphere-N gave no improvement in total N uptake of broadcast UAN or surface band UAN treatments. Broadcast urea+Agrotain, broadcast urea +Super U, broadcast ESN and broadcast ESN/urea blend treatments did not result in improvements in total nitrogen uptake when compared to broadcast urea.

Following the trend which was observed in 2008 at the Manhattan location, there is a strong correlation between the number of green leaves below the ear and nitrogen use efficiency (0.64) and total nitrogen uptake (0.79) (Table 4.2). In fact there is a stronger correlation between the green leaves below the ear and these two measurements in 2009 than in 2008.

Unlike the 2008 growing season, in 2009 some nitrogen use efficiencies were above 50% with select treatments. Some combinations of application method, timing and nitrogen products do appear to have the potential to increase nitrogen use efficiency. Conversely, some combinations of products and application timing or nitrogen products appear to be less efficient and decrease nitrogen use efficiency. When these practices are identified, farmers should seriously consider shifting towards practices or technologies that result in higher nitrogen recovery without the application of additional nitrogen.

Ottawa 2009

In 2009, grain yields were found to be much lower at the Ottawa location than the Manhattan location (Table 2.6). This can likely be attributed to delayed planting due to heavy spring rains, and significant green snap of plants which occurred with a thunderstorm shortly after tasseling. Approximately 30 % of the plants at this site were lost due to stalk breakage. The potential for N loss due to ammonia volatilization, immobilization and denitrification were also very high at this site. Ear leaf N content was very low at this location, well below the 27 g kg^{-1} suggested critical level. Ammonia volatilization was likely high as indicated by the better performance of the non-volatile ammonium nitrate application. Conditions were excellent for N loss from both volatilization and denitrification following N applications. Soil conditions at the time of N application were moist, followed by a five day period of no rainfall when temperatures were high. In the three weeks following fertilization, there were several rainfall events (<25.4 mm total) followed by a period of heavy rainfall (>102 mm) which resulted in the potential for denitrification (Table 2.3).

In general N uptake and N recovery were low regardless of sources or products used. In 2009 this was likely due to both a high ammonia volatilization and denitrification potential over an extended period, and the reduced effective plant stand due to greensnap.

Table 2.6 Ottawa 2009 results as affected by N product, timing, and method of application

Treatment	Earleaf N	Green leaves below ear	Total N Uptake	NUE	Grain Yield
	g kg^{-1}		kg N ha^{-1}	percent	Mg ha^{-1}
Control	13.95	3.35	49	na	4.51
Broadcast Winter Urea	16.03	4.25	56	7	4.76
Broadcast Winter ESN	16.15	5.25	61	13	5.27
Broadcast Urea	15.58	5.30	62	14	5.45
Broadcast Urea plus Agrotain	16.15	4.95	66	19	5.57
Broadcast Super U urea	18.10	5.40	60	11	5.68
Broadcast ESN	17.08	5.85	66	18	5.52
Broadcast 50/50 ESN/Urea	17.98	5.30	58	13	5.16
Broadcast UAN	14.85	3.80	59	11	5.07
Broadcast UAN + Agrotain Plus	15.50	4.35	59	10	4.96
Broadcast UAN+ Nutra-sphere	15.03	4.05	53	6	4.46
Surface Banded UAN	15.85	4.10	58	9	4.98
Surface Banded UAN + Agrotain Plus	16.85	4.50	62	13	4.91
Surface Banded UAN+ Nutra-sphere	16.43	4.30	56	7	5.04
Ammonium nitrate	18.20	5.80	74	27	6.63
Broadcast 101 kg Urea	16.65	5.10	68	15	5.79
Broadcast 134 kg Urea	17.58	5.80	67	9	6.01
Broadcast 168 kg Urea	17.80	6.20	77	13	6.75
Pr>F	.2124	<.0001	<.0001	.0451	<.0001
CV	12.8	10.8	11.4	63	9.6
LSD (.05)	2.99	0.75	10	11	0.73
LSD (.10)	2.49	0.62	8.3	9	0.61

At this location, an N response curve was developed with the use of high rates of broadcast urea. This response curve was used to predict the equivalent urea rate that would need to be applied to achieve similar yields as different N products and application methods (Fig 2.2)

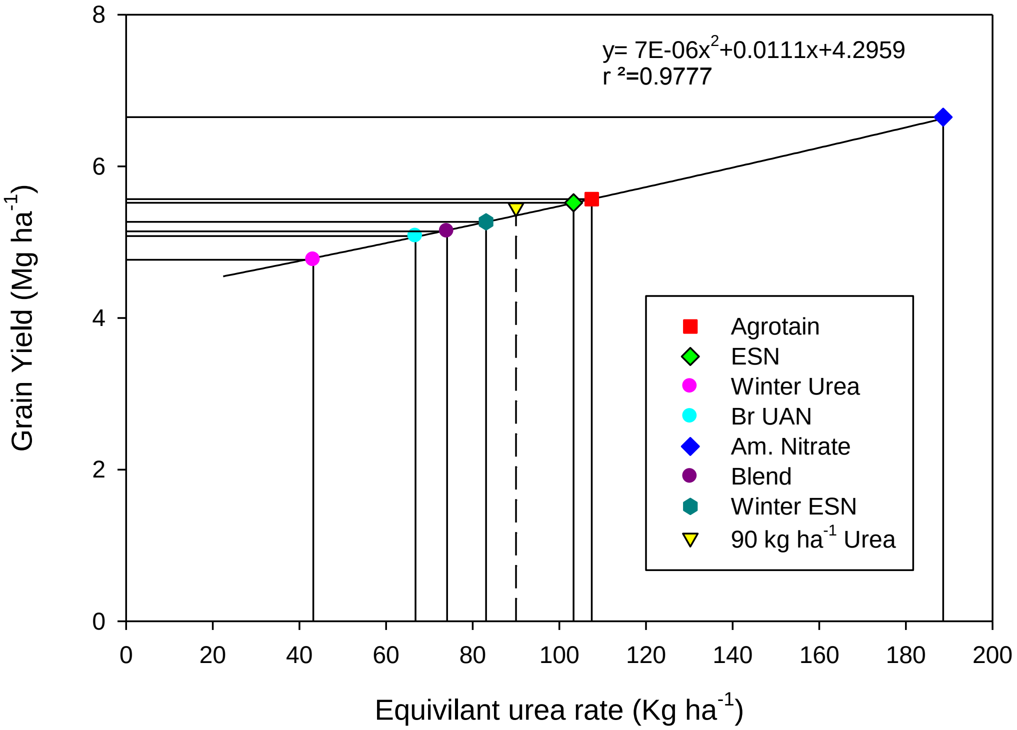

Figure 2-2 Impact of N products and practices on corn yields at Ottawa, 2009

As can be seen in Figure 2.2 the crop responded to the highest rate of N applied as urea, and the curve gives no indications of leveling off. The recovery of applied N was very low, indicating an extreme level of N loss. As in Figure 2.1, the other N treatment yields are plotted on the urea based response curve, and those treatments to the right of the equivalent rate of urea are much more efficient, and those to the left are less efficient. The application of 90 kg N ha^{-1} as ammonium nitrate plus starter was the equivalent of applying 189 kg N ha^{-1} of broadcast urea. Since ammonium nitrate is not subject to ammonia volatilization loss, this makes it clear that high levels of ammonia volatilization loss likely occurred at this site. The broadcast applications of urea+Agrotain was the equivalent of applying 107 kg N ha^{-1} of broadcast urea, similarly the broadcast urea coated with ESN was the equivalent of applying 103 kg N ha^{-1} of broadcast urea. This adds additional evidence that ammonia volatilization was a significant issue at this site.

However, the low yield, N content in the leaf, N uptake and total N recovery all strongly suggest that extreme N loss from some other mechanism such as denitrification likely occurred at this site in 2009 also. The non volatile N application of ammonium nitrate did result in a significant increase in nitrogen use efficiency compared to all other treatments, but still only 27% of the N applied was recovered by the plant, far less than the 50% assumed in the KSU nitrogen recommendation equation.

Hutchinson 2009

In 2009, grain yields were good at this location. However plant stands were variable both in plant numbers and days from planting to emergence, due to a problem with seed slot closure which impacted plant maturity throughout the growing season. This resulted in a great amount of variability in yield and N recovery, and no differences among N treatments were observed. Conditions at this location were conducive to N loss from ammonia volatilization based on the lack of rainfall in the thirteen days following N application (Table 2.3). There was also a potential for immobilization due to high residue levels. No differences were observed in earleaf N concentrations, in fact no response to the addition of N was observed further showing that the variability present had a significant impact on our results. Despite the fact that there were no statistical differences in yield, there may be some supporting conclusions that can be made using the N response curve to correlate equivalent urea rate of N products and practices. As with the Ottawa and Manhattan locations, at Hutchinson high rates of broadcast urea were applied to establish an N response curve. The predicted urea rate to achieve similar yields followed the same trends as the other two locations in 2009. The application of ammonium nitrate as a non volatile N was the equivalent of applying 204 kg N ha^{-1} as spring broadcast urea, the broadcast ESN application was the equivalent of applying 162 kg N ha^{-1} as broadcast urea and the ESN/Urea blend was the equivalent of applying 162 kg N ha^{-1} as broadcast urea. Treatments found to have different results than other locations were the broadcast urea+Agrotain and broadcast UAN applications. The broadcast urea+Agrotain was only equivalent to applying 83 kg N ha^{-1} of broadcast urea whereas the broadcast UAN treatment was equivalent to applying 99 kg N ha^{-1} broadcast urea. Practices that proved to be less effective than broadcast urea were winter applied broadcast ESN, which was equivalent to applying 57 kg N ha^{-1} as broadcast urea and winter applied broadcast urea which was equivalent to applying only 33 kg N ha^{-1} as spring broadcast urea.

Differences in plant height and maturity plagued numerous measurements that were taken throughout the growing season. No difference was seen in the nitrogen use efficiencies of different application methods, timing and products. The results of total N uptake were variable as well, and no strong conclusions can be made regarding the differences between treatments.

Table 2.7 Hutchinson 2009 results as affected by N product, timing, and method of application

Treatment	Earleaf N	Green leaves below ear	Total N Uptake	NUE	Grain Yield
	g kg^{-1}		kg N ha^{-1}	percent	Mg ha^{-1}
Control	21.63	3.00	107	na	7.55
Broadcast Winter Urea	21.28	3.25	124	19	7.84
Broadcast Winter ESN	21.53	3.80	130	25	8.06
Broadcast Urea	22.15	3.80	154	49	8.86
Broadcast Urea plus Agrotain	21.90	4.35	146	44	8.34
Broadcast Super U urea	21.63	3.40	144	42	8.67
Broadcast ESN	21.28	4.00	136	33	8.77
Broadcast 50/50 ESN/Urea	21.95	3.40	129	24	7.58
Broadcast UAN	22.25	4.05	144	42	8.44
Broadcast UAN + Agrotain Plus	21.93	4.20	143	41	8.63
Broadcast UAN+ Nutra-sphere	22.90	3.55	143	40	8.99
Surface Banded UAN	20.25	3.95	124	19	7.88
Surface Banded UAN + Agrotain Plus	20.95	4.00	144	41	8.69
Surface Banded UAN+ Nutra-sphere	21.53	3.45	123	18	7.86
Ammonium nitrate	22.20	4.65	149	47	9.11
Broadcast 100.8 kg Urea	21.85	4.45	163	45	8.68
Broadcast 134.4 kg Urea	22.68	4.20	145	24	7.96
Broadcast 168 kg Urea	22.73	4.50	183	40	9.25
Pr>F	0.81	0.038	0.0005	0.719	0.4
CV	7.3	17.4	13.3	70.4	12.7
LSD (.05)	NS	NS	NS	NS	NS
LSD (.10)	NS	NS	NS	NS	NS

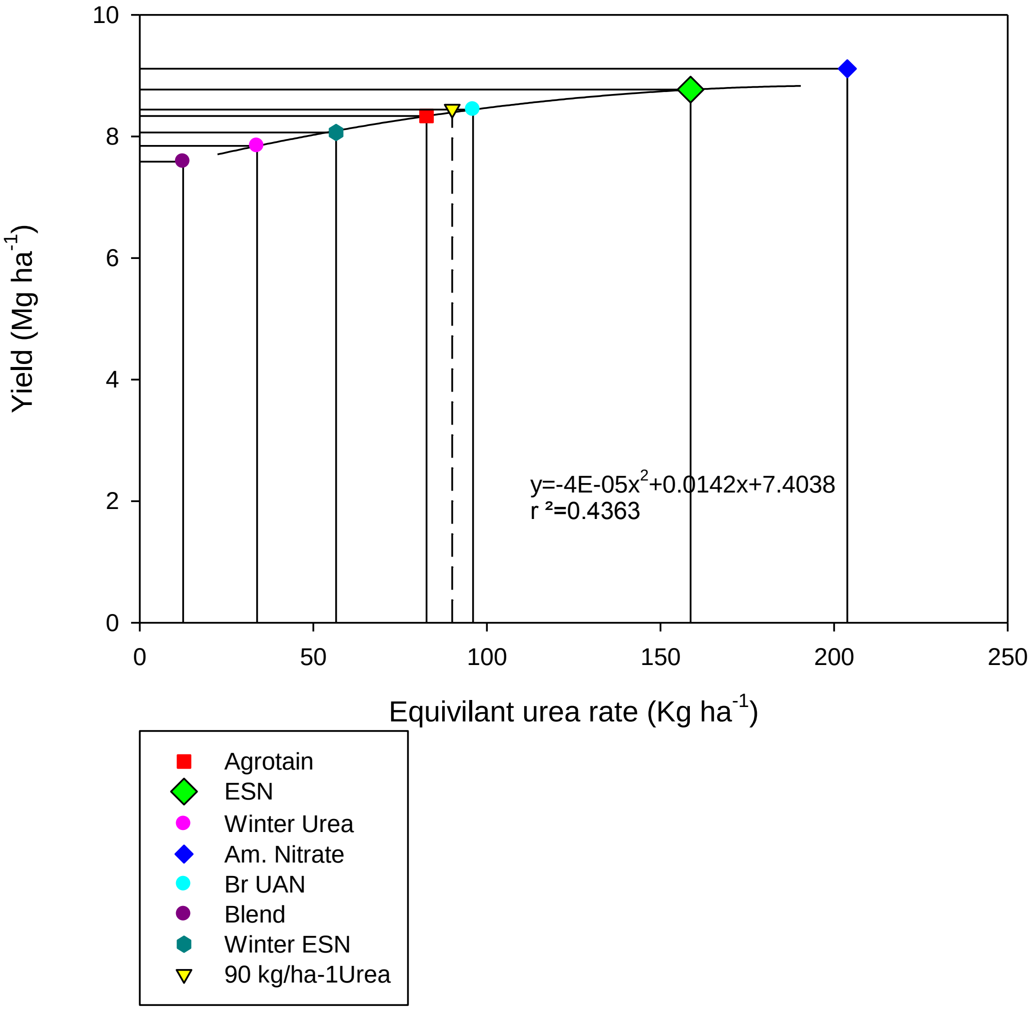

Figure 2-3 Impact of N products and practices on corn yields at Hutchinson, 2009

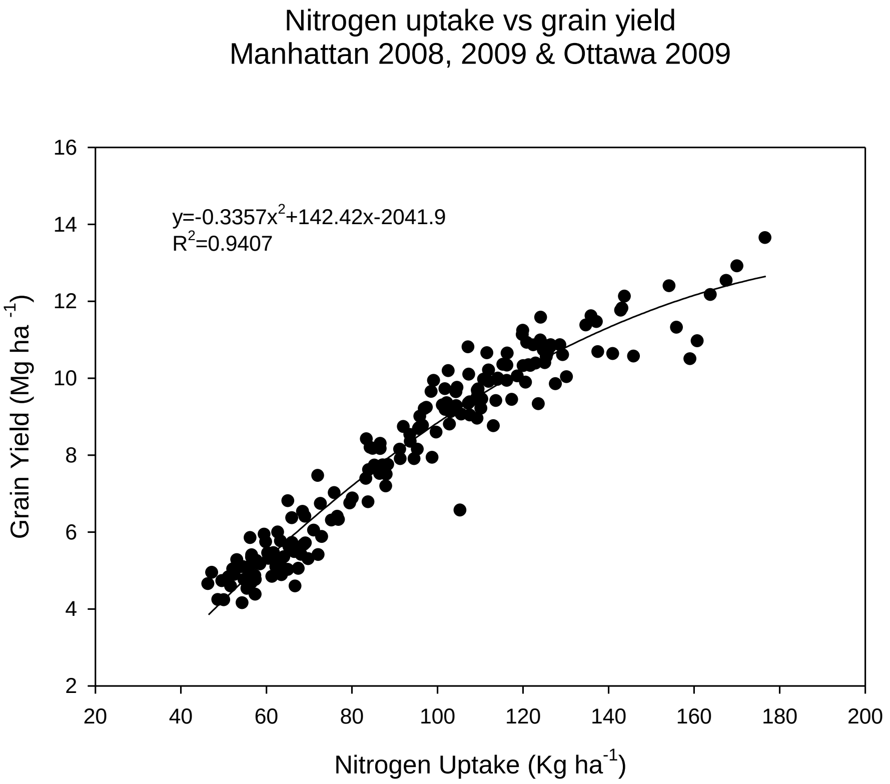

Figure 2-4 Effect of nitrogen uptake on grain yield across all nitrogen treatments

A strong relationship between the amount of nitrogen that was taken up by the plant (nitrogen uptake) and the amount of grain yield subsequently produced was found. Figure 2.4 demonstrates this relationship. In this figure all nitrogen application treatments and nitrogen application rates are combined. This shows the importance of applying N fertilizers to corn in Kansas, and getting the applied nitrogen into the plant. Note also that the equation used to describe the data is a quadratic equation, and that the increase in grain yield per unit of N uptake decreases as N uptake increases. This relationship, commonly referred to as utilization efficiency, is summarized in figure 2.5. This basically is the result of the plants need for N becoming met or saturated, and other factors such as light, leaf area, water or CO_2 becoming the factor limiting photosynthesis and yield.

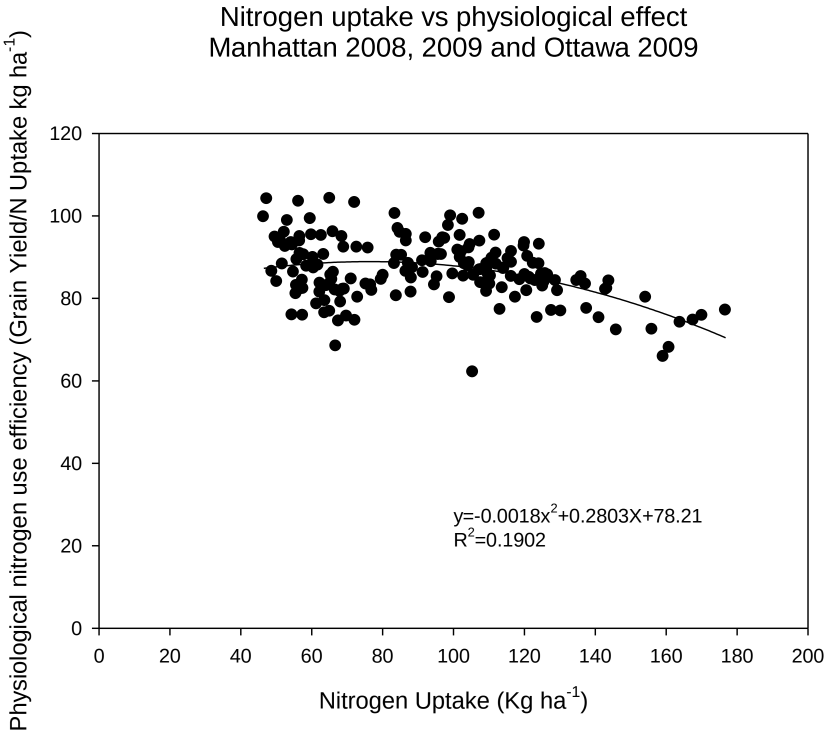

Figure 2-5 Effect of nitrogen uptake vs physiological nitrogen use efficiency across all treatments.

Examining this relationship more closely, you can see that when physiological nitrogen use efficiency, which is calculated using the grain yield kg ha^{-1} divided by the nitrogen uptake kg ha^{-1}, is compared to nitrogen uptake, there is a range where increasing nitrogen uptake results in increased grain yield, though the yield per unit of nitrogen uptake remains constant or nearly constant. However as total nitrogen uptake continues to increase, grain yield/nitrogen uptake does not, and will in fact start to decrease. This is explained by “luxury consumption of N” beyond the need of the plant occurs, and increased nitrogen uptake does not result in an increase in grain yields.

The most common way people think of increasing N uptake in corn is increasing the N supply. Figure 2.6 shows the relationship between N application rate and plant N uptake observed at Manhattan and Ottawa in 2009. At both sites N uptake increases significantly as N rate applied increases. It is interesting however to note the differences in shape and slope of the two curves. At Manhattan, N uptake increases rapidly and near linearly with the first 123 kg N applied. As N rate continues to increase, the rate of N uptake decreases, reaching a maximum as total application approaches 200kg N ha^{-1}. The response to N at Ottawa in terms of N uptake is much less dynamic, with a much lower rate of N utilization, N uptake per unit of N applied. So while increasing N rate will likely increase N uptake in many cases, the rate of N uptake may well vary with locations, N loss potential, and fertilizer material applied.

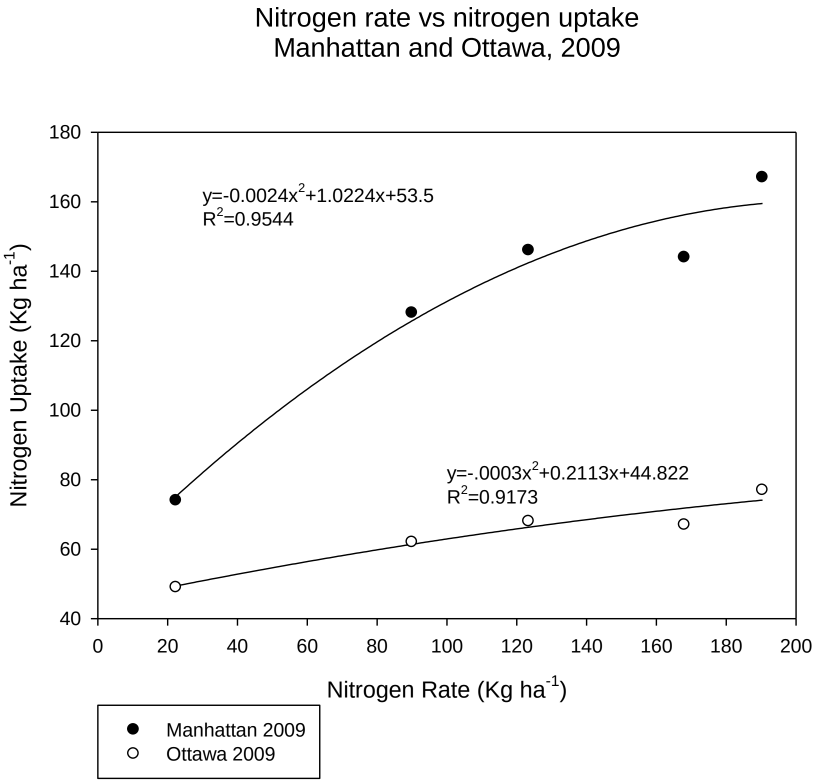

Figure 2-6 Nitrogen uptake as a function of increasing nitrogen rate of spring broadcast urea, Manhattan and Ottawa 2009.

This is clearly shown in Figure 2.7, where yield as a function of N uptake is shown holding N application rate constant, but comparing various N management strategies, products or application methods. From Figure 2.7 it is evident that nitrogen uptake is not simply a function of nitrogen rate applied, but also a function of how efficient the fertilizer application system is at supplying N to the plant. Upon further investigation, calculating the N recovery percentage, or NUE of these different N strategies and comparing the nitrogen use efficiency and nitrogen uptake of all treatments applied at a constant 90 kg ha^{-1} rate, suggests that nitrogen uptake can be influenced as much by the percent recovery of applied nitrogen (NUE), as N rate, Figure 2.8.

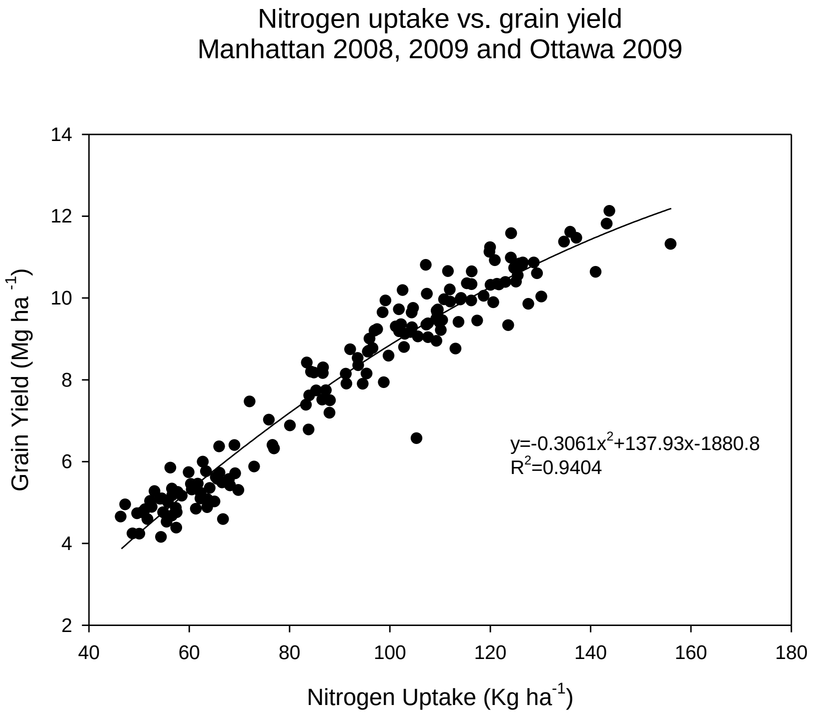

Figure 2-7 Nitrogen uptake vs grain yield using 90 kg ha^{-1} applications at Manhattan 2008, 2009 and Ottawa 2009.

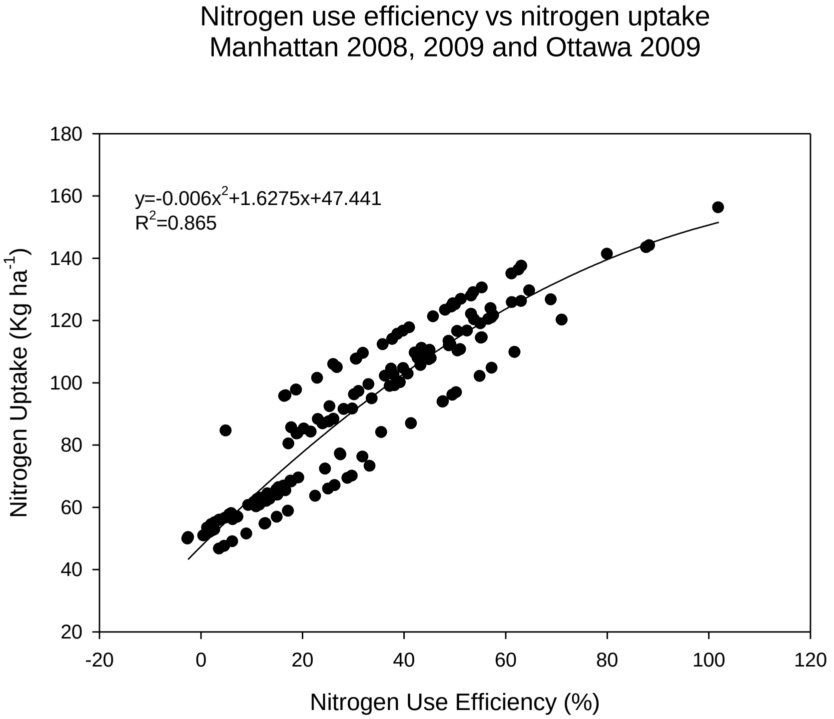

Figure 2-8 Nitrogen use efficiency (calculated as percent of N applied as fertilizer recovered in the plant) vs nitrogen uptake obtained using different N management application

strategies, all applied at a constant 90 kg ha-1 application rate. Manhattan 2008, 2009 and Ottawa 2009.

Figure 2.9 represents the relationship between nitrogen use efficiency and grain yield when the Manhattan 2008, 2009, and Ottawa 2009 results are combined, only using the 90kg ha^{-1} N treatments. As you can see from this figure, nitrogen use efficiency clearly impacts nitrogen uptake and subsequently grain yield. When comparing the NUE of treatments applied in both years in Manhattan; the NUE found from broadcast urea+Agrotain was 57%, broadcast urea+Super U was 58%, broadcast ESN coated urea was 48%, broadcast ESN/Urea blend was 54% and broadcast urea was 49%. Treatments that resulted in lower NUE were broadcast UAN with 37%, surface banded UAN with 34%, broadcast winter applied urea with 30% and broadcast winter ESN coated urea with 41%. The nitrogen use efficiency of the 101, 134 and 168 kg ha^{-1} broadcast urea were 55%, 42% and 47%, respectively. This strengthens the argument that increasing nitrogen rate is not the only way to increase nitrogen uptake and yield.

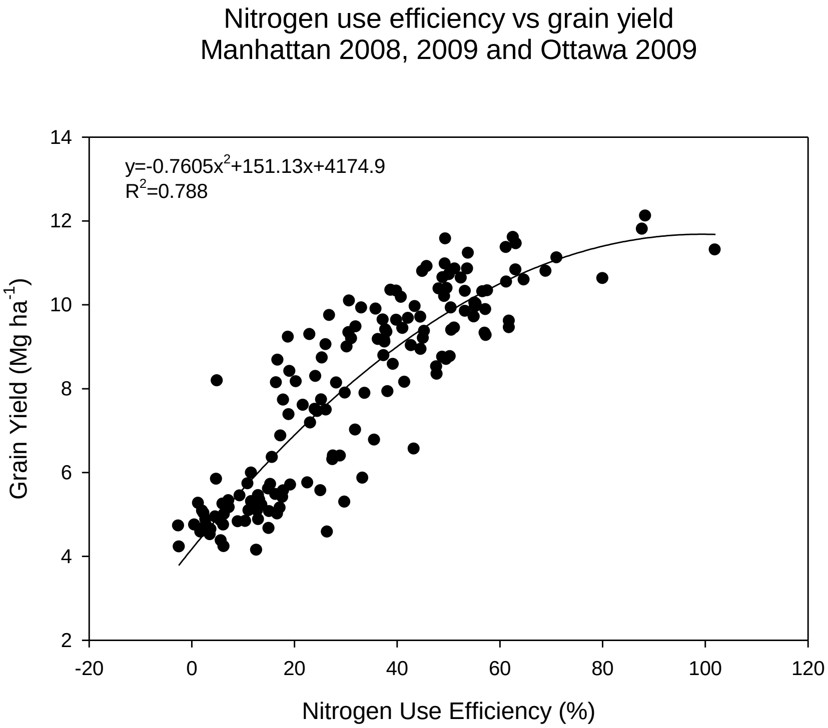

Figure 2-9 Nitrogen use efficiency vs grain yield using 90 kg ha^{-1} applications at Manhattan 2008, 2009 and Ottawa 2009.

Conclusions

Timing of application, method of application and nitrogen additives all can result in different nitrogen use efficiency in no-till corn. The delayed release of winter applied ESN resulted in higher yields than winter applied urea, but is not as efficient as spring applied urea, ESN or ESN/urea blend. Winter applications of urea are not recommended, as higher nitrogen rates will be required to match the performance of spring applied urea. The all ESN treatment was less effective than the ESN/Urea blend indicating that a blended product would be the best option as it would pair immediately supplied urea to the growing crop with slowly released nitrogen that will be available for plant uptake over time. The use of an ESN/urea blend has the added benefit of reducing the cost to producers compared to an all ESN option.

Granular urea products were found to be more efficient than UAN applications in this study. When UAN is applied, however, method of application is important to consider. When high residue levels exist, sub-surface banded UAN performed significantly better than surface applied UAN.

When conditions exist for nitrogen loss through ammonia volatilization, the use of urease inhibitors can increase yields and improve nitrogen use efficiency. The use of a Nutrasphere-N was not found to be beneficial, even when conditions for denitrification existed.

Many producers, understanding that nitrogen loss is a factor to consider, increase their nitrogen rates to compensate for nitrogen losses, and avoid sacrificing yield. However, when the relationships between nitrogen uptake, grain yield and nitrogen use efficiency is examined, it is apparent that simply applying more nitrogen may not be the most efficient or cost effective way to increase nitrogen uptake. Management decisions that utilize more efficient application practices such as the use of broadcast urea, broadcast urea+Agrotain, broadcast urea+Super U and the ESN/Urea blend are needed.

The use of these tools to prevent nitrogen loss and increase nitrogen use efficiency can improve producers’ productivity when managed correctly. Just as importantly, using these improved technologies will allow producers to reduce nitrogen emissions and have better environmental stewardship

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CHAPTER 3 - Use of Nitrogen Management Products and Practices to Enhance Yield and Nitrogen Use Efficiency in No-Till Grain Sorghum

Abstract

Long-term research shows that nitrogen (N) fertilizer is usually needed to optimize production of grain sorghum (*Sorghum bicolor* L.) in Kansas. Grain sorghum is grown under dryland conditions across the state and is typically grown by using no-till production systems. These systems leave a large amount of surface residue on the soil surface, which can lead to ammonia volatilization losses from surface applications of urea-containing fertilizers and immobilization of N fertilizers placed in contact with the residue. Leaching and denitrification can also be a problem on some soils. A project was initiated in 2008 and expanded in 2009, to quantify the effect of a number of commercially available products marketed to enhance N utilization by sorghum. Conditions at the sites used varied widely in 2009 with conditions present which could lead to ammonia volatilization and immobilization at most sites, and denitrification and leaching at others. At locations where N loss limited yield, Manhattan and Ottawa, the use of these products and practices enhanced yield. However at locations where N loss was minimal, or low yields limited N response, Tribune and Partridge, the use of these practices was not helpful

Introduction

Grain sorghum (*Sorghum bicolor* (L.) Moench) is an important crop grown under conservation tillage in the central and southern Great Plains. Grain sorghum acreage has the potential for increase, particularly in areas of the Great Plains where declining water tables are affecting the economy of irrigation for water-intensive crops. Approximately 1.2 million ha of grain sorghum are currently grown each year in Kansas (USDA-NASS, 2009) and of the summer crops routinely grown in this region, grain sorghum is the most drought tolerant. Much of the sorghum is currently grown utilizing no-tillage (Kastens et al., 2006) as a means of conserving yield limiting water. One factor that continues to be a problem in high residue farming systems (conservation tillage) however, is N fertilizer management. Research is Kansas has shown that many of the N management practices commonly used in the production of sorghum today may result in low N recovery.

Performance of N fertilizers that contain urea, including UAN, may be affected when broadcast on heavy residue cover through the processes of ammonia volatilization (Lamond, 1991). Urea based nitrogen fertilizer products are susceptible to volatilization losses of nitrogen if surface applied and not incorporated. Urease enzymes in the soil and plant residues convert the urea component to free ammonia. If this conversion occurs at the soil surface and is accompanied by warm sunny days, as much as 15-20% of the urea-based nitrogen may volatilize within a week after application (Bundy, 2001). If a half inch or more of rain occurs within the first 24 hours after surface application, the risk of subsequent volatilization also drops to essentially zero (Bundy, 2001). The risk of volatilization loss is greatest with high-residue cropping systems, moist soil surface, warm sunny days after application, and surface soil pH levels greater than 7.0. Volatilization risk is also higher on lighter textured soils with low buffer capacity (Nielson, 2006)

Another sorghum production practice which may decrease nitrogen recovery by crops is the timing of nitrogen application. It is a common practice in Kansas to broadcast surface apply N as urea in late winter or early spring to wheat stubble in hopes of reducing ammonia volatilization. But this practice could lead to increased immobilization by soil organisms, in addition to enhanced denitrification or leaching. Soil microbes that decompose high carbon-content plant residues to organic matter use soil N during the decomposition process (Killpack and Buchholz, 1993). Consequently, the nitrogen from the soil or surface-applied fertilizer is “tied up” in the decomposing organic matter and is temporarily unavailable for plant uptake until decomposition is completed, and the microbial population decreases, and mineralization of the nitrogen occurs. Such immobilization of soil N applied fertilizer can be especially prevalent in high-residue no-till cropping systems. Unfortunately, applying N fertilizer in the fall or winter to corn residues has not been shown to reduce N immobilization or speed residue decomposition (Nielson, 2006).

Considering these obstacles in sorghum production, a better understanding of the relative efficiencies available from different N fertilizer products, fertilizer additives, and application practices has the potential to allow producers to select practices which are more efficient and potentially more profitable. Urease inhibitors, nitrification inhibitors, or polymer coated urea represent various forms of nitrogen loss “insurance” that add cost to nitrogen management program. Like any insurance policy, the policy will “pay off” only if conditions are suitable for N loss to occur prior to plant uptake (Nielsen, 2006). One such product available today is controlled release fertilizer. Controlled release fertilizer products have been available for more than thirty years. Best known of these products is sulfur-coated urea. Unfortunately, sulfur coated urea has not proven to be a useful agronomic product, in part because the cost of coating is high relative to the cost of N fertilizer. Recent advances in polymer technology have created a whole new type of controlled release fertilizer. Agrium Inc. has introduced a PCU (polymer coated urea) called ESN that is priced competitively in the agricultural market (Schwab and Murdock 2005). In order for this product to be agronomically useful however, the producer must be able to reduce the rate of applied nitrogen by the amount expected to be saved as a result of using the additive. To be economical, the cost of the saved N must exceed the price of the additive (Schwab and Murdock, 2005).

Fertilizer additives of interest which could impact N use efficiency currently on the market include the urease inhibitor NBPT (N—(-(n-butyl)thiophosphoric triamide) which goes by the trade name Agrotain, Agrotain Plus that combines NBPT with the nitrification inhibitor DCD (dicyandiamide). A cogranulated urea product with NBPT and DCD marketed as Super U, and the product Nutrasphere-N, a maleic-itaconic co-polymer that claims to “work in the soil at the molecular level to prevent leaching and volatilization by creating an active shield that manages nitrogen in the soil. This shield prevents the action of urease in volatilization and slows nitrification reactions, which lead to nitrate leaching, and allows the plant better access to stable forms of nitrogen throughout the growing season”. (Specialty Fertilizer Products web site).

Application method, particularly as used with liquid N products such as UAN, can also be used to reduce N loss, particularly in the reduced or no-till production systems that are increasing popular in the central great plains, and that leave a layer of crop residues on the soil surface which can result in increased soil water content and reduced soil temperatures during the growing season. This can lead to increased N losses through leaching and denitrification (Thomas et al. 1973; Unger, 1978). The movement to no-till cropping systems, combined with the production practice of applying nitrogen as broadcast urea-ammonium nitrate (UAN) solutions or granular urea can lead to nitrogen being unavailable for plant uptake due to immobilization. The application method used to apply nitrogen is an important factor when trying to increase nitrogen uptake and efficiency. Urea-ammonium nitrate solution and urea make up 47 and 30%, respectively, of the N fertilizer used in the Mid-Atlantic area (Berry and Harget, 1991). Mengel et al., 1982, found injection of UAN below the residue consistently outperformed surface broadcast UAN or broadcast urea in no-till corn in Indiana. Fox found in Pennsylvania that nitrogen fertilizer use efficiency of UAN applied to no-till corn was in the order: at-plant spray<at-plant band< sidedress band< sidedress inject (Fox, 1993).

The objective of this study was to quantify some of the relationships found between N source, the use of fertilizer additives, method of application and time of N application and N loss/use efficiency found in no-till sorghum production in Kansas, with the ultimate goal of assisting farmers in selecting specific combinations of fertilizer products, additives and application techniques that could enhance yield and profitability on their farm.

Materials and Methods

Field experiments were carried out at three locations in 2008 and four locations in 2009 to evaluate the relative nitrogen use efficiency obtained in no-till grain sorghum using a number of different N fertilizer sources, application methods, products or additive to fertilizers claiming to enhance performance, and timing of nitrogen application. The locations used, soils present and soil test levels for each site are given in Table 3.1.

Table 3.1 Description of soils present at grain sorghum nitrogen study sites

Location and year	Soil Series	Soil pH	Mehlich-3 P mg kg $^{-1}$	Exchangeable K mg kg $^{-1}$	Organic Matter g kg^{-1}	NH_4-N mg kg^{-1}	NO_3-N mg kg^{-1}
2008 Agronomy North Farm, Manhattan	Smolan silt loam	5.8	23	257	24	8.3	3.6
2008, East Central Experiment Field, Ottawa	Woodson silt loam	6.5	5	200	21	10.6	2
2008, South Central Experiment Field, Partridge	Funmar-Tevar loams	6	35	353	17	4.2	7
2009, Agronomy North Farm, Manhattan	Ivan and Kennebec loams	7.3	10.2	162	19	7.5	4.6
2009, East Central Experiment Field, Ottawa	Woodson silt loam	6.7	7	116	18	3.3	9
2009, South Central Experiment Field, Partridge	Funmar-Tevar loams	5.76	25	330	14	11	6.9
2009, West Central Experiment Field, Tribune	Ulysses silt loam	7.6	31	>500	16	7.3	5.4

Tillage and Previous Crops

In 2008 the study was initiated at three sites across the State of Kansas. The first location was at the Agronomy North Farm near Manhattan, KS (39°20’70.96” N lat.; 96°59’09.73” W long).The experiment was no-tilled planted into wheat (*triticum aestivum* L.) stubble. Plots were 15.2 meters long and 3.04 meters (4 rows) wide and arranged in a randomized complete block design with four replications. Starter fertilizer was applied to all treatments, including a starter only control, at a rate of 22 kg N ha^{-1} as UAN. Manhattan 2008 is the only location in which starter fertilizer was applied. The treatments used were:

1. Starter N only;
2. Broadcast granular urea;
3. Broadcast granular urea treated with Agrotain. (NBPT, N-butyl-thiophosporic triamide);
4. Broadcast granular urea/Super U co-granulated with a combination of NBPT and DCD(dicyandiamide);
5. Broadcast granular ESN urea (urea coated with polyurethane);
6. A 50/50 ESN/urea blend;
7. Broadcast sprayed UAN;
8. Surface banded UAN;
9. Surface banded UAN with Agrotain Plus;
10. Coulter- banded UAN.

Starter fertilizer and the coulter banded UAN was placed approximately 5 cm deep in the row middles. All treatments were applied 34 days after application at Manhattan, in an effort to obtain a period of 5 or more days with a forcast of 30% probability of rain or less, in an effort to maximize volatilization potential.

The second location used was at the East Central Research Station near Ottawa, KS (38°53’85.89” N lat.; 95°24’46.9” W long.) This experiment was no- till planted into wheat/double crop soybean (*tritucum aestivum* L./ *Glycine max*) stubble. The third location was at the South Central Research field near Partridge, KS (37°96’17.49” N lat.; 98°12’25.5” W long.). This experiment was no-till planted into soybean stubble. No starter N treatments were applied at the Ottawa or Partridge locations. Plots were 15.2 meters long and 3.04 meters (4 rows) wide and arranged in a randomized complete block design with four replications. The treatments used at the Ottawa and Partridge location were:

1. No N Control
2. Broadcast granular urea;
3. Broadcast granular urea treated with Agrotain. (NBPT, N-butyl-thiophosporic triamide);
4. A 50/50 ESN/urea blend;
5. Broadcast sprayed UAN;
6. Surface banded UAN.

Treatments were applied at planting in Ottawa and 19 days following planting at Partridge. All treatments at all three locations in 2008 were applied at a N rate of 67 kg N ha^{-1}

In 2009 the study continued at the Agronomy North Farm in Manhattan (39°21’22.92” N lat.; 96°59’76.84” W long.), the East Central Experiment Field near Ottawa (38°53’63.74” N lat.; 95°24’41.13” W long.) and the South Central Experiment Field near Partridge (37°96’07.94 N lat.; 98°12’16.7” W long.). An additional location at the Southwest Research Station near Tribune, KS was added (38°52’94.64” N lat.; 101°65’90.58” W long.). The Manhattan location was no-till planted into soybean stubble; Ottawa was no-till planted into double crop soybeans stubble following wheat, while the Partridge and Tribune locations were no-till planted into wheat stubble. No starter fertilizer treatments were used.

All plots were 15.2 meters long and 3.04 meters (4 rows) wide and arranged in a randomized complete block design with four replications. All treatments were applied in 2009 at a rate of 67 kg N ha^{-1} unless otherwise noted. Specific treatments used in 2009 were:

1. Control, no N applied;
2. Broadcast granular urea applied in winter;
3. Broadcast ESN applied in winter;
4. Broadcast granular urea applied at planting;
5. Broadcast granular urea treated with Agrotain (NBPT, N-butyl-thiophosporic triamide);
6. Broadcast granular urea/Super U co-granulated with a combination of NBPT and DCD (dicyandiamide);
7. Broadcast granular ESN urea (urea coated with polyurethane);
8. A 50/50 ESN/urea blend;

9. Broadcast sprayed UAN;
10. Broadcast sprayed UAN plus Agrotain Plus, a combination of NBPT and DCD;
11. Broadcast sprayed UAN with Nutrisphere-N
12. Surface banded UAN;
13. Surface banded UAN with Agrotain Plus;
14. Surface banded UAN with Nutrisphere-N;
15. Coulter- banded UAN (Manhattan Only);
16. Broadcast prilled ammonium nitrate, a non-volatile N source (Ottawa, Partridge and Tribune);
17. Broadcast granular urea at 34 kg N ha^{-1};
18. Broadcast granular urea at 101 kg N ha^{-1};
19. Broadcast granular urea at 134 kg N ha^{-1}.

At the Manhattan location, the coulter banded UAN was placed approximately 5.0 cm below the soil surface in the row middles. The winter broadcast urea and winter broadcast ESN was applied on February 4 in Manhattan; February 6 in Ottawa and February 27 in Hutchinson. The Tribune location did not receive the winter applied broadcast urea and broadcast ESN treatments. The winter applications were applied to help quantify the efficiency of applying an application of nitrogen several months in advance of planting as this is a common production practice used in central KS to avoid ammonia volatilization. The 34, 101 and 134 kg ha^{-1} rate of broadcast urea were added in order to define a nitrogen response function at each location. All treatments (minus the winter treatments) were applied at planting at Manhattan, Ottawa and Tribune. Due to delay in planting caused by weather, treatments were applied a month prior to planting at Partridge. The coulter band treatment of UAN was used to represent a non-volatile N (NVN) source, and was used in both 2008 and 2009 at the Agronomy North Farm. At the Ottawa, Partridge and Tribune locations, ammonium nitrate was used in place of coulter banded UAN as the NVN source.

A summary of important dates and cultural practices used at each location may be found in Table 3.2.

Table 3.2 Summary of important dates, hybrids, pesticides and cultural practices used in these experiments

Location and year	Manhattan 2008	Ottawa 2008	Partridge 2008	Manhattan 2009	Ottawa 2009	Partridge 2009	Tribune 2009
Previous crop	Wheat	Wheat double crop soybeans	Soybeans	Soybeans	Double crop soybeans after wheat	Wheat	Wheat
Sorghum hybrid	DKSA 54-00	P84G62	P856456	DKSA 54-00	P54G62	P84G62	P86G32
Planted population ha^{-1}	135,850	148,200	148,200	177,840	148,200	111,150	87,438
Planting date	19-May	21-May	6-June	19-May	21-May	25-June	1-June
Winter application	N/A	N/A	N/A	4-Feb	6-Feb	27-Feb	N/A
Spring application	23-June	21-May	25-June	19-May	20-May	21-May	22-May
Total N Rate kg/ha^{-1}	90	67	67	67	67	67	67
Flag leaf samples collected	30-July	6-Aug	5-Aug	3-Aug	8-Aug	N/A	12-Aug
Harvest	24-Sep	3-Nov	18-Nov	5-Oct	6-Nov	24-Nov	1-Dec

Soil Sampling and Analysis

At each location in each year, a composite soil sample was taken from each replication to a depth of 15 cm for pH, available phosphorus (P), exchangeable potassium (K), soil organic matter (SOM) and a depth of 60 cm for profile ammonium and nitrate. Sampling was done using a hand probe, and samples consisted of 12 to 15 individual cores composited to form an individual composite sample. Values reported in Table 3.2 are the means of four composite samples. Analysis were done by the KSU Soil Testing lab using procedures described in Recommended Chemical Soil Testing Procedures for the North Central Region NCRR Publication no. 221 (1998)

Tissue Sampling and analysis

Measurements of plant nitrogen were made to document the relative effectiveness of each treatment. Flag leaves were collected at half bloom to determine plant N content. All samples were dried at 60°C and ground to pass a 0.5-mm stainless steel sieve. Concentrations of N were digested using a Sulfuric acid-hydrogen peroxide digest. The extract containing ammonia was analyzed by a colorimetric procedure (nitropruside -sodium hypochlorite) using RFA Methodology No. A303-S072, Total Kjeldahl Nitrogen.

Grain Yield and Grain Analysis

At the Manhattan location in both 2008 and 2009 as well as Partridge in 2009, plots were hand harvested by marking 5.3-m of plot and collecting all of the heads in both rows of this area. The hand harvested sorghum was thrashed using an Almaco mechanical thrasher; a grain sample was collected for each plot to determine grain N content and grain moisture. The Ottawa location, both years, as well as the Partridge location in 2008 and the Tribune location in 2009 were mechanically harvested. Plots were mechanically harvested using a 2 row plot combine with which grain samples were collected to determine individual plot moisture and test weight Yields at all locations were corrected to 135 g kg^{-1} moisture content.

Nitrogen in the grain was determined by collecting a representative sub sample from each plot, drying, grinding, and analyzing for total N. All plot analysis was done by the KSU Soil Testing Lab.

Statistical Analysis

Data for plant tissue, grain and treatment differences were analyzed using SAS version 9.1 with proc GLM at alpha levels of 0.10 and 0.05.

Results and Discussion

North Farm 2008

In 2008 at the Agronomy North Farm, grain yields had a significant response to the application of nitrogen. Nitrogen applications were made when there was little chance of rainfall for ten days. This effort was made in an attempt to simulate the typical conditions in which grain sorghum is grown across the state. In 2008, there was a rainfall event of approx. 29 mm three days following N application (Table 3.3), which would likely have moved the broadcast urea below the residue layer and down into the soil profile. Despite conditions that would appear to have reduced the potential for N loss, there were significant differences seen between treatments. The application of broadcast urea/Super U produced yields that were significantly higher than the broadcast urea rate at the alpha 0.05 level (Table 3.4).

Table 3.3 Rainfall and temperature following nitrogen application on grain sorghum sites

	Manhattan 2008	Ottawa 2008	Partridge 2008	Manhattan 2009	Ottawa 2009	Partridge 2009	Tribune 2009
Total rainfall 7 days after N application (mm)	33	76	40	0	3.81	1.02	14.7
Average Temp 7 days after N application (°C)	30°	27°	32°	30°	28°	27°	24°

Source: KSU Weather Data Library

Table 3.4 Manhattan 2008 results as affected by N product and method of application

Treatment	Flag Leaf N	Grain N	Grain Yield
	g kg^{-1}	g kg^{-1}	Mg ha^{-1}
Starter N only	20.10	10.35	2.77
Broadcast Urea	23.70	10.6	6.01
Broadcast Urea plus Agrotain	24.58	11.03	6.70
Broadcast Super U urea	24.23	11.20	6.78
Broadcast ESN	24.45	11.68	6.18
Broadcast 50/50 ESN/Urea	23.65	10.83	6.32
Broadcast UAN	22.00	9.95	6.10
Surface Band UAN	22.88	10.28	5.06
Surface Band UAN + Agrotain Plus	23.38	10.33	5.91
Coulter Band UAN	23.23	10.80	6.36

Pr>F	<.0001	0.0015	<.0001
CV	4.55	4.72	8.92
LSD (.05)	1.47	0.74	0.75
LSD (.10)	1.27	0.61	0.62

The application of broadcast urea+Agrotain, produced similar yields to Super U, though not significantly different from the plain urea using an alpha 0.05. The higher yields from these two treatments, both of which contained the urease inhibitor, would suggest that N losses from ammonia volatilization were high at this site. Coulter banded UAN, and the broadcast polyurethane-coated ESN/urea blend yields were also substantially higher than those of the untreated broadcast urea, however not significantly higher using an alpha of 0.05. It should be noted that the application of broadcast ESN was slightly less effective than the broadcast ESN/urea blend. Similar results were also seen with the comparison of ESN and the ESN/urea blend in corn Chapter 2 and re-enforce that this is a likely result of a too slow release of N from the coated ESN granule. The application of broadcast applied UAN and surface banded UAN plus Agrotain Plus provided yields equal to broadcast urea, but significantly greater than the application of surface band applied UAN at the alpha 0.05 level. This response is contradictory to what we would expect to occur, especially since the broadcast treatment resulted in significant leaf burn at the time of application which we believed would result in lower yields than other N treatments. However work by Randall et al (2003) in Minnesota on corn showed that leaf burn prior to the 6 leaf stage had no impact on corn yield. The broadcast application would also have been expected to yield less based on the high residue level present and the potential for immobilization.

Ottawa 2008

In 2008 the Ottawa location received rainfall totaling 76 mm in the six days following nitrogen application. This provided conditions which would not be conducive to ammonia volatilization. Yields at this location were also very low, likely due to the high amount of rainfall which occurred shortly after planting and nitrogen application and prevented proper herbicide application. Weed pressure was heavy at this location and a cultivator was used in an attempt to suppress weeds between the rows. In spite of these problems, the application of nitrogen fertilizer gave a significant increase in yields at the alpha 0.05 level when compared to the unfertilized check treatment. However little difference in yields were seen between N treatments in yield, leaf N or grain N at this location in 2008.

Table 3.5 Ottawa 2008 results as affected by N product and method of application

Treatment	Flag Leaf N	Grain N	Grain Yield
	g kg^{-1}	g kg^{-1}	Mg ha^{-1}
No N Control	18.25	12.54	1.91
Broadcast Urea	21.30	12.05	4.37
Broadcast Urea plus Agrotain	21.00	12.72	4.14
Broadcast 50/50 ESN/Urea	20.95	11.54	4.31
Broadcast UAN	22.03	11.71	3.84
Surface Band UAN	21.53	11.99	5.06
Pr>F	0.105	0.401	0.0009
CV	8.69	7.15	18.68
LSD (.05)	2.69	1.29	1.05
LSD (.10)	2.22	1.06	0.86

Partridge 2008

Results from the Partridge research station are summarized in Table 3.6. In 2008 grain yields were excellent and little response was seen with the addition of nitrogen. Rainfall of >32mm was received within two days of nitrogen applications, so little N loss from volatilization would be expected. When comparing treatments, no statistical differences were seen between nitrogen products or methods of application. Flag leaf N concentrations of above 27 g kg^{-1}, the critical level, further illustrate that nitrogen did not appear to be a limiting factor at this location and therefore yield was not affected by the application of nitrogen.

Table 3.6 Partridge 2008 results as affected by N product and method of application

Treatment	Flag Leaf N	Grain N	Grain Yield
	g kg^{-1}	g kg^{-1}	Mg ha^{-1}
No N Control	26.55	14.07	7.46
Broadcast Urea	27.82	14.45	8.02
Broadcast Urea plus Agrotain	27.69	14.95	7.74
Broadcast 50/50 ESN/Urea	27.99	14.14	7.9
Broadcast UAN	28.07	14.13	7.93
Surface Band UAN	28.50	14.68	7.64

Pr>F	0.045	0.972	0.41
CV	2.79	12.17	5.23
LSD (.05)	1.15	2.60	0.6
LSD (.10)	0.95	2.10	0.5

North Farm 2009

In 2009 at the Agronomy North Farm, there were fourteen days following nitrogen application in which there were no rainfall events. In the following 22 days there were four significant rainfall events with precipitation totaling 210 mm in that time period. The potential for N loss through ammonia volatilization or immobilization loss of surface applied N was high because of moist soil at the time of application, good drying conditions and a large amount of crop residue on the soil surface. The potential for denitrification was also present because of the series of significant rainfall events which occurred 15-36 days following N application.

An increase in yields was observed with the addition of nitrogen fertilizer in 2009. When compared to the broadcast application of urea, no significant differences in yield were observed between any of the broadcast solid material treatments at this site. Similar yields to the granular materials were also obtained with the coulter banded UAN, and the SB UAN plus Nutrisphere-N. The use of all broadcast UAN and most surface banded UAN treatments were significantly lower or near significantly lower than those obtained with coulter banded UAN or application of the granular products. This would suggest that immobilization of applied N was the primary N loss risk at this site in 2009.

Little difference in flag leaf N or grain N was observed as result of treatment at this site in 2009.

Table 3.7 Manhattan 2009 results as affected by N product, timing, and method of application

Treatment	Flag Leaf N	Grain N	Grain Yield
	g kg^{-1}	g kg-1	Mg ha-1
No N Control	21.15	8.85	6.51
Broadcast Winter Urea	21.25	9.10	8.16
Broadcast Winter ESN	23.15	9.18	8.65
Broadcast Urea	23.05	9.23	8.58

Broadcast Urea plus Agrotain	25.03	9.63	9.04
Broadcast Super U urea	23.93	9.05	8.03
Broadcast ESN	24.45	9.4	8.77
Broadcast 50/50 ESN/Urea	23.35	9.2	8.11
Broadcast UAN	21.58	8.8	7.32
Broadcast UAN+Agrotain Plus	22.63	8.83	6.82
Broadcast UAN+ Nutra-sphere	23.3	8.9	7.52
Surface Band UAN	24.73	8.98	7.57
Surface Band UAN+Agrotain Plus	24.25	9.18	7.90
Surface Band UAN+Nutra-sphere	24.33	9.33	8.74
Coulter Band UAN	25.78	9.58	8.86
Broadcast 34 kg Urea	21.40	8.88	7.13
Broadcast 101 kg Urea	24.68	9.48	9.21
Broadcast 134 kg Urea	24.30	10.28	9.75
Pr>F	0.0002	<.0001	<.0001
CV	6.28	4.07	9.28
LSD (.05)	2.09	0.53	1.09
LSD (.10)	1.74	0.44	0.91

In 2009 additional rates of N were applied in order to define the N response function. This data suggests that the optimum N rate, using broadcast granular urea would have been between 101 and 134 kg, N ha-1. So while the N treatments were applied at a rate well below optimum, the lack of response to additives such as urease inhibitors or nitrification inhibitors suggests minimal N loss from mechanisms other than immobilization.

The urea N response curve was used to predict the equivalent urea rate that would need to be applied to achieve similar yields to those obtain by using different N products and application methods (Fig 3.1).

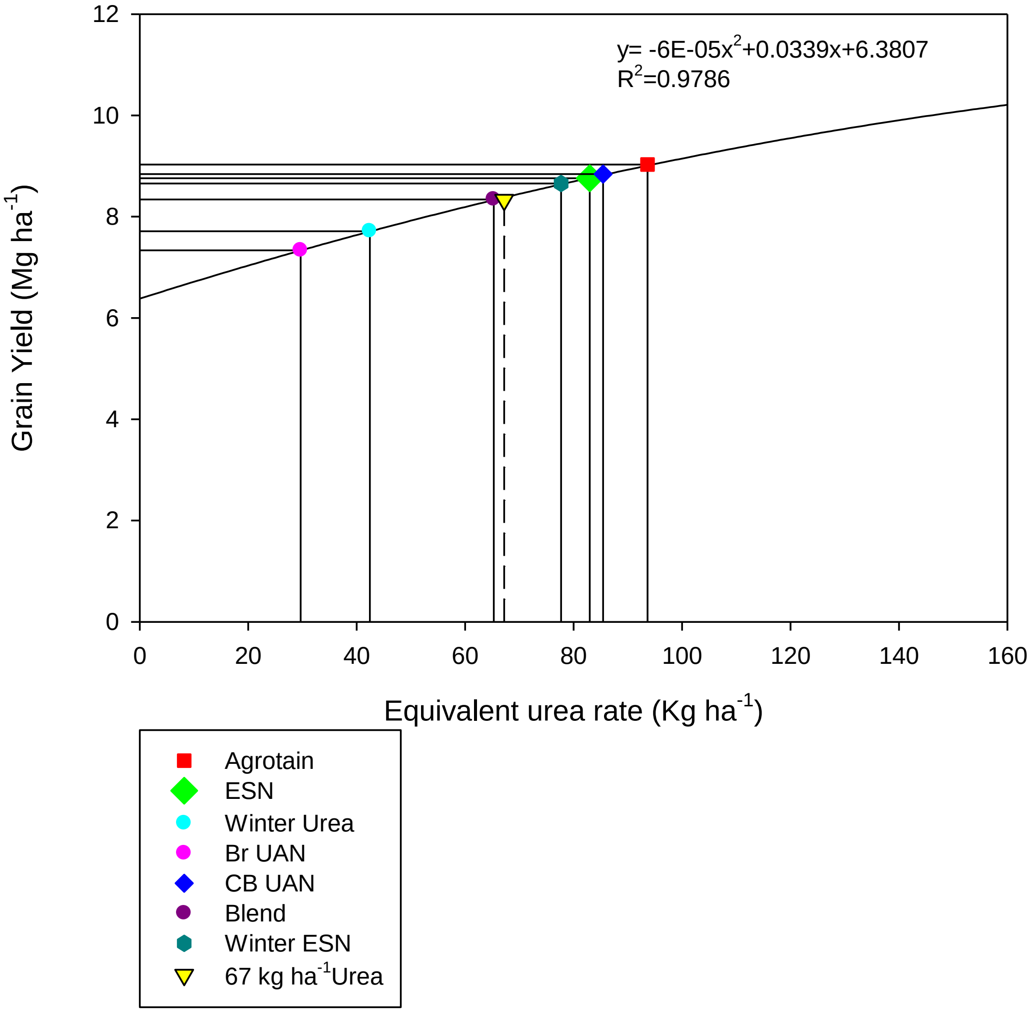

Figure 3-1 Impact of N products and practices on corn yields at Manhattan, 2009

The base treatment of spring broadcast urea is indicated by the dashed line. Any treatment to the right of the dashed vertical line defining the response to 67 kg N ha^{-1} from broadcast urea, would indicate a treatment which resulted in higher yield, or was more effective than granular urea. Conversely any treatment to the left would be less effective. Using this approach, essentially all granular materials were to the right while all liquid materials except coulter banded UAN and SB Nutrisphere N would be to the left, or less effective.

The application of broadcast ESN was the equivalent of applying 83 kg N ha $^{-1}$ of broadcast urea, the surface banded Nutrisphere-N was equivalent to applying 82 kg N ha^{-1} as urea, the application of broadcast urea + Agrotain was the equivalent of applying 94 kg N ha^{-1} of broadcast urea and the application of coulter banded UAN as a non-volatile N source was the equivalent of applying 85 kg N ha^{-1} of broadcast urea. In comparison to these increased equivalent urea rates, the application of winter applied broadcast urea was the equivalent to applying 42 kg N ha^{-1} broadcast urea and broadcast applied UAN was the equivalent to applying 30 kg N ha^{-1} broadcast urea. These responses demonstrate that the selection of more efficient application methods, timing or the use of alternative products is needed. Even though yields may not be statistically significant using traditional mean separations, the application of different N products had the potential to effectively gain the equivalent of an additional 27-47 kg N ha^{-1}. When practices are used that provide lower nitrogen use efficiency, more N would be needed.

Ottawa 2009

In 2009 at the Ottawa location, there were thirteen days between the application of nitrogen and a rainfall of > 10 mm, the suggested amount needed to incorporate broadcast applied urea and prevent volatilization (Fox and Hoffman, 1981and Fox et al., 1986). Again using spring applied urea as a base, a significant response to N was observed at this site, winter applied urea was also less effective than spring applied. The winter applied ESN treatment also increased grain yields when compared to the winter applied urea treatment, but was not different than spring applied urea. The use of products with urease inhibitors, or controlled release products, both of which would reduce potential ammonia volatilization loss, in the spring showed consistent trends to higher yields at this site. At the .10 alpha level, broadcast ESN and the broadcast ESN/urea blend significantly increased grain yields compared to spring broadcast urea. The use of liquid UAN broadcast or surface banded showed a trend towards lower yields than granular materials at this site also, with the exception of when a urease inhibitor was added to broadcast UAN.

Table 3.8 Ottawa 2009 results as affected by N product, timing, and method of application

Treatment	Flag Leaf N	Grain N	Grain Yield
	g kg^{-1}	g kg^{-1}	Mg ha^{-1}
No N Control	17.75	9.33	4.38
Broadcast Winter Urea	18.35	9.23	5.41
Broadcast Winter ESN	20.03	9.45	6.31
Broadcast Urea	19.30	9.45	6.03
Broadcast Urea plus Agrotain	19.78	9.38	6.59
Broadcast Super U urea	18.78	9.43	6.57
Broadcast ESN	20.58	9.53	6.90
Broadcast 50/50 ESN/Urea	19.30	9.33	6.77
Broadcast UAN	19.73	9.23	5.59
Broadcast UAN+Agrotain Plus	19.28	9.15	6.13
BroadcastUAN+ Nutra-sphere	18.70	9.48	5.31
Surface Band UAN	19.13	9.05	5.36
Surface Band UAN+Agrotain Plus	19.13	9.50	5.26
Surface Band UAN+Nutra-sphere	19.43	9.40	5.57
Ammonium Nitrate- NVN	20.58	9.70	6.90
Broadcast 34kg Urea	18.38	8.95	5.18
Broadcast 101 kg Urea	20.00	9.43	6.88
Broadcast 134 kg Urea	20.50	9.60	6.50
Pr>F	0.172	0.505	<.0001
CV	7.08	4.10	10.42
LSD (.05)	1.94	0.54	0.88
LSD (.10)	1.62	0.45	0.74

A nitrogen response curve was again developed using the response to rates of broadcast urea at this location, in order to calculate the equivalent urea rate needed to achieve similar yields as nitrogen products and practices used (Fig 3.2).

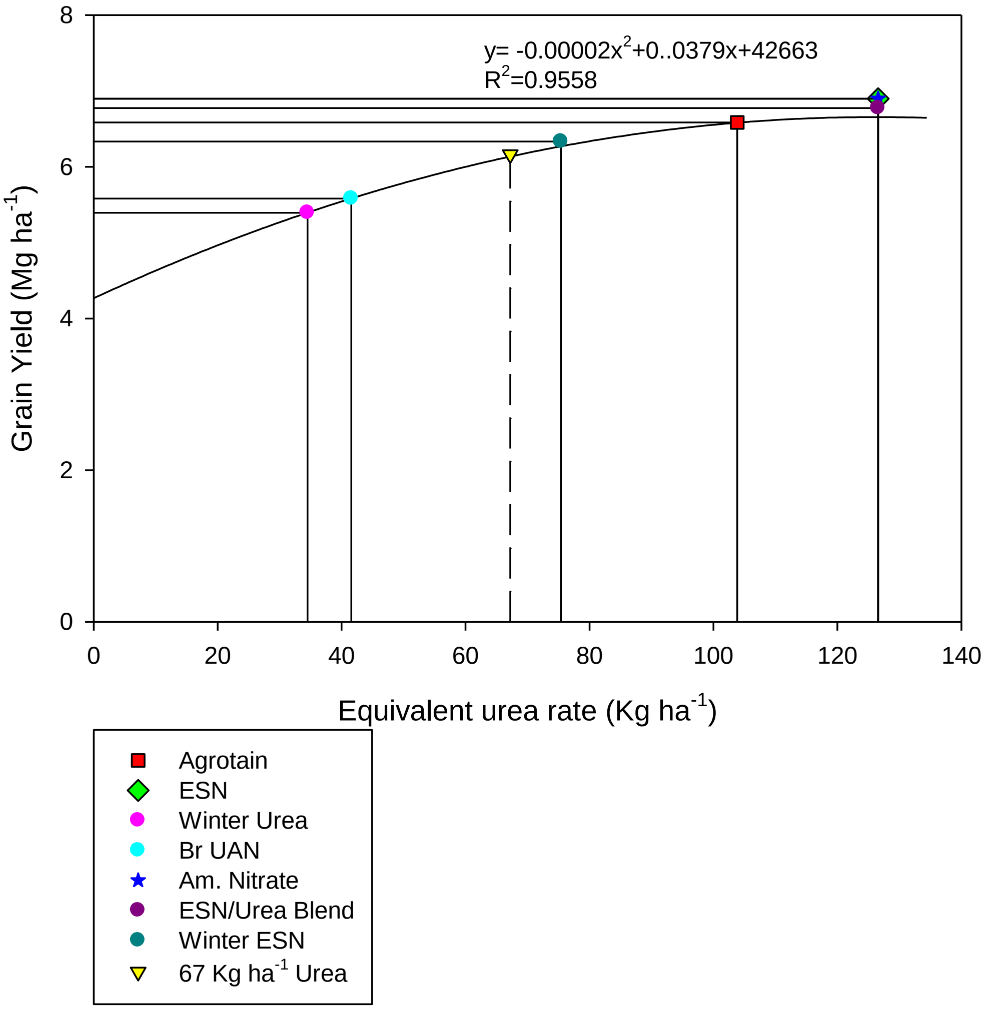

Figure 3-2 Impact of N products and practices on grain sorghum yields at Ottawa, 2009

The broadcast ESN, broadcast ESN/urea blend and non volatile ammonium nitrate treatments which were applied at a rate of 67kg N ha^{-1} were all the equivalent to applying 127 kg N ha^{-1} broadcast urea. Broadcast urea+Agrotain was the equivalent to applying 104 kg N ha^{-1} broadcast urea and winter applied ESN was the equivalent to applying 75 kg N ha^{-1} broadcast urea. Less efficient applications where broadcast applied UAN which was the equivalent to applying 42 kg N ha^{-1} broadcast urea and the winter urea application was equivalent to applying 34 kg N ha^{-1} broadcast urea.

Partridge 2009

This research was continued in 2009 at the Partridge location, and yields are summarized in Table 3.9. Rainfall in the ten days following nitrogen application did not exceed 10 mm, and combined with the high residue present, would have given a high potential for ammonia volatilization of surface applied nitrogen fertilizers. Although the potential for volatilization was present, yields were low and highly variable since an improper herbicide application was made that severely damaged emerging plants. This combined with the late planting of grain sorghum which resulted in plants that were not able to reach physiological maturity within the growing season resulted in inconsistent responses that are difficult to explain. No statistical differences were seen between treatments.

Table 3.9 Partridge 2009 results as affected by N product, timing, and method of application

Treatment	Grain N	Grain Yield
	g kg^{-1}	Mg ha^{-1}
No N Control	12.98	2.55
Broadcast Winter Urea	12.68	3.17
Broadcast Winter ESN	13.00	2.73
Broadcast Urea	12.88	2.61
Broadcast Urea plus Agrotain	13.10	3.10
Broadcast Super U urea	13.10	2.91
Broadcast ESN	13.30	2.84
Broadcast 50/50 ESN/Urea	12.45	2.62
Broadcast UAN	12.38	3.46
Broadcast UAN+Agrotain Plus	12.88	3.53
Broadcast UAN+ Nutra-sphere	13.10	3.49
Surface Band UAN	12.60	2.51
Surface Band UAN+Agrotain Plus	13.50	2.72
Surface Band UAN+Nutra-sphere	12.75	2.45
Ammonium Nitrate- NVN	13.40	3.08
Broadcast 34kg Urea	12.88	3.26
Broadcast 101 kg Urea	12.48	3.32

Broadcast 134 kg Urea	12.40	3.37
Pr>F	0.71	0.69
CV	6.00	27.61
LSD (.05)	NS	NS
LSD (.10)	NS	NS

Tribune 2009

In 2009 a research location was added at Tribune, Ks. Rainfall totaling 10 mm occurred five days after application of nitrogen treatments. A response to nitrogen application was observed, however no statistical differences were observed between treatments at the alpha 0.05 level. Though not significant, the broadcast ESN/urea treatment did increase yields compared to the broadcast ESN treatment.

Table 3.10 Tribune 2009 results as affected by N product and method of application

Treatment	Flag Leaf N	Grain N	Grain Yield
	g kg^{-1}	g kg^{-1}	Mg ha^{-1}
No N Control	26.38	11.93	5.59
Broadcast Urea	28.23	14.18	7.12
Broadcast Urea plus Agrotain	27.55	14.25	7.30
Broadcast Super U urea	27.53	14.15	6.81
Broadcast ESN	28.03	13.80	6.57
Broadcast 50/50 ESN/Urea	28.20	14.00	7.06
Broadcast UAN	29.05	14.10	7.05
Broadcast UAN+Agrotain Plus	28.75	13.85	6.96
BroadcastUAN+ Nutra-sphere	29.00	13.85	6.81
Surface Band UAN	27.30	13.90	6.64
Surface Band UAN+Agrotain Plus	28.85	13.78	6.92
Surface Band UAN+Nutra-sphere	28.53	13.53	6.86
Ammonium Nitrate- NVN	27.78	13.88	6.73
Broadcast 33.6 kg Urea	27.95	13.50	6.55
Broadcast 100.8 kg Urea	28.45	14.95	6.99
Broadcast 134.4 kg Urea	30.45	15.48	6.80
Pr>F	0.0058	<.0001	0.0054
CV	4.00	4.81	6.88
LSD (.05)	NS	NS	NS
LSD (.10)	NS	NS	NS

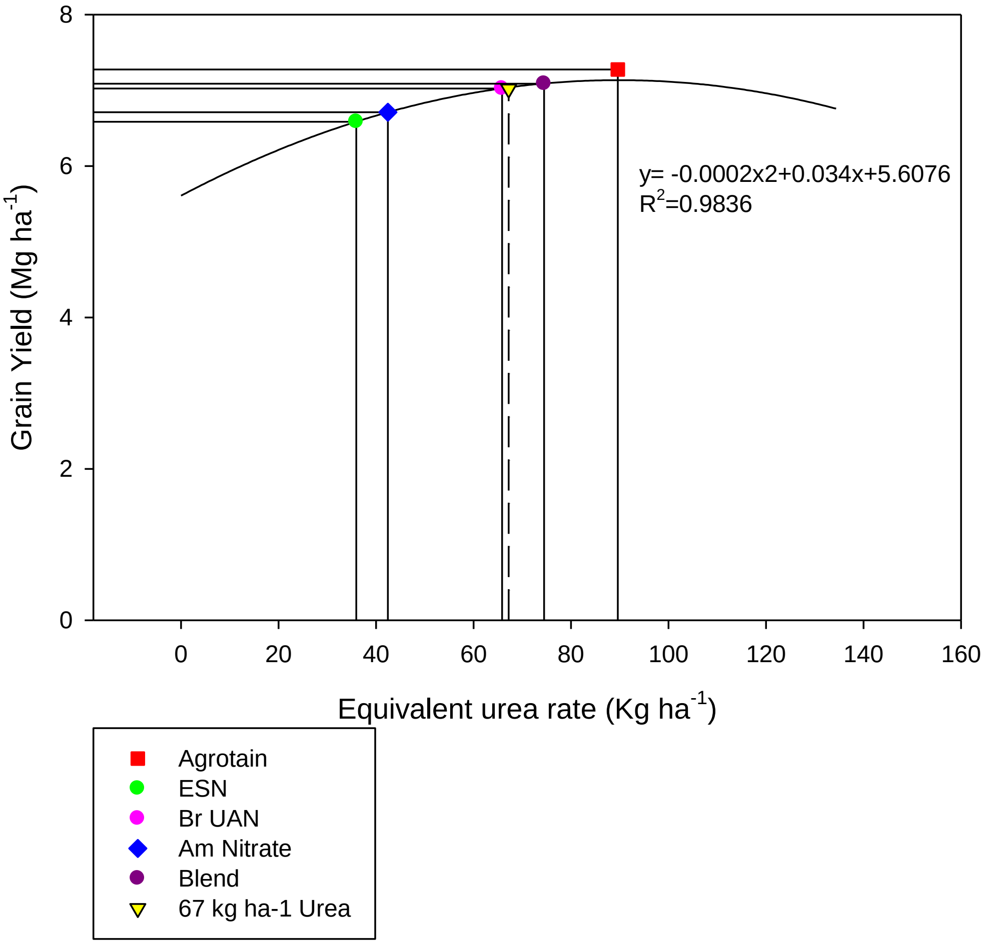

Figure 3-3 Impact of N products and practices on grain sorghum yields at Tribune, 2009

The nitrogen response curve which was obtained shows some increased urea equivalency with the addition of a urease inhibitor or controlled release urea/urea blend when compared to broadcast urea. The application of broadcast urea+Agrotain was the equivalent of applying 90 kg N ha^{-1} broadcast urea and the broadcast ESN/urea blend treatment was equivalent to applying 74 kg N ha^{-1} broadcast urea. These results are similar to those that were obtained at other research locations. The application of broadcast UAN was the equivalent of applying 66 kg N ha^{-1} broadcast urea, this result is not what we would have expected to see, especially in a high residue cropping system. Additional results that did not correspond with results obtained from other locations were the application of broadcast ESN which was the equivalent of applying 36 kg ha^{-1}

broadcast urea and the non volatile N treatment of ammonium nitrate which was the equivalent of applying 42 kg N ha^{-1} broadcast urea.

Combined site year analysis

Table 3.11 Comparison of method of application and product response across six site years; Manhattan, Ottawa, Partridge 2008 and Manhattan, Ottawa, Tribune 2009

Treatment	Grain Yield Mg ha^{-1}
Control	4.79
Broadcast Urea	6.71
Broadcast Urea+Agrotain	6.94
Broadcast ESN/Urea blend	6.77
Broadcast UAN	6.33
Surface Band UAN	6.07
LSD 0.05	0.33
LSD 0.10	0.28

Table 3.12 Comparison of method of application, timing of application, and product response, Manhattan and Ottawa 2009.

Treatment	Grain Yield Mg ha^{-1}
Control	5.44
Broadcast Winter Urea	6.77
Broadcast Winter ESN	7.46
Broadcast Urea	7.27
Broadcast Urea+Agrotain	7.84
Broadcast ESN	7.84
Broadcast UAN	6.46
Surface Band UAN	6.46
LSD 0.05	0.65
LSD 0.10	0.55

Table 3.11 illustrates the differences seen between method of application and nitrogen products used when data from Manhattan, Ottawa and Partridge 2008 and Manhattan, Ottawa

and Tribune 2009 are combined. The application of broadcast urea was found to be better than the application of both broadcast and surface banded UAN. The addition of Agrotain to urea was not found to be greater than the use of broadcast urea.

In the comparison of timing of application, method of application and use of nitrogen additives, Manhattan 2009 and Ottawa 2009 grain yields were evaluated (Table 3.12). The use of broadcast winter applied urea produced lower grain yields than spring applied urea using an alpha 0.05. Winter applied ESN resulted in grain yields that were not different than the spring applied urea, but was significantly better than winter applied urea. Broadcast applied urea was a significantly better method of application than both the broadcast and surface band applied UAN. The addition of Agrotain to urea increased grain yields when compared to urea alone, however the increase in yield was not significant.

Conclusions

Careful management of nitrogen is needed in no-till grain sorghum production. Timing of nitrogen application was found to have a significant impact on grain sorghum yields. The delayed release of winter applied ESN resulted in higher grain yields than winter applied urea and has the potential to safeguard nitrogen loss and produce yields similar to spring applied urea. Winter applications of urea are not recommended, as higher nitrogen rates will be required to match the performance of spring applied urea. When winter application must be made, the use of ESN coated urea to protect against nitrogen loss is recommended.

In the production of grain sorghum, granular urea was found to be more efficient than UAN applications. Unlike the results with corn, comparing methods of application of UAN was not found to have an effect on grain yields.

When conditions for nitrogen loss exist, the use of urease inhibitors can increase yields and improve nitrogen use efficiency. With such high volatility in nitrogen prices, the extra safeguard that urease inhibitors provide can be beneficial. The use of Nutrasphere-N was not found to be beneficial and is not recommended.

The use of these tools to prevent nitrogen loss and increase nitrogen use efficiency can improve producers' productivity when managed correctly. When N loss is occurring, the use of N use enhancing products can enhance yield while minimizing total N inputs. The use of these types of products and practices to address specific concerns or loss mechanisms can be more efficient, and potentially cost effective, than simply increasing N application rate. Just as importantly, using these improved technologies will allow producers to take better care of the land through environmental stewardship.

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CHAPTER 4 - Use of number of green leaves below the ear as a simple tool to evaluate nitrogen sufficiency in corn

Abstract

Nitrogen loss through mechanisms such as ammonia volatilization, leaching and denitrification occur regularly in Kansas. With the rapid increase in availability of high clearance sprayers, farmers now have a simple and relatively inexpensive tool to apply additional N to corn late in the season, if N loss does occur in their field. Assuming the crop will respond to late applied N, the problem becomes determining if N is needed and how much to apply. Producers need simple, inexpensive tools which can help them assess the N status of the plant throughout the growing season, and if additional nitrogen applications need to be made, how much N should be applied. A tool currently used to assess nitrogen content in the plant during the growing season is tissue analysis of corn ear leaves when approximately 75% of silks have emerged. When earleaf nitrogen concentrations are found to be less than a critical level of 27 g kg^{-1}, nitrogen is considered limiting. This method of determining nitrogen content is useful, but can be costly to producers when the cost to collect samples, prepare samples for analysis and the analysis itself are considered and is time consuming. A method of counting the number of green leaves below the ear was developed with the hopes of potentially using this information to help producers make informed management decisions quickly with virtually little or no cost.

Research was done in 2008 and 2009, using plots established to assess nitrogen use efficiency of a range of N management practices, to determine if there was a strong relationship between the number of green leaves remaining below the ear shortly after pollination and yield and N content of corn plants and plant parts. Green leaf number was found to strongly correlate with grain yield, and in most cases was a better indicator of nitrogen status and yield of the plant than earleaf nitrogen concentrations.

Introduction

Deficiencies of N during the growth of corn results in firing, the premature death of lower leaves. The death of each leaf progresses from the tip to the stalk and is preceded by a change in color from green to yellow. The death of leaves progresses up the stalk as the plant matures and the number of leaves affected at any stage of maturity tend to increase with the severity of the deficiency. Most corn producers associate firing with N deficiencies and use it as a convenient indicator of N status. Lack of interest in describing relationships between firing and yields probably is best explained by widespread recognition that amounts of firing are influences by moisture availability and other factors in addition to N availability. Also, tissue analysis generally has been accepted as a superior tool for evaluating N status (Binford,1993). The method of using tissue analysis is useful in determining if nitrogen is limiting, but can be costly to the producer based on the time and money needed to collect samples, and in most cases, the cost incurred to have a testing facility prepare the samples for analysis as well as the analysis cost itself.

On farm research was done at Ohio State University by La Barge (1999) to observe yield response and post-mortem stalk nitrate nitrogen concentration when different nitrogen rates were applied. Measurements were taken when corn was at the R4 growth stage and the number of green, healthy leaves below the ear leaf were counted. This provided an index of firing, a common system of nitrogen deficiency. This research hypothesized that leaf health could provide an efficient means of determining if adequate nitrogen nutrition was provided. When field check strips were established using varying N rates, research has shown that the index of leaf health can be as accurate as lab analyzed leaf tissue to identify low/sufficient nitrogen conditions. La Barge believed that this index may provide farmers a tool to observe field response to nitrogen. His research showed that the trend was for more healthy green-leaf counts below the earleaf as N rates increased. The 202 and 269 kg N ha^{-1} rates were found to have significantly higher numbers of green leaves and yield, than the 45 and 67 kg N ha^{-1} rates.

Fox et al. (2001) observed that in central and southeastern Pennsylvania when 4-5 green leaves were present at and below the earleaf there is no N deficiency over 95% of the time. This research went on to state that of those plants with less than 4 green leaves only 50% were N deficient. Normalizing visual ratings seemed to remove much of the error caused by factors other than N fertility.

Binford and Blackmer (1993) did similar research in Iowa, but evaluated leaf ratings and the link to physiological age of corn plants. In their system, ratings were taken at R1, R2, R3, R4 and R5. Their results suggest that leaf ratings provide slightly greater sensitivity when performed at stages R3 to R5 than R1. They also developed an adjusted leaf rating which is defined as the leaf ratings on plants within a test area subtracted from the highest leaf rating that can be attained by adding N fertilizers under otherwise similar conditions.

Binford and Blackmer (1993) found that the predictabilities (R^2 values) of the relationship between grain yields and leaf ratings tended to be about as good as those for the relationships between grain yields and rates of N fertilizations. The R^2 values observed for yields vs. leaf ratings also tended to be about as good as those observed for yields vs. leaf N concentrations. Binford and Blackmer (1993) goes on to say that these findings indicate that leaf firing deserves attention as an indicator of N status in corn because yield response measurements usually are considered to be the standard for defining the N status of corn and because leaf N concentrations serve as the basis for the tissue test most commonly used to evaluate N status of corn. The value of a tool for evaluating N status, however, is determined more by its ability to function across a reasonable range of conditions than by its ability to function within individual fields. Binford and Blackmer's research found that relatively poor performance of leaf ratings in the pooled models supported the generally accepted idea that factors other than N deficiencies (e.g. moisture stresses, corn diseases, differences between hybrids) can influence the amount of firing. Relatively good performance of adjusted leaf ratings is noteworthy because leaf ratings require much less time, effort and expense than do leaf N analyses. The use of adjusted leaf ratings significantly reduces problems caused by the tendency for leaf ratings to decrease with time between R1 and the R5 stages at all rate of nitrogen application. Adjusted leaf ratings could be obtained easily in production agriculture if fields contained small areas where N was applied at rates known to be higher than needed to attain maximum yields.

With the increase in the number of high clearance sprayers on farms across the Midwest, farmers now have the capability to correct N deficiencies inexpensively if simple, quick and inexpensive tools such as green leaf counts or firing indexes could be developed. Thus there is a potential for these tools to be utilized if correlations between number of green leaves below the ear and N response, NUE, and Total N Uptake can be developed.

Materials and Methods

Field plot information

Information regarding the establishment of the field plots used to make grean leaf ratings is discussed in Chapter two.

Firing Ratings

Leaf ratings for corn are defined as the average number of green leaves below the primary ear. Average number of green leaves below the earleaf measurements were taken approximately 10 days after pollination. When counting the number of green leaves on a plant, each leaf was assigned a value of 0 or 1 based on visual firing present. For example, a leaf that was completely green was assigned a value of 1, while a leaf that had any nitrogen deficiency symptoms (firing) was assigned a value of 0. Mean leaf ratings for individual plots were determined by counting green leaves on 5 randomly selected plants in the two center rows of the plot. Leaf ratings were based on the number of green leaves, rather than the number of dead leaves, because leaves that die early in the season often fall from the plant and cannot be detected later in the season.

Statistical Analysis

Data for green leaf differences were analyzed using SAS version 9.1 with proc GLM using an alpha level of 0.05. Correlations between green leaves and grain yield, earleaf N concentrations, grain N concentrations, whole plant N concentrations, total nitrogen uptake and nitrogen use efficiency were made using SAS version 9.1 with the Pearson correlation coefficients.

Results and Discussion

Green leaf Ratings

The numbers of green leaves at and below the primary ear at four N responsive N management experiments conducted in 2008 and 2009 are summarized in Table 4.1. At all four sites, a significant increase in yield was observed, to applied N. Grain yield, N uptake and leaf N content all varied across treatments and locations. Green leaf ratings were made approximately 10 days after pollination, a time when nitrogen stress would be very evident. Statistical differences between treatments in leaf ratings were found using an analysis of variance and an alpha level of 0.05. No nitrogen control plots showed severe firing with 1.75 to 3.35 green leaves remaining below ear, while well fertilized plots had in excess of 5 green leaves remaining.

Table 4.1. Green leaves below the ear as affected by N product, timing, and method of application

	Manhattan 2008	Manhattan 2009	Ottawa 2009	Hutchinson 2009
Treatment	Green leaves below the ear			
	5 plant average			
Control	1.75	3.15	3.35	3
Urea @ winter	na	4	4.25	3.25
Broadcast ESN-coated urea@ winter	na	4.1	5.25	3.8
Broadcast Urea	2.7	5.15	5.3	3.8
Broadcast Urea+Agrotain	2.8	5.75	4.95	4.35
Broadcast Urea+Super U	3.45	4.8	5.4	3.4
Broadcast ESN-coated urea	3.1	5.55	5.85	4
Broadcast 50% urea+ 50% ESN urea	2.95	5.2	5.3	3.4
Broadcast UAN	2.2	4.3	3.8	4.05
Broadcast UAN+ Agrotain Plus	2.35	4.5	4.35	4.2
Broadcast UAN+NutriSphere-N	na	3.65	4.05	3.55
Surface Band UAN	2.6	4.3	4.1	3.95
Surface Brand UAN +Agrotain Plus	3.45	5.05	4.5	4
Surface Band UAN+NutriSphere-N	na	4.15	4.3	3.45
Coulter band UAN+Agrotain Plus	3	na	na	na
NVN	3.2	5.35	5.8	4.65
Broadcast 100.8kg Urea	na	5.45	5.1	4.45
Broadcast 134.4kg Urea	na	6.1	5.8	4.2
Broadcast168kg Urea	na	6	6.2	4.5
LSD (.05)	0.57	0.97	0.75	0.96

Figure 4-1 No N control, 1.75 green leaves below the ear, 4.9 Mg grain ha^{-1}

Figure 4-2 Broadcast UAN, 2.2 green leaves below the ear, 7.3 Mg grain ha^{-1}

Figure 4-3 Broadcast urea, 2.7 green leaves below the ear, 8.31 Mg grain ha^{-1}

Figure 4-4 Coulter banded UAN with Agrotain Plus, 3.0 green leaves below the ear. 9.34 Mg grain ha^{-1}

As can be seen from the data in Table 4.1, the numbers of green leaves present varies between locations, and reflects the differences in inherent N supply of the locations, N loss present and yield as reported in chapter two.

Photographs of selected plots from Manhattan in 2008 are presented to illustrate some of these relationships. Photograph 1 (Figure 1) shows the highly fired control plots, while photos 2 through 4 (Figure 2-4) show plots with increasing N status and yield.

Pearson correlation coefficients between numbers of green leaves below the ear and earleaf N, whole plant N, grain N, yield, total N uptake and nitrogen use efficiency are given in Table 3.2. At Manhattan in 2008 and 2009 and at Ottawa in 2009, all locations with a significant response to N and clear differences between treatments in plant N contents and yield, strong positive correlations were observed between green leaf numbers and earleaf N content, total N uptake, nitrogen use efficiency of the management practices used and grain yield. At Hutchinson in 2009, however little or no response to N was observed, and no correlations were found, as one would expect.

Table 4.2 Pearson correlation coefficients between green leaves below the ear (r) and Earleaf N%, Whole plant N %, Grain N %, Yield, Total N uptake and NUE

	Manhattan 2008	Manhattan 2009	Ottawa 2009	Hutchinson 2009
		Green leaves below the ear		
Ear leaf N %	0.50*	0.56*	0.52*	0.18
Whole Plant N %	0.25	0.35*	0.63	0.33*
Grain N %	0.18	0.74*	0.32	0.28
Yield	0.75*	0.68*	0.68*	0.29
Total N Uptake	0.66*	0.79*	0.41*	0.46*
NUE	0.50*	0.64*	0.63*	-0.15

* Significant at the 0.05 probability level.

Figure 4.5 shows the relationship between the number of green leaves 10 days after pollination and grain yield found at Manhattan in 2008. The correlation is quite strong, with an r^2 of 0.62.

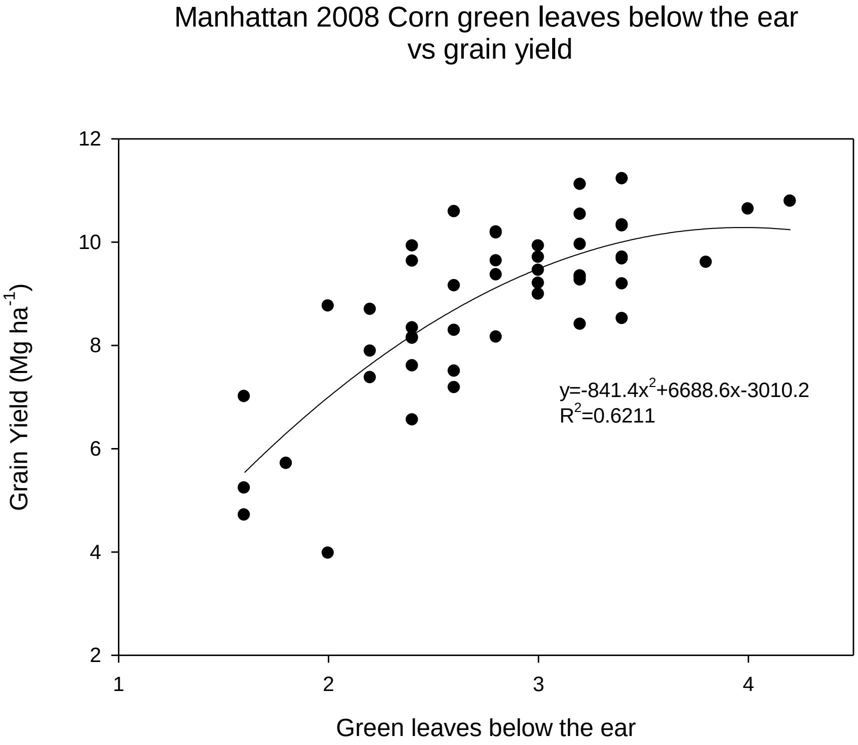

Figure 4-5 Relationship between number of green leaves and grain yield, Manhattan 2008

Figure 4.6 shows the relationship between earleaf N content at silking and grain yield also at Manhattan in 2008. This relationship is not as strong, with a r^2 of only 0.44.

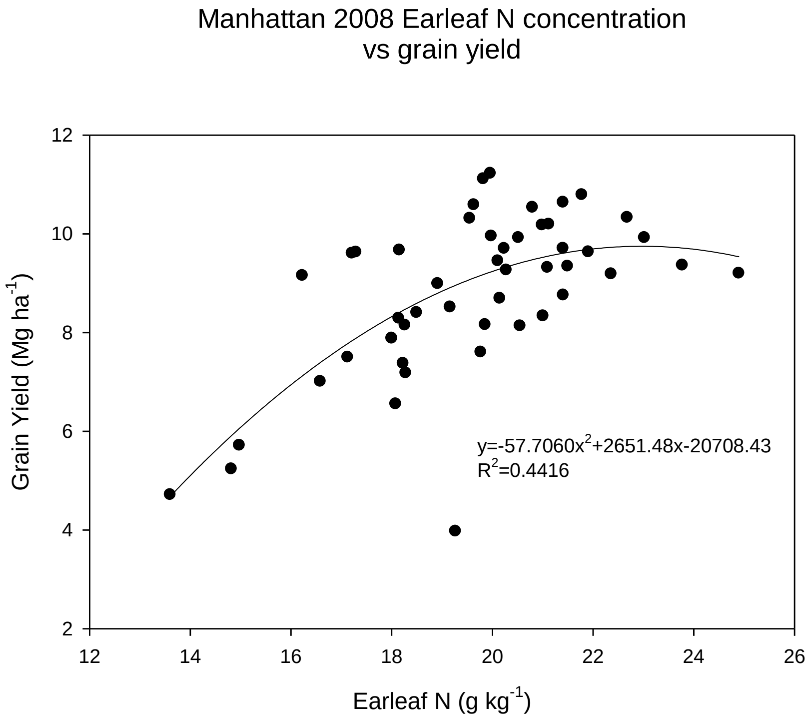

Figure 4-6 Relationship between earleaf N concentration and grain yield, Manhattan 2008

Similar relationships from Manhattan in 2009 and Ottawa in 2009 are shown in Figures 4.3 to 4.6. Again significant correlations between the numbers of greenleaves below the ear and yield and earleaf N and yield are found at these additional N responsive sites. But in both additional cases the correlations are stronger between the numbers of green leaves and yield than earleaf N and yield.

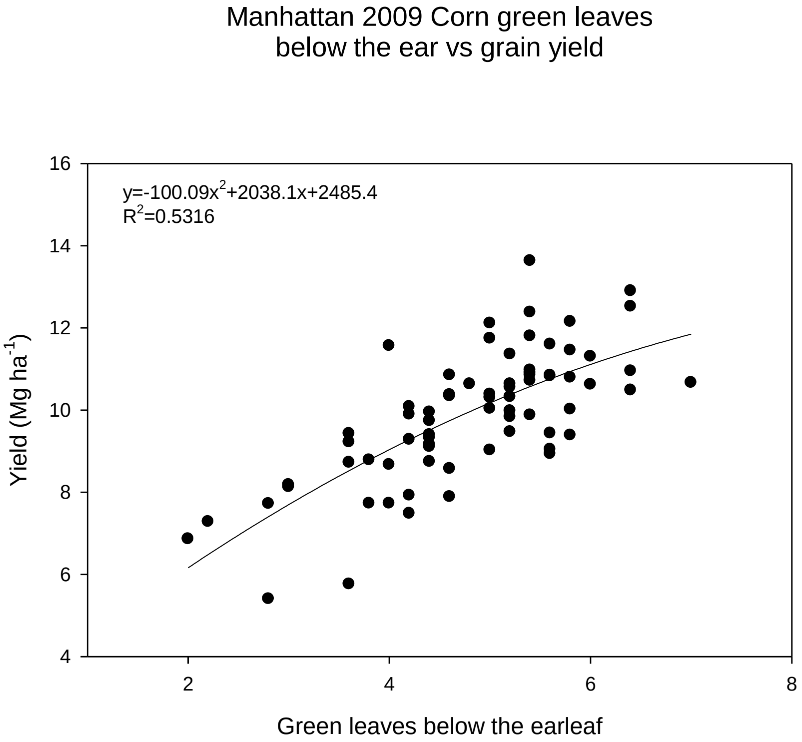

Figure 4-7 Relationship between number of green leaves and grain yield, Manhattan 2009

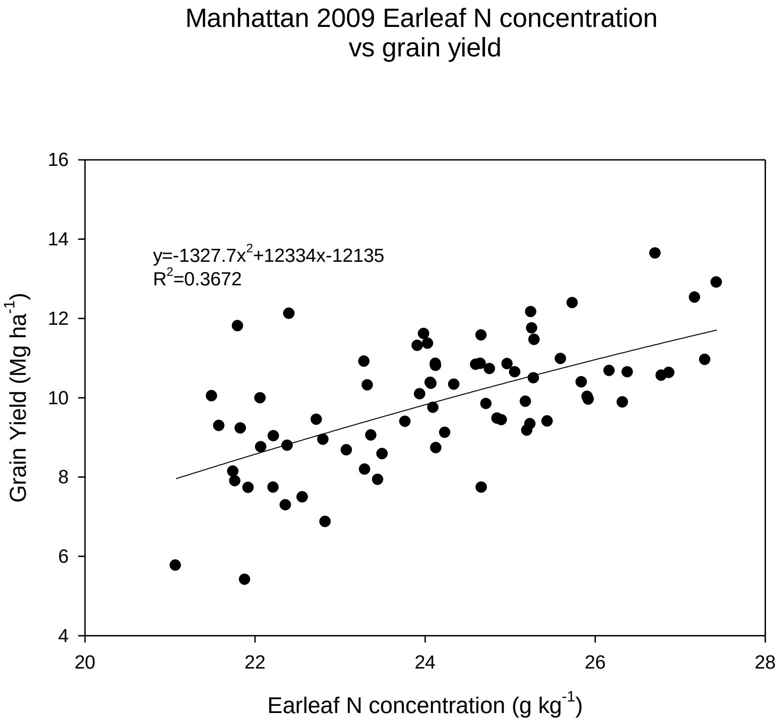

Figure 4-8 Relationship between earleaf N concentration and grain yield, Manhattan 2009

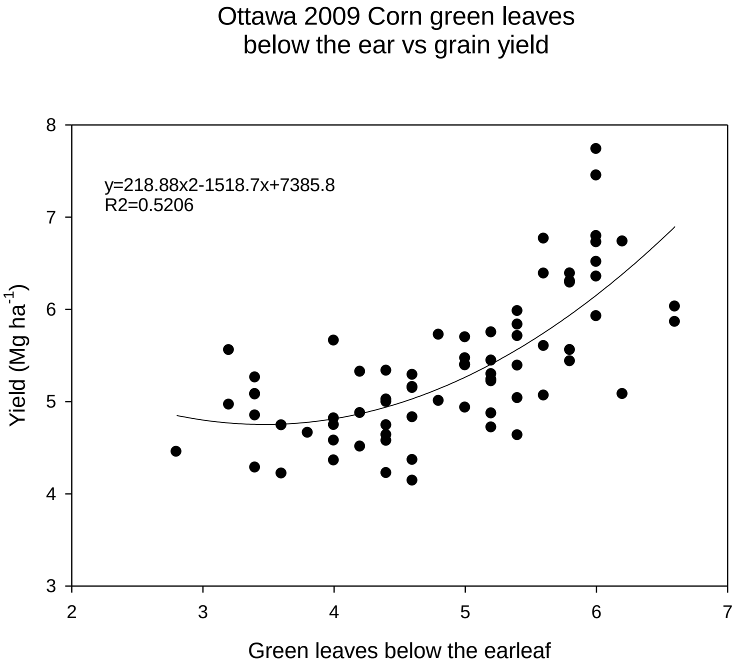

Figure 4-9 Relationship between number of green leaves and grain yield, Ottawa 2009

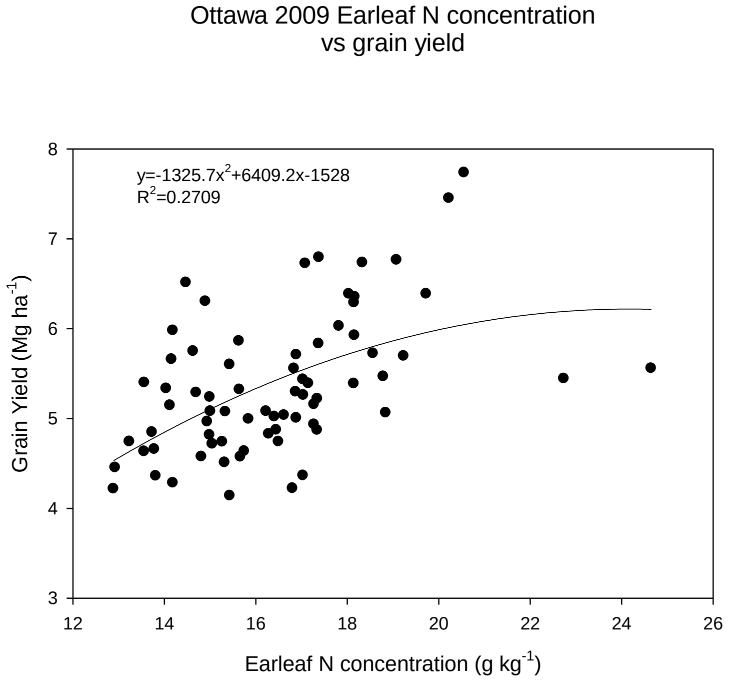

Figure 4-10 Relationship between earleaf N concentration and grain yield, Ottawa 2009

These relationships support the findings of LaBarge (1999), Fox (2001) and Binford and Blackmer (1993) that leaf firing ratings have potential to serve as a quick, inexpensive means of assessing the N status and potentially could be used to guide late season N applications. This work also suggests that green leaf numbers, or firing ratings may actually be better tools to guide late season N applications than the traditional earleaf N content, commonly used to assess mid-season N status.

Clearly additional work will be required to determine if visual firing ratings can be both correlated to N status over a broad range of soils and genetic families and calibrated to provide N rate guidance. However this preliminary data is very encouraging. Further development is clearly warranted.

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Appendix A - Components of Corn Yield from 2008 and 2009

Table A.1 Components of yield corn yield, Manhattan 2008

Year	Plot	Product	Starter N kg ha^{-1}	N Rate kg ha^{-1}	Total N Rate	Biomass kg ha^{-1}	Earleaf N %	WP N %	Grain yield Mg ha^{-1}	Grain N %
2008	108	Control	22.4	0	22.4	8306	1.50	0.27	5.7	0.83
2008	203	Control	22.4	0	22.4	8524	1.48	0.26	5.2	0.78
2008	305	Control	22.4	0	22.4	8813	1.36	0.27	4.7	0.90
2008	407	Control	22.4	0	22.4	5186	1.93	0.24	4.0	0.83
2008	101	Urea	22.4	89.6	112	12395	1.83	0.26	7.2	0.91
2008	206	Urea	22.4	89.6	112	11110	2.27	0.32	10.3	0.98
2008	308	Urea	22.4	89.6	112	10887	1.98	0.26	7.6	0.86
2008	406	Urea	22.4	89.6	112	8744	1.83	0.30	8.1	0.88
2008	109	Agrotain	22.4	89.6	112	10700	2.05	0.25	9.9	0.86
2008	205	Agrotain	22.4	89.6	112	10222	1.96	0.32	10.6	1.08
2008	303	Agrotain	22.4	89.6	112	11014	2.30	0.34	9.9	0.94
2008	412	Agrotain	22.4	89.6	112	9745	2.03	0.33	9.3	0.92
2008	104	Super U	22.4	89.6	112	12870	1.82	0.31	9.7	0.86
2008	212	Super U	22.4	89.6	112	12209	2.08	0.26	10.5	1.06
2008	311	Super U	22.4	89.6	112	10898	2.00	0.29	11.2	0.93
2008	411	Super U	22.4	89.6	112	9401	1.72	0.30	9.6	1.00
2008	103	ESN	22.4	89.6	112	10864	1.85	0.23	8.4	0.83
2008	202	ESN	22.4	89.6	112	11601	2.11	0.28	10.2	0.92
2008	304	ESN	22.4	89.6	112	10507	2.02	0.27	9.7	0.99
2008	410	ESN	22.4	89.6	112	9346	1.92	0.27	8.5	0.95
2008	111	ESN/Urea blend	22.4	89.6	112	12398	1.96	0.33	10.3	0.92
2008	201	ESN/Urea blend	22.4	89.6	112	9645	2.10	0.25	10.2	0.91
2008	312	ESN/Urea blend	22.4	89.6	112	10508	1.73	0.29	9.6	0.91
2008	402	ESN/Urea blend	22.4	89.6	112	10480	1.98	0.27	11.1	0.98
2008	106	Br UAN	22.4	89.6	112	12482	1.82	0.22	7.4	0.89
2008	208	Br UAN	22.4	89.6	112	9320	1.81	0.25	6.6	1.48

Table A.1 continued

Year	Plot	Product	Starter N kg ha^{-1}	N Rate kg ha^{-1}	Total N Rate	Biomass kg ha^{-1}	Earleaf N %	WP N %	Grain yield Mg ha^{-1}	Grain N %
2008	302	Br UAN	22.4	89.6	112	10461	1.81	0.28	8.3	0.83
2008	409	Br UAN	22.4	89.6	112	9928	1.66	0.26	7.0	0.85
2008	112	Br SU	22.4	89.6	112	12444	1.62	0.34	9.2	0.81
2008	204	Br SU	22.4	89.6	112	11363	1.80	0.34	7.9	0.85
2008	301	Br SU	22.4	89.6	112	11204	1.71	0.24	7.5	0.94
2008	401	Br SU	22.4	89.6	112	11191	2.14	0.30	8.8	0.86
2008	105	SB UAN	22.4	89.6	112	10102	1.99	0.29	8.2	0.80
2008	211	SB UAN	22.4	89.6	112	11932	2.38	0.31	9.4	0.89
2008	309	SB UAN	22.4	89.6	112	10490	2.06	0.28	8.1	0.91
2008	404	SB UAN	22.4	89.6	112	10593	2.10	0.30	8.3	0.88
2008	110	SB SU	22.4	89.6	112	11366	2.00	0.32	9.9	0.89
2008	210	SB SU	22.4	89.6	112	9630	2.14	0.25	10.6	0.98
2008	306	SB SU	22.4	89.6	112	9769	2.15	0.30	9.3	0.93
2008	403	SB SU	22.4	89.6	112	10965	2.14	0.31	9.7	0.84
2008	107	CB UAN	22.4	89.6	112	11400	2.24	0.27	9.2	0.86
2008	207	CB UAN	22.4	89.6	112	8781	2.18	0.28	10.8	0.91
2008	307	CB UAN	22.4	89.6	112	13014	2.49	0.30	9.2	0.91
2008	408	CB UAN	22.4	89.6	112	10010	2.02	0.32	8.7	0.87
2008	102	CB SU	22.4	89.6	112	10076	1.89	0.30	9.0	0.87
2008	209	CB SU	22.4	89.6	112	9566	2.19	0.26	9.6	0.91
2008	310	CB SU	22.4	89.6	112	11537	2.11	0.43	9.3	0.94
2008	405	CB SU	22.4	89.6	112	11026	2.01	0.32	9.4	0.93

Table A.2 Components of yield corn yield, Manhattan 2009

Year	Plot	Product	Starter N hg ha^{-1}	N Rate kg ha^{-1}	Total N Rate	Biomass kg ha^{-1}	Earleaf N %	WP N %	Grain yield Mg ha^{-1}	Grain N %
2009	106	Control	22.4	0	22.4	4895	2.24	0.49	7.28	0.91
2009	210	Control	22.4	0	22.4	4686	2.22	0.40	7.73	0.94
2009	309	Control	22.4	0	22.4	5651	2.11	0.42	5.76	0.94
2009	401	Control	22.4	0	22.4	5734	1.84	0.40	5.40	0.92
2009	103	Winter Urea	22.4	67.2	89.6	5525	2.47	0.55	9.83	1.17
2009	206	Winter Urea	22.4	67.2	89.6	5290	2.16	0.41	9.28	1.01
2009	301	Winter Urea	22.4	67.2	89.6	4695	2.19	0.41	7.72	1.02
2009	406	Winter Urea	22.4	67.2	89.6	6933	2.47	0.36	7.72	0.95
2009	105	Winter ESN	22.4	67.2	89.6	5611	2.47	0.43	11.56	1.02
2009	213	Winter ESN	22.4	67.2	89.6	6202	2.17	0.47	8.13	0.96
2009	312	Winter ESN	22.4	67.2	89.6	6329	2.22	0.44	9.02	1.04
2009	414	Winter ESN	22.4	67.2	89.6	5698	2.59	0.47	9.95	1.04
2009	111	Urea	22.4	67.2	89.6	4997	2.52	0.48	9.89	1.06
2009	216	Urea	22.4	67.2	89.6	5450	2.58	0.48	10.38	1.13
2009	314	Urea	22.4	67.2	89.6	5799	2.63	0.49	9.88	1.11
2009	404	Urea	22.4	67.2	89.6	7418	2.39	0.54	11.30	1.22
2009	108	Agrotain	22.4	67.2	89.6	6059	2.56	0.50	10.97	1.01
2009	218	Agrotain	22.4	67.2	89.6	6444	2.59	0.50	10.02	1.16
2009	310	Agrotain	22.4	67.2	89.6	6311	2.69	0.48	10.62	1.23
2009	408	Agrotain	22.4	67.2	89.6	6190	2.41	0.47	10.79	1.07
2009	115	Super U	22.4	67.2	89.6	5810	2.40	0.50	11.36	1.10
2009	211	Super U	22.4	67.2	89.6	4813	2.47	0.44	10.85	1.18
2009	307	Super U	22.4	67.2	89.6	5759	2.42	0.42	9.11	1.03
2009	405	Super U	22.4	67.2	89.6	6717	2.24	0.44	12.11	1.11
2009	101	ESN	22.4	67.2	89.6	5899	2.40	0.50	11.60	1.09
2009	217	ESN	22.4	67.2	89.6	5202	2.53	0.47	11.45	1.17

Table A.2 Continued

Year	Plot	Product	Starter N hg ha^{-1}	N Rate kg ha^{-1}	Total N Rate	Biomass kg ha^{-1}	Earleaf N %	WP N %	Grain yield Mg ha^{-1}	Grain N %
2009	318	ESN	22.4	67.2	89.6	6030	2.28	0.46	8.93	1.08
2009	413	ESN	22.4	67.2	89.6	7022	2.21	0.45	9.98	0.98
2009	102	ESN/Urea blend	22.4	67.2	89.6	5542	2.33	0.47	10.90	1.03
2009	203	ESN/Urea blend	22.4	67.2	89.6	5537	2.43	0.44	10.32	1.05
2009	302	ESN/Urea blend	22.4	67.2	89.6	4816	2.64	0.43	10.63	1.07
2009	411	ESN/Urea blend	22.4	67.2	89.6	6060	2.18	0.44	11.80	1.17
2009	118	Br UAN	22.4	67.2	89.6	5770	2.41	0.51	10.37	1.07
2009	204	Br UAN	22.4	67.2	89.6	6233	2.49	0.58	9.43	1.02
2009	315	Br UAN	22.4	67.2	89.6	6878	2.21	0.51	8.74	1.06
2009	407	Br UAN	22.4	67.2	89.6	6000	2.35	0.47	8.57	0.99
2009	112	Br SU	22.4	67.2	89.6	5786	2.54	0.49	9.39	1.08
2009	208	Br SU	22.4	67.2	89.6	5353	2.49	0.45	9.47	1.07
2009	313	Br SU	22.4	67.2	89.6	5776	2.24	0.42	8.78	1.06
2009	417	Br SU	22.4	67.2	89.6	5936	2.18	0.49	7.88	0.93
2009	113	BR Nutra-sphere	22.4	67.2	89.6	5878	2.28	0.48	6.86	0.90
2009	202	BR Nutra-sphere	22.4	67.2	89.6	5194	2.31	0.45	8.67	0.99
2009	305	BR Nutra-sphere	22.4	67.2	89.6	5212	2.52	0.40	9.16	1.05
2009	412	BR Nutra-sphere	22.4	67.2	89.6	6579	2.26	0.43	7.48	0.95
2009	107	SB UAN	22.4	67.2	89.6	5114	2.33	0.41	8.18	0.92
2009	205	SB UAN	22.4	67.2	89.6	4620	2.18	0.43	9.22	1.00
2009	316	SB UAN	22.4	67.2	89.6	5896	2.33	0.49	10.30	1.05
2009	418	SB UAN	22.4	67.2	89.6	6532	2.27	0.48	9.44	1.00
2009	110	SB SU	22.4	67.2	89.6	5063	2.52	0.46	9.33	1.07
2009	209	SB SU	22.4	67.2	89.6	4434	2.41	0.44	9.74	1.03
2009	317	SB SU	22.4	67.2	89.6	6475	2.46	0.54	10.82	1.00
2009	416	SB SU	22.4	67.2	89.6	5039	2.38	0.50	9.38	1.07

Table A.2 Continued

Year	Plot	Product	Starter N hg ha^{-1}	N Rate kg ha^{-1}	Total N Rate	Biomass kg ha^{-1}	Earleaf N %	WP N %	Grain yield Mg ha^{-1}	Grain N %
2009	109	SB Nutra-sphere	22.4	67.2	89.6	5629	2.39	0.49	10.08	0.94
2009	212	SB Nutra-sphere	22.4	67.2	89.6	5271	2.41	0.39	10.34	1.09
2009	308	SB Nutra-sphere	22.4	67.2	89.6	5209	2.41	0.40	8.72	0.97
2009	409	SB Nutra-sphere	22.4	67.2	89.6	6238	2.35	0.56	7.92	0.95
2009	117	CB UAN	22.4	67.2	89.6	5424	2.48	0.57	10.71	1.04
2009	214	CB UAN	22.4	67.2	89.6	5358	2.41	0.45	10.85	1.12
2009	304	CB UAN	22.4	67.2	89.6	5391	2.15	0.42	10.03	1.13
2009	402	CB UAN	22.4	67.2	89.6	6398	2.34	0.46	9.04	1.00
2009	114	100.8kg Urea	22.4	100.8	123.2	5806	2.53	0.50	11.74	1.15
2009	207	100.8kg Urea	22.4	100.8	123.2	5487	2.51	0.41	10.63	1.15
2009	303	100.8kg Urea	22.4	100.8	123.2	6920	2.68	0.47	10.55	1.28
2009	410	100.8kg Urea	22.4	100.8	123.2	6744	2.72	0.54	12.52	1.24
2009	104	134.4kg Urea	22.4	134.4	156.8	6199	2.57	0.52	12.38	1.17
2009	201	134.4kg Urea	22.4	134.4	156.8	5272	2.50	0.49	10.84	1.06
2009	306	134.4kg Urea	22.4	134.4	156.8	6891	2.73	0.49	10.95	1.37
2009	403	134.4kg Urea	22.4	134.4	156.8	6008	2.62	0.39	10.67	1.26
2009	116	168kg Urea	22.4	168	190.4	5944	2.67	0.52	13.63	1.27
2009	215	168kg Urea	22.4	168	190.4	5493	2.52	0.55	12.15	1.30
2009	311	168kg Urea	22.4	168	190.4	6070	2.74	0.45	12.90	1.31
2009	415	168kg Urea	22.4	168	190.4	7699	2.53	0.62	10.48	1.26

Table A.3 Components of Corn Yield, Ottawa 2009

Year	Plot	Product	Starter N hg ha^{-1}	N Rate kg ha^{-1}	Total N Rate	Biomass kg ha^{-1}	Earleaf N %	WP N %	Grain yield Mg ha^{-1}	Grain N %
2009	106	Control	22.4	0	22.4	5691	1.49	0.28	4.96	0.86
2009	210	Control	22.4	0	22.4	5785	1.38	0.32	4.36	0.86
2009	309	Control	22.4	0	22.4	3644	1.42	0.36	4.28	0.83
2009	401	Control	22.4	0	22.4	4430	1.29	0.43	4.45	0.88
2009	103	Winter Urea	22.4	67.2	89.6	6717	1.63	0.35	4.83	0.93
2009	206	Winter Urea	22.4	67.2	89.6	6461	1.73	0.34	5.15	0.80
2009	301	Winter Urea	22.4	67.2	89.6	5305	1.68	0.38	4.22	0.81
2009	406	Winter Urea	22.4	67.2	89.6	4951	1.37	0.43	4.85	0.88
2009	105	Winter ESN	22.4	67.2	89.6	5429	1.74	0.29	5.83	0.82
2009	213	Winter ESN	22.4	67.2	89.6	7186	1.69	0.38	5.01	0.89
2009	312	Winter ESN	22.4	67.2	89.6	4993	1.41	0.40	5.15	0.89
2009	414	Winter ESN	22.4	67.2	89.6	5713	1.62	0.42	5.08	0.89
2009	111	Urea	22.4	67.2	89.6	7556	1.54	0.30	5.60	0.90
2009	216	Urea	22.4	67.2	89.6	6662	1.73	0.37	5.22	0.86
2009	314	Urea	22.4	67.2	89.6	4886	1.46	0.42	5.75	0.88
2009	404	Urea	22.4	67.2	89.6	5061	1.50	0.41	5.24	0.83
2009	108	Agrotain	22.4	67.2	89.6	8175	1.91	0.38	6.76	0.93
2009	218	Agrotain	22.4	67.2	89.6	6589	1.69	0.36	5.30	0.82
2009	310	Agrotain	22.4	67.2	89.6	4489	1.50	0.37	4.82	0.85
2009	408	Agrotain	22.4	67.2	89.6	6352	1.36	0.39	5.40	0.95
2009	115	SU	22.4	67.2	89.6	6362	1.82	0.28	6.35	0.90
2009	211	SU	22.4	67.2	89.6	5797	2.27	0.34	5.44	0.91
2009	307	SU	22.4	67.2	89.6	5453	1.73	0.24	4.93	0.82
2009	405	SU	22.4	67.2	89.6	5133	1.42	0.37	5.98	0.86
2009	101	ESN	22.4	67.2	89.6	5432	1.70	0.31	5.43	0.95

Table A.3 Continued

Year	Plot	Product	Starter N hg ha^{-1}	N Rate kg ha^{-1}	Total N Rate	Biomass kg ha^{-1}	Earleaf N %	WP N %	Grain yield Mg ha^{-1}	Grain N %
2009	217	ESN	22.4	67.2	89.6	6198	1.88	0.40	5.06	0.91
2009	318	ESN	22.4	67.2	89.6	5866	1.56	0.48	5.86	0.91
2009	413	ESN	22.4	67.2	89.6	6523	1.69	0.39	5.71	0.84
2009	102	ESN/Urea	22.4	67.2	89.6	5494	1.51	0.27	4.72	0.88
2009	203	ESN/Urea	22.4	67.2	89.6	5249	1.86	0.33	5.72	0.89
2009	302	ESN/Urea	22.4	67.2	89.6	6066	2.46	0.37	5.56	0.93
2009	411	ESN/Urea	22.4	67.2	89.6	5018	1.36	0.38	4.63	0.93
2009	118	Br UAN	22.4	67.2	89.6	6837	1.68	0.40	5.56	0.87
2009	204	Br UAN	22.4	67.2	89.6	4874	1.56	0.38	5.32	0.85
2009	315	Br UAN	22.4	67.2	89.6	5082	1.38	0.36	4.66	0.97
2009	407	Br UAN	22.4	67.2	89.6	5916	1.32	0.37	4.74	0.83
2009	112	Br SU	22.4	67.2	89.6	6114	1.73	0.43	4.87	0.91
2009	208	Br SU	22.4	67.2	89.6	5755	1.57	0.35	4.57	0.82
2009	313	Br SU	22.4	67.2	89.6	4961	1.50	0.39	5.08	0.82
2009	417	Br SU	22.4	67.2	89.6	6328	1.40	0.40	5.33	0.86
2009	113	BR Nutra-sphere	22.4	67.2	89.6	6544	1.65	0.35	4.74	0.87
2009	202	BR Nutra-sphere	22.4	67.2	89.6	5379	1.53	0.32	4.74	0.84
2009	305	BR Nutra-sphere	22.4	67.2	89.6	5945	1.54	0.39	4.14	0.89
2009	412	BR Nutra-sphere	22.4	67.2	89.6	5386	1.29	0.36	4.22	0.87
2009	107	SB UAN	22.4	67.2	89.6	6403	1.70	0.24	5.26	0.85
2009	205	SB UAN	22.4	67.2	89.6	5635	1.64	0.33	4.87	0.83
2009	316	SB UAN	22.4	67.2	89.6	6348	1.47	0.48	5.29	0.88
2009	418	SB UAN	22.4	67.2	89.6	6127	1.53	0.39	4.51	0.84
2009	110	SB SU	22.4	67.2	89.6	6131	1.92	0.35	5.69	1.00
2009	209	SB SU	22.4	67.2	89.6	5031	1.64	0.34	5.02	0.83
2009	317	SB SU	22.4	67.2	89.6	6694	1.48	0.46	4.57	0.93
2009	416	SB SU	22.4	67.2	89.6	5717	1.70	0.46	4.36	0.85

Table A.3 Continued

Year	Plot	Product	Starter N hg ha^{-1}	N Rate kg ha^{-1}	Total N Rate	Biomass kg ha^{-1}	Earleaf N %	WP N %	Grain yield Mg ha^{-1}	Grain N %
2009	109	SB Nutra-sphere	22.4	67.2	89.6	6478	1.88	0.40	5.47	0.88
2009	212	SB Nutra-sphere	22.4	67.2	89.6	6561	1.58	0.35	4.99	0.78
2009	308	SB Nutra-sphere	22.4	67.2	89.6	5516	1.58	0.25	4.64	0.84
2009	409	SB Nutra-sphere	22.4	67.2	89.6	4911	1.53	0.42	5.07	0.78
2009	117	CB UAN	22.4	67.2	89.6	7638	1.97	0.35	6.39	0.92
2009	214	CB UAN	22.4	67.2	89.6	5113	2.02	0.35	7.45	0.86
2009	304	CB UAN	22.4	67.2	89.6	6398	1.80	0.34	6.38	0.88
2009	402	CB UAN	22.4	67.2	89.6	6360	1.49	0.45	6.30	0.91
2009	114	100.8kg Urea	22.4	100.8	123.2	6094	1.71	0.37	6.72	0.89
2009	207	100.8kg Urea	22.4	100.8	123.2	8441	1.72	0.42	5.39	0.81
2009	303	100.8kg Urea	22.4	100.8	123.2	5957	1.81	0.29	5.39	0.86
2009	410	100.8kg Urea	22.4	100.8	123.2	6393	1.42	0.41	5.66	0.89
2009	104	134.4kg Urea	22.4	134.4	156.8	6394	1.82	0.26	5.92	0.86
2009	201	134.4kg Urea	22.4	134.4	156.8	6162	1.81	0.46	6.29	0.88
2009	306	134.4kg Urea	22.4	134.4	156.8	5244	1.74	0.33	6.79	0.84
2009	403	134.4kg Urea	22.4	134.4	156.8	6415	1.66	0.50	5.03	0.84
2009	116	168kg Urea	22.4	168	190.4	7323	2.06	0.31	7.73	1.01
2009	215	168kg Urea	22.4	168	190.4	7034	1.83	0.39	6.73	0.91
2009	311	168kg Urea	22.4	168	190.4	5316	1.45	0.37	6.51	0.89
2009	415	168kg Urea	22.4	168	190.4	5632	1.78	0.51	6.03	0.84

Table A.4 Components of Corn Yield, Hutchinson 2009

Year	Plot	Product	Starter N hg ha^{-1}	N Rate kg ha^{-1}	Total N Rate	Biomass kg ha^{-1}	Earleaf N %	WP N %	Grain yield Mg ha^{-1}	Grain N %
2009	106	Control	22.4	0	22.4	5342	2.28	0.39	6.16	1.31
2009	210	Control	22.4	0	22.4	4326	2.16	0.43	8.09	1.06
2009	309	Control	22.4	0	22.4	5495	2.10	0.40	8.03	1.56
2009	401	Control	22.4	0	22.4	5372	2.11	0.55	7.95	1.45
2009	103	Winter Urea	22.4	67.2	89.6	5952	2.04	0.52	7.00	1.47
2009	206	Winter Urea	22.4	67.2	89.6	5419	2.12	0.56	7.79	1.27
2009	301	Winter Urea	22.4	67.2	89.6	4760	2.12	0.46	8.31	1.47
2009	406	Winter Urea	22.4	67.2	89.6	6485	2.23	0.69	8.28	1.63
2009	105	Winter ESN	22.4	67.2	89.6	5800	2.10	0.50	7.83	1.23
2009	213	Winter ESN	22.4	67.2	89.6	7303	2.17	0.45	8.38	1.48
2009	312	Winter ESN	22.4	67.2	89.6	6375	2.26	0.70	7.12	1.62
2009	414	Winter ESN	22.4	67.2	89.6	5825	2.08	0.44	8.93	1.49
2009	111	Urea	22.4	67.2	89.6	5435	1.94	0.42	9.58	1.47
2009	216	Urea	22.4	67.2	89.6	6928	2.31	0.63	9.50	1.50
2009	314	Urea	22.4	67.2	89.6	8194	2.46	0.74	7.51	1.66
2009	404	Urea	22.4	67.2	89.6	5333	2.15	0.54	8.86	1.54
2009	108	Agrotain	22.4	67.2	89.6	6301	1.73	0.53	7.80	1.30
2009	218	Agrotain	22.4	67.2	89.6	5950	2.43	0.70	10.32	1.64
2009	310	Agrotain	22.4	67.2	89.6	6826	2.42	0.71	7.70	1.71
2009	408	Agrotain	22.4	67.2	89.6	5805	2.18	0.52	7.52	1.62
2009	115	Super U	22.4	67.2	89.6	6799	2.20	0.39	9.69	1.39
2009	211	Super U	22.4	67.2	89.6	4448	2.13	0.62	9.05	1.59
2009	307	Super U	22.4	67.2	89.6	5960	2.10	0.54	7.25	1.63
2009	405	Super U	22.4	67.2	89.6	7166	2.22	0.58	8.71	1.68
2009	101	ESN	22.4	67.2	89.6	5322	2.02	0.45	7.80	1.50
2009	217	ESN	22.4	67.2	89.6	7072	2.26	0.59	10.73	1.44

Table A.4 Continued

Year	Plot	Product	Starter N hg ha^{-1}	N Rate kg ha^{-1}	Total N Rate	Biomass kg ha^{-1}	Earleaf N %	WP N %	Grain yield Mg ha^{-1}	Grain N %
2009	318	ESN	22.4	67.2	89.6	4304	2.12	0.49	7.67	1.38
2009	413	ESN	22.4	67.2	89.6	5842	2.11	0.53	8.87	1.59
2009	102	ESN/Urea blend	22.4	67.2	89.6	5480	1.97	0.55	6.02	1.31
2009	203	ESN/Urea blend	22.4	67.2	89.6	4994	2.29	0.61	8.44	1.45
2009	302	ESN/Urea blend	22.4	67.2	89.6	5685	2.24	0.81	8.13	1.53
2009	411	ESN/Urea blend	22.4	67.2	89.6	4934	2.28	0.53	7.75	1.66
2009	118	Br UAN	22.4	67.2	89.6	7535	2.33	0.58	8.95	1.52
2009	204	Br UAN	22.4	67.2	89.6	6321	2.38	0.56	7.39	1.53
2009	315	Br UAN	22.4	67.2	89.6	6086	2.16	0.56	8.79	1.63
2009	407	Br UAN	22.4	67.2	89.6	5309	2.03	0.46	8.64	1.64
2009	112	Br SU	22.4	67.2	89.6	6715	2.10	0.51	7.53	1.48
2009	208	Br SU	22.4	67.2	89.6	5546	2.29	0.49	9.33	1.42
2009	313	Br SU	22.4	67.2	89.6	5577	2.29	0.53	7.80	1.64
2009	417	Br SU	22.4	67.2	89.6	7748	2.09	0.69	9.86	1.50
2009	113	BR Nutra-sphere	22.4	67.2	89.6	5835	2.01	0.37	10.45	1.43
2009	202	BR Nutra-sphere	22.4	67.2	89.6	4505	2.24	0.54	7.95	1.42
2009	305	BR Nutra-sphere	22.4	67.2	89.6	4490	2.69	0.89	8.88	1.63
2009	412	BR Nutra-sphere	22.4	67.2	89.6	6004	2.22	0.59	8.68	1.57
2009	107	SB UAN	22.4	67.2	89.6	6182	2.10	0.45	7.20	1.47
2009	205	SB UAN	22.4	67.2	89.6	5137	2.22	0.64	7.79	1.41
2009	316	SB UAN	22.4	67.2	89.6	3619	1.83	0.51	7.63	1.49
2009	418	SB UAN	22.4	67.2	89.6	7313	1.95	0.52	8.91	1.46
2009	110	SB SU	22.4	67.2	89.6	6102	1.95	0.45	9.49	1.44
2009	209	SB SU	22.4	67.2	89.6	5847	2.29	0.65	6.86	1.47
2009	317	SB SU	22.4	67.2	89.6	7508	2.31	0.63	7.43	1.57
2009	416	SB SU	22.4	67.2	89.6	6639	1.83	0.55	11.00	1.51

Table A.4 Continued

Year	Plot	Product	Starter N hg ha^{-1}	N Rate kg ha^{-1}	Total N Rate	Biomass kg ha^{-1}	Earleaf N %	WP N %	Grain yield Mg ha^{-1}	Grain N %
2009	109	SB Nutra-sphere	22.4	67.2	89.6	6683	2.03	0.52	9.15	1.28
2009	212	SB Nutra-sphere	22.4	67.2	89.6	5229	2.18	0.53	7.36	1.56
2009	308	SB Nutra-sphere	22.4	67.2	89.6	4132	2.23	0.53	7.10	1.46
2009	409	SB Nutra-sphere	22.4	67.2	89.6	5654	2.17	0.50	7.83	1.61
2009	117	CB UAN	22.4	67.2	89.6	5997	2.07	0.51	8.89	1.50
2009	214	CB UAN	22.4	67.2	89.6	4768	2.30	0.43	10.39	1.50
2009	304	CB UAN	22.4	67.2	89.6	7119	2.25	0.65	8.37	1.62
2009	402	CB UAN	22.4	67.2	89.6	4784	2.26	0.51	8.79	1.70
2009	114	100.8kg Urea	22.4	100.8	123.2	7522	2.14	0.53	9.95	1.57
2009	207	100.8kg Urea	22.4	100.8	123.2	6270	2.17	0.65	8.50	1.56
2009	303	100.8kg Urea	22.4	100.8	123.2	7533	2.25	0.87	8.16	1.74
2009	410	100.8kg Urea	22.4	100.8	123.2	6155	2.18	0.76	8.10	1.60
2009	104	134.4kg Urea	22.4	134.4	156.8	6386	2.24	0.78	8.58	1.50
2009	201	134.4kg Urea	22.4	134.4	156.8	6646	2.16	0.75	8.21	1.65
2009	306	134.4kg Urea	22.4	134.4	156.8	3900	2.36	0.54	7.50	1.38
2009	403	134.4kg Urea	22.4	134.4	156.8	7088	2.31	0.80	7.54	1.66
2009	116	168kg Urea	22.4	168	190.4	8054	2.25	0.61	8.41	1.59
2009	215	168kg Urea	22.4	168	190.4	7324	2.24	0.72	10.02	1.56
2009	311	168kg Urea	22.4	168	190.4	7585	2.26	1.14	7.83	1.79
2009	415	168kg Urea	22.4	168	190.4	6229	2.34	0.76	10.73	1.68

Appendix B - Components of Grain Sorghum Yield from 2008 and 2009

Table B.1 Components of Grain Sorghum Yield, Manhattan 2008

Year	Plot	Product	Starter N hg ha^{-1}	N Rate kg ha^{-1}	Total N Rate	Flag Leaf N %	Grain yield Mg ha^{-1}	Grain N %
2008	107	Control	22.4	0	0	2.03	3.67	0.99
2008	208	Control	22.4	0	0	1.93	2.00	1.03
2008	305	Control	22.4	0	0	2.06	2.46	1.04
2008	405	Control	22.4	0	0	2.02	2.94	1.08
2008	108	Urea	22.4	67.2	89.6	2.39	5.22	1.01
2008	205	Urea	22.4	67.2	89.6	2.48	6.28	1.04
2008	308	Urea	22.4	67.2	89.6	2.35	5.99	1.07
2008	406	Urea	22.4	67.2	89.6	2.26	6.57	1.12
2008	102	Agrotain	22.4	67.2	89.6	2.42	6.75	1.10
2008	210	Agrotain	22.4	67.2	89.6	2.49	7.35	1.16
2008	309	Agrotain	22.4	67.2	89.6	2.43	7.01	1.10
2008	404	Agrotain	22.4	67.2	89.6	2.49	5.69	1.05
2008	103	Super U	22.4	67.2	89.6	2.36	7.65	1.10
2008	202	Super U	22.4	67.2	89.6	2.30	6.63	1.05
2008	302	Super U	22.4	67.2	89.6	2.44	6.22	1.17
2008	409	Super U	22.4	67.2	89.6	2.59	6.63	1.16
2008	101	ESN	22.4	67.2	89.6	2.51	6.25	1.15
2008	209	ESN	22.4	67.2	89.6	2.27	5.88	1.13
2008	310	ESN	22.4	67.2	89.6	2.54	6.14	1.19
2008	410	ESN	22.4	67.2	89.6	2.46	6.46	1.20
2008	110	ESN/Urea Blend	22.4	67.2	89.6	2.39	6.60	1.02
2008	201	ESN/Urea Blend	22.4	67.2	89.6	2.36	6.89	1.07
2008	301	ESN/Urea Blend	22.4	67.2	89.6	2.28	6.20	1.06
2008	402	ESN/Urea Blend	22.4	67.2	89.6	2.43	5.57	1.18
2008	105	Br UAN	22.4	67.2	89.6	2.34	5.83	0.97
2008	306	Br UAN	22.4	67.2	89.6	2.32	5.88	0.97

Table B.1 Continued

Year	Plot	Product	Starter N hg ha^{-1}	N Rate kg ha^{-1}	Total N Rate	Flag Leaf N %	Grain yield Mg ha^{-1}	Grain N %
2008	203	Br UAN	22.4	67.2	89.6	2.05	6.36	1.00
2008	407	Br UAN	22.4	67.2	89.6	2.21	5.91	1.02
2008	104	SB UAN	22.4	67.2	89.6	2.33	5.45	1.00
2008	206	SB UAN	22.4	67.2	89.6	2.32	5.06	1.00
2008	307	SB UAN	22.4	67.2	89.6	2.08	4.32	1.02
2008	401	SB UAN	22.4	67.2	89.6	2.42	5.43	1.09
2008	204	SB Super U	22.4	67.2	89.6	2.43	6.21	1.04
2008	303	SB Super U	22.4	67.2	89.6	2.43	5.99	1.09
2008	106	SB Super U	22.4	67.2	89.6	2.20	6.32	0.99
2008	408	SB Super U	22.4	67.2	89.6	2.17	5.56	1.03
2008	109	CB UAN	22.4	67.2	89.6	2.38	6.30	1.06
2008	207	CB UAN	22.4	67.2	89.6	2.24	6.51	1.01
2008	304	CB UAN	22.4	67.2	89.6	2.39	5.90	1.05
2008	403	CB UAN	22.4	67.2	89.6	2.28	6.73	1.20

Table B.2 Components of Grain Sorghum Yield, Ottawa 2008

Year	Plot	Product	Starter N hg ha^{-1}	N Rate kg ha^{-1}	Total N Rate	Flag Leaf N %	Grain yield Mg ha^{-1}	Grain N %
2008	105	Control	0	0	0	1.83	2.29	1.33
2008	204	Control	0	0	0	1.98	1.75	1.25
2008	305	Control	0	0	0	1.88	1.59	1.21
2008	402	Control	0	0	0	1.61	2.03	1.23
2008	101	Urea	0	67.2	67.2	1.90	3.70	1.23
2008	206	Urea	0	67.2	67.2	2.33	4.38	1.21
2008	304	Urea	0	67.2	67.2	2.37	5.57	1.22
2008	405	Urea	0	67.2	67.2	1.92	3.83	1.16
2008	103	Agrotain	0	67.2	67.2	2.18	4.19	1.46
2008	202	Agrotain	0	67.2	67.2	2.19	3.30	1.33
2008	306	Agrotain	0	67.2	67.2	2.13	4.22	1.15
2008	401	Agrotain	0	67.2	67.2	1.90	4.85	1.14
2008	104	ESN/Urea Blend	0	67.2	67.2	2.10	3.62	1.13
2008	201	ESN/Urea Blend	0	67.2	67.2	2.00	4.70	1.12
2008	302	ESN/Urea Blend	0	67.2	67.2	2.33	4.10	1.27
2008	403	ESN/Urea Blend	0	67.2	67.2	1.95	4.82	1.10
2008	106	Br UAN	0	67.2	67.2	2.17	4.35	1.19
2008	203	Br UAN	0	67.2	67.2	2.03	2.85	1.14
2008	301	Br UAN	0	67.2	67.2	2.43	4.26	1.22
2008	404	Br UAN	0	67.2	67.2	2.18	3.91	1.14
2008	102	SB UAN	0	67.2	67.2	2.08	4.02	1.10
2008	205	SB UAN	0	67.2	67.2	2.09	2.89	1.22
2008	303	SB UAN	0	67.2	67.2	2.42	5.29	1.33
2008	406	SB UAN	0	67.2	67.2	2.02	3.97	1.15

Table B.3 Components of Grain Sorghum Yield, Partridge 2008

Year	Plot	Product	Starter N hg ha^{-1}	N Rate kg ha^{-1}	Total N Rate	Flag Leaf N %	Grain yield Mg ha^{-1}	Grain N %
2008	105	Control	0	0	0	2.62	7.80	1.17
2008	204	Control	0	0	0	2.59	7.40	1.22
2008	305	Control	0	0	0	2.79	7.40	1.63
2008	402	Control	0	0	0	2.62	7.21	1.61
2008	101	Urea	0	67.2	67.2	2.83	7.40	1.37
2008	206	Urea	0	67.2	67.2	2.77	8.10	1.37
2008	304	Urea	0	67.2	67.2	2.70	8.08	1.58
2008	405	Urea	0	67.2	67.2	2.84	8.48	1.46
2008	103	Agrotain	0	67.2	67.2	2.75	7.70	1.32
2008	202	Agrotain	0	67.2	67.2	2.74	7.46	1.36
2008	306	Agrotain	0	67.2	67.2	2.83	7.94	1.69
2008	401	Agrotain	0	67.2	67.2	2.75	7.83	1.61
2008	104	ESN/Urea Blend	0	67.2	67.2	2.80	8.37	1.40
2008	201	ESN/Urea Blend	0	67.2	67.2	2.63	7.54	1.21
2008	302	ESN/Urea Blend	0	67.2	67.2	2.80	8.17	1.36
2008	403	ESN/Urea Blend	0	67.2	67.2	2.97	7.53	1.68
2008	106	Br UAN	0	67.2	67.2	2.83	8.06	1.48
2008	203	Br UAN	0	67.2	67.2	2.76	7.85	1.36
2008	301	Br UAN	0	67.2	67.2	2.83	7.61	1.26
2008	404	Br UAN	0	67.2	67.2	2.81	8.19	1.55
2008	102	SB UAN	0	67.2	67.2	2.85	7.53	1.41
2008	205	SB UAN	0	67.2	67.2	2.81	8.59	1.34
2008	303	SB UAN	0	67.2	67.2	2.83	7.19	1.70
2008	406	SB UAN	0	67.2	67.2	2.90	7.22	1.42

Table B.4 Components of Grain Sorghum Yield, Manhattan 2009

Year	Plot	Product	Starter N hg ha^{-1}	N Rate kg ha^{-1}	Total N Rate	Flag Leaf N %	Grain yield Mg ha^{-1}	Grain N %
2009	106	Control	0	0	0	2.14	6.52	0.88
2009	205	Control	0	0	0	2.13	6.65	0.89
2009	307	Control	0	0	0	2.10	7.24	0.86
2009	411	Control	0	0	0	2.09	5.60	0.91
2009	111	WinterUrea	0	67.2	67.2	1.90	7.99	0.91
2009	217	WinterUrea	0	67.2	67.2	2.26	9.52	0.91
2009	317	WinterUrea	0	67.2	67.2	2.07	7.75	0.94
2009	409	WinterUrea	0	67.2	67.2	2.27	7.38	0.88
2009	107	WinterESN	0	67.2	67.2	2.34	8.36	0.93
2009	216	WinterESN	0	67.2	67.2	2.50	8.52	0.92
2009	302	WinterESN	0	67.2	67.2	2.29	8.88	0.93
2009	414	WinterESN	0	67.2	67.2	2.13	8.83	0.89
2009	105	Urea	0	67.2	67.2	2.43	8.93	0.97
2009	201	Urea	0	67.2	67.2	2.38	8.38	0.88
2009	308	Urea	0	67.2	67.2	2.38	9.35	0.90
2009	413	Urea	0	67.2	67.2	2.03	7.66	0.94
2009	115	Agrotain	0	67.2	67.2	2.44	7.96	0.92
2009	207	Agrotain	0	67.2	67.2	2.48	9.83	0.90
2009	314	Agrotain	0	67.2	67.2	2.36	9.50	1.01
2009	403	Agrotain	0	67.2	67.2	2.73	8.88	1.02
2009	110	SU	0	67.2	67.2	2.19	8.90	0.92
2009	202	SU	0	67.2	67.2	2.54	8.33	0.87
2009	304	SU	0	67.2	67.2	2.35	5.69	0.88
2009	401	SU	0	67.2	67.2	2.49	9.20	0.95
2009	113	ESN	0	67.2	67.2	2.30	9.40	0.97
2009	211	ESN	0	67.2	67.2	2.57	9.57	0.96

Table B.4 Continued

Year	Plot	Product	Starter N hg ha^{-1}	N Rate kg ha^{-1}	Total N Rate	Flag Leaf N %	Grain yield Mg ha^{-1}	Grain N %
2009	305	ESN	0	67.2	67.2	2.34	6.65	0.87
2009	402	ESN	0	67.2	67.2	2.57	9.47	0.96
2009	108	50/50Blend	0	67.2	67.2	2.23	8.08	0.90
2009	218	50/50Blend	0	67.2	67.2	2.33	8.55	0.96
2009	303	50/50Blend	0	67.2	67.2	2.62	7.45	0.89
2009	415	50/50Blend	0	67.2	67.2	2.16	8.35	0.93
2009	114	BRUAN	0	67.2	67.2	2.10	7.15	0.88
2009	212	BRUAN	0	67.2	67.2	2.32	7.98	0.89
2009	306	BRUAN	0	67.2	67.2	2.27	6.90	0.87
2009	418	BRUAN	0	67.2	67.2	1.94	7.28	0.88
2009	104	Br UAN+SU	0	67.2	67.2	2.27	8.10	0.92
2009	204	Br UAN+SU	0	67.2	67.2	2.32	6.43	0.87
2009	311	Br UAN+SU	0	67.2	67.2	2.26	6.72	0.85
2009	410	Br UAN+SU	0	67.2	67.2	2.20	6.04	0.89
2009	109	BRUAN+Nutra-Sphere	0	67.2	67.2	2.30	7.15	0.92
2009	214	BRUAN+Nutra-Sphere	0	67.2	67.2	2.43	7.64	0.86
2009	312	BRUAN+Nutra-Sphere	0	67.2	67.2	2.26	7.21	0.90
2009	406	BRUAN+Nutra-Sphere	0	67.2	67.2	2.33	8.08	0.88
2009	102	SB UAN	0	67.2	67.2	2.54	7.87	0.92
2009	210	SB UAN	0	67.2	67.2	2.56	7.87	0.87
2009	301	SB UAN	0	67.2	67.2	2.40	7.18	0.93
2009	408	SB UAN	0	67.2	67.2	2.39	7.36	0.87
2009	117	SBUAN+SU	0	67.2	67.2	2.55	7.86	0.93
2009	213	SBUAN+SU	0	67.2	67.2	2.02	8.21	0.88
2009	315	SBUAN+SU	0	67.2	67.2	2.33	7.99	0.92
2009	416	SBUAN+SU	0	67.2	67.2	2.49	7.53	0.94
2009	112	SB UAN+Nutra-Sphere	0	67.2	67.2	2.49	8.67	0.92

Table B.4 Continued

Year	Plot	Product	Starter N hg ha^{-1}	N Rate kg ha^{-1}	Total N Rate	Flag Leaf N %	Grain yield Mg ha^{-1}	Grain N %
2009	215	SB UAN+Nutra-Sphere	0	67.2	67.2	2.26	8.70	0.86
2009	313	SB UAN+Nutra-Sphere	0	67.2	67.2	2.41	8.54	0.95
2009	404	SB UAN+Nutra-Sphere	0	67.2	67.2	2.57	9.04	1.00
2009	101	CB UAN	0	67.2	67.2	2.51	8.80	1.02
2009	208	CB UAN	0	67.2	67.2	2.64	8.05	0.88
2009	318	CB UAN	0	67.2	67.2	2.44	8.75	0.94
2009	405	CB UAN	0	67.2	67.2	2.72	9.82	0.99
2009	116	33.6Urea	0	33.6	33.6	2.09	7.14	0.87
2009	203	33.6Urea	0	33.6	33.6	2.28	7.51	0.86
2009	316	33.6Urea	0	33.6	33.6	1.97	6.38	0.92
2009	407	33.6Urea	0	33.6	33.6	2.22	7.51	0.90
2009	118	100.8Urea	0	100.8	100.8	2.56	9.48	0.96
2009	209	100.8Urea	0	100.8	100.8	2.55	8.84	0.90
2009	310	100.8Urea	0	100.8	100.8	2.43	9.19	0.94
2009	417	100.8Urea	0	100.8	100.8	2.33	9.34	0.99
2009	103	134.4Urea	0	134.4	134.4	2.39	9.65	1.00
2009	206	134.4Urea	0	134.4	134.4	2.62	9.99	1.01
2009	309	134.4Urea	0	134.4	134.4	2.45	8.89	1.02
2009	412	134.4Urea	0	134.4	134.4	2.26	10.49	1.08

Table B.5 Components of Grain Sorghum Yield, Ottawa 2009

Year	Plot	Product	Starter N hg ha^{-1}	N Rate kg ha^{-1}	Total N Rate	Flag Leaf N %	Grain yield Mg ha^{-1}	Grain N %
2009	106	Control	0	0	0	2.00	5.13	0.90
2009	205	Control	0	0	0	1.78	3.48	0.92
2009	307	Control	0	0	0	1.79	4.08	0.98
2009	411	Control	0	0	0	1.53	4.82	0.93
2009	111	WinterUrea	0	67.2	67.2	1.76	5.99	0.93
2009	217	WinterUrea	0	67.2	67.2	1.96	5.64	0.94
2009	317	WinterUrea	0	67.2	67.2	1.94	5.29	0.90
2009	409	WinterUrea	0	67.2	67.2	1.68	4.73	0.92
2009	107	WinterESN	0	67.2	67.2	2.05	7.43	0.97
2009	216	WinterESN	0	67.2	67.2	2.12	6.06	0.94
2009	302	WinterESN	0	67.2	67.2	1.95	5.84	0.93
2009	414	WinterESN	0	67.2	67.2	1.89	5.94	0.94
2009	105	Urea	0	67.2	67.2	2.01	6.30	0.93
2009	201	Urea	0	67.2	67.2	2.17	5.19	1.00
2009	308	Urea	0	67.2	67.2	1.71	6.24	0.90
2009	413	Urea	0	67.2	67.2	1.83	6.41	0.95
2009	115	Agrotain	0	67.2	67.2	1.93	6.05	0.92
2009	207	Agrotain	0	67.2	67.2	2.12	6.51	0.98
2009	314	Agrotain	0	67.2	67.2	1.87	7.35	0.94
2009	403	Agrotain	0	67.2	67.2	1.99	6.46	0.91
2009	110	SU	0	67.2	67.2	1.82	7.81	0.95
2009	202	SU	0	67.2	67.2	1.99	5.81	0.91
2009	304	SU	0	67.2	67.2	1.92	6.35	0.92
2009	401	SU	0	67.2	67.2	1.78	6.32	0.99
2009	113	ESN	0	67.2	67.2	2.15	7.32	0.99
2009	211	ESN	0	67.2	67.2	2.12	6.87	0.97

Table B.5 Continued

Year	Plot	Product	Starter N hg ha^{-1}	N Rate kg ha^{-1}	Total N Rate	Flag Leaf N %	Grain yield Mg ha^{-1}	Grain N %
2009	305	ESN	0	67.2	67.2	2.05	6.54	0.91
2009	402	ESN	0	67.2	67.2	1.91	6.87	0.94
2009	108	50/50Blend	0	67.2	67.2	2.00	7.48	0.96
2009	218	50/50Blend	0	67.2	67.2	2.01	6.68	0.96
2009	303	50/50Blend	0	67.2	67.2	1.93	6.81	0.90
2009	415	50/50Blend	0	67.2	67.2	1.78	6.11	0.91
2009	114	BRUAN	0	67.2	67.2	1.98	6.37	0.93
2009	212	BRUAN	0	67.2	67.2	1.97	4.74	0.91
2009	306	BRUAN	0	67.2	67.2	1.71	5.11	0.94
2009	418	BRUAN	0	67.2	67.2	1.83	6.14	0.91
2009	104	Br UAN+SU	0	67.2	67.2	1.97	6.80	0.94
2009	204	Br UAN+SU	0	67.2	67.2	2.01	5.32	0.88
2009	311	Br UAN+SU	0	67.2	67.2	1.84	6.41	0.91
2009	410	Br UAN+SU	0	67.2	67.2	1.89	5.99	0.93
2009	109	BR UAN+Nutra- Sphere	0	67.2	67.2	1.76	6.13	1.05
2009	214	BR UAN+Nutra-Sphere	0	67.2	67.2	2.01	5.54	0.87
2009	312	BR UAN+Nutra-Sphere	0	67.2	67.2	1.90	4.60	0.91
2009	406	BR UAN+Nutra-Sphere	0	67.2	67.2	1.81	4.97	0.96
2009	102	SB UAN	0	67.2	67.2	1.87	5.90	0.90
2009	210	SB UAN	0	67.2	67.2	1.98	5.52	0.89
2009	301	SB UAN	0	67.2	67.2	1.92	5.50	0.91
2009	408	SB UAN	0	67.2	67.2	1.88	4.54	0.92
2009	117	SBUAN+SU	0	67.2	67.2	1.90	5.79	1.00
2009	213	SBUAN+SU	0	67.2	67.2	2.14	5.68	0.97
2009	315	SBUAN+SU	0	67.2	67.2	1.95	4.71	0.94
2009	416	SBUAN+SU	0	67.2	67.2	1.66	4.87	0.89

Table B.5 Continued

Year	Plot	Product	Starter N hg ha^{-1}	N Rate kg ha^{-1}	Total N Rate	Flag Leaf N %	Grain yield Mg ha^{-1}	Grain N %
2009	112	SB UAN+Nutra-Sphere	0	67.2	67.2	2.00	6.52	1.01
2009	215	SB UAN+Nutra-Sphere	0	67.2	67.2	2.05	5.03	0.92
2009	313	SB UAN+Nutra-Sphere	0	67.2	67.2	1.80	5.38	0.88
2009	404	SB UAN+Nutra-Sphere	0	67.2	67.2	1.92	5.35	0.95
2009	101	Am. Nitrate	0	67.2	67.2	2.29	7.15	1.05
2009	208	Am. Nitrate	0	67.2	67.2	2.17	6.84	0.91
2009	318	Am. Nitrate	0	67.2	67.2	1.72	6.70	0.96
2009	405	Am. Nitrate	0	67.2	67.2	2.05	6.92	0.96
2009	116	33.6 Urea	0	33.6	33.6	1.81	5.87	0.92
2009	203	33.6 Urea	0	33.6	33.6	1.96	4.39	0.90
2009	316	33.6 Urea	0	33.6	33.6	1.86	4.62	0.87
2009	407	33.6 Urea	0	33.6	33.6	1.72	5.85	0.89
2009	118	100.8 Urea	0	100.8	100.8	2.04	7.18	0.91
2009	209	100.8 Urea	0	100.8	100.8	2.10	5.98	0.93
2009	310	100.8 Urea	0	100.8	100.8	1.98	7.14	0.94
2009	417	100.8 Urea	0	100.8	100.8	1.88	7.22	0.99
2009	103	134.4 Urea	0	134.4	134.4	2.05	6.82	1.01
2009	206	134.4 Urea	0	134.4	134.4	2.22	6.90	0.93
2009	309	134.4 Urea	0	134.4	134.4	1.88	6.47	0.95
2009	412	134.4 Urea	0	134.4	134.4	2.05	5.81	0.95

Table B.6 Components of Grain Sorghum Yield, Partridge 2009

Year	Plot	Product	Starter N hg ha^{-1}	N Rate kg ha^{-1}	Total N Rate	Flag Leaf N %	Grain yield Mg ha^{-1}	Grain N %
2009	106	Control	0	0	0	na	1.34	1.21
2009	210	Control	0	0	0	na	2.74	1.25
2009	309	Control	0	0	0	na	3.54	1.37
2009	401	Control	0	0	0	na	2.57	1.36
2009	103	Winter Urea	0	67.2	67.2	na	4.05	1.33
2009	206	Winter Urea	0	67.2	67.2	na	3.04	1.18
2009	301	Winter Urea	0	67.2	67.2	na	3.39	1.20
2009	406	Winter Urea	0	67.2	67.2	na	2.19	1.36
2009	105	Winter ESN	0	67.2	67.2	na	1.35	1.47
2009	213	Winter ESN	0	67.2	67.2	na	2.82	1.31
2009	312	Winter ESN	0	67.2	67.2	na	3.71	1.13
2009	414	Winter ESN	0	67.2	67.2	na	3.02	1.29
2009	111	Urea	0	67.2	67.2	na	1.86	1.17
2009	216	Urea	0	67.2	67.2	na	1.58	1.36
2009	314	Urea	0	67.2	67.2	na	3.21	1.31
2009	404	Urea	0	67.2	67.2	na	3.80	1.31
2009	108	Agrotain	0	67.2	67.2	na	3.13	1.32
2009	218	Agrotain	0	67.2	67.2	na	2.83	1.29
2009	310	Agrotain	0	67.2	67.2	na	3.33	1.35
2009	408	Agrotain	0	67.2	67.2	na	3.09	1.28
2009	115	SU	0	67.2	67.2	na	2.98	1.36
2009	211	SU	0	67.2	67.2	na	2.51	1.28
2009	307	SU	0	67.2	67.2	na	1.67	1.29
2009	405	SU	0	67.2	67.2	na	4.48	1.31
2009	101	ESN	0	67.2	67.2	na	3.15	1.43
2009	217	ESN	0	67.2	67.2	na	1.09	1.33

Table B.6 Continued

Year	Plot	Product	Starter N hg ha^{-1}	N Rate kg ha^{-1}	Total N Rate	Flag Leaf N %	Grain yield Mg ha^{-1}	Grain N %
2009	318	ESN	0	67.2	67.2	na	3.33	1.29
2009	413	ESN	0	67.2	67.2	na	3.79	1.27
2009	102	ESN/Urea	0	67.2	67.2	na	2.51	1.32
2009	203	ESN/Urea	0	67.2	67.2	na	2.81	1.21
2009	302	ESN/Urea	0	67.2	67.2	na	3.60	1.17
2009	411	ESN/Urea	0	67.2	67.2	na	1.54	1.28
2009	118	Br UAN	0	67.2	67.2	na	3.48	1.28
2009	204	Br UAN	0	67.2	67.2	na	3.70	1.19
2009	315	Br UAN	0	67.2	67.2	na	4.31	1.15
2009	407	Br UAN	0	67.2	67.2	na	2.36	1.33
2009	112	Br SU	0	67.2	67.2	na	2.63	1.25
2009	208	Br SU	0	67.2	67.2	na	3.79	1.31
2009	313	Br SU	0	67.2	67.2	na	3.27	1.24
2009	417	Br SU	0	67.2	67.2	na	4.42	1.35
2009	113	BR Nutra-sphere	0	67.2	67.2	na	3.32	1.32
2009	202	BR Nutra-sphere	0	67.2	67.2	na	3.64	1.19
2009	305	BR Nutra-sphere	0	67.2	67.2	na	2.90	1.28
2009	412	BR Nutra-sphere	0	67.2	67.2	na	4.09	1.45
2009	107	SB UAN	0	67.2	67.2	na	2.69	1.25
2009	205	SB UAN	0	67.2	67.2	na	2.00	1.31
2009	316	SB UAN	0	67.2	67.2	na	2.38	1.20
2009	418	SB UAN	0	67.2	67.2	na	2.96	1.28
2009	110	SB SU	0	67.2	67.2	na	2.00	1.44
2009	209	SB SU	0	67.2	67.2	na	3.13	1.38
2009	317	SB SU	0	67.2	67.2	na	2.04	1.32
2009	416	SB SU	0	67.2	67.2	na	3.72	1.26

Table B.6 Continued

Year	Plot	Product	Starter N hg ha^{-1}	N Rate kg ha^{-1}	Total N Rate	Flag Leaf N %	Grain yield Mg ha^{-1}	Grain N %
2009	109	SB Nutra-sphere	0	67.2	67.2	na	2.25	1.28
2009	212	SB Nutra-sphere	0	67.2	67.2	na	2.70	1.18
2009	308	SB Nutra-sphere	0	67.2	67.2	na	3.50	1.22
2009	409	SB Nutra-sphere	0	67.2	67.2	na	1.35	1.42
2009	117	CB UAN	0	67.2	67.2	na	2.90	1.33
2009	214	CB UAN	0	67.2	67.2	na	2.93	1.34
2009	304	CB UAN	0	67.2	67.2	na	2.76	1.29
2009	402	CB UAN	0	67.2	67.2	na	3.73	1.40
2009	114	33.6 Urea	0	33.6	33.6	na	2.45	1.37
2009	207	33.6 Urea	0	33.6	33.6	na	4.42	1.23
2009	303	33.6 Urea	0	33.6	33.6	na	3.02	1.24
2009	410	33.6 Urea	0	33.6	33.6	na	3.15	1.31
2009	104	100.8 Urea	0	100.8	100.8	na	3.45	1.26
2009	201	100.8 Urea	0	100.8	100.8	na	3.79	1.18
2009	306	100.8 Urea	0	100.8	100.8	na	2.51	1.29
2009	403	100.8 Urea	0	100.8	100.8	na	3.52	1.26
2009	116	134.4 Urea	0	134.4	134.4	na	2.32	1.33
2009	215	134.4 Urea	0	134.4	134.4	na	3.13	1.17
2009	311	134.4 Urea	0	134.4	134.4	na	3.82	1.18
2009	415	134.4 Urea	0	134.4	134.4	na	4.21	1.28

Table B.7 Components of Grain Sorghum Yield, Tribune 2009

Year	Plot	Product	Starter N hg ha^{-1}	N Rate kg ha^{-1}	Total N Rate	Flag Leaf N %	Grain yield Mg ha^{-1}	Grain N %
2009	104	Control	0	0	0	2.74	6.62	1.29
2009	212	Control	0	0	0	2.53	4.78	1.17
2009	306	Control	0	0	0	2.80	6.03	1.05
2009	416	Control	0	0	0	2.48	4.92	1.26
2009	106	Urea	0	67.2	67.2	2.93	6.96	1.49
2009	203	Urea	0	67.2	67.2	2.83	7.07	1.43
2009	307	Urea	0	67.2	67.2	2.76	7.24	1.37
2009	404	Urea	0	67.2	67.2	2.77	7.20	1.38
2009	116	Agrotain	0	67.2	67.2	2.67	7.76	1.47
2009	208	Agrotain	0	67.2	67.2	2.75	6.90	1.40
2009	305	Agrotain	0	67.2	67.2	2.92	7.63	1.44
2009	407	Agrotain	0	67.2	67.2	2.68	6.90	1.39
2009	110	SU	0	67.2	67.2	2.82	6.90	1.49
2009	206	SU	0	67.2	67.2	2.61	6.84	1.38
2009	314	SU	0	67.2	67.2	2.93	6.69	1.42
2009	401	SU	0	67.2	67.2	2.65	6.83	1.37
2009	101	ESN	0	67.2	67.2	2.81	6.53	1.48
2009	207	ESN	0	67.2	67.2	2.86	6.83	1.36
2009	315	ESN	0	67.2	67.2	2.79	6.69	1.37
2009	402	ESN	0	67.2	67.2	2.75	6.24	1.31
2009	105	ESN/UREA blend	0	67.2	67.2	2.78	7.53	1.44
2009	209	ESN/UREA blend	0	67.2	67.2	2.68	6.60	1.42
2009	311	ESN/UREA blend	0	67.2	67.2	2.96	7.10	1.37
2009	403	ESN/UREA blend	0	67.2	67.2	2.86	7.01	1.37
2009	115	Br UAN	0	67.2	67.2	2.97	7.80	1.40
2009	201	Br UAN	0	67.2	67.2	2.72	7.08	1.38

Table B.7 Continued

Year	Plot	Product	Starter N hg ha-1	N Rate kg ha-1	Total N Rate	Flag Leaf N %	Grain yield Mg ha-1	Grain N %
2009	316	Br UAN	0	67.2	67.2	2.95	6.66	1.47
2009	412	Br UAN	0	67.2	67.2	2.98	6.66	1.39
2009	112	Br UAN+ SU	0	67.2	67.2	2.87	7.25	1.42
2009	204	Br UAN+ SU	0	67.2	67.2	2.70	7.18	1.36
2009	312	Br UAN+ SU	0	67.2	67.2	2.99	6.73	1.39
2009	415	Br UAN+ SU	0	67.2	67.2	2.94	6.66	1.37
2009	107	Br UAN+Nutra-Sphere	0	67.2	67.2	3.07	6.81	1.53
2009	210	Br UAN+Nutra-Sphere	0	67.2	67.2	2.79	6.19	1.23
2009	302	Br UAN+Nutra-Sphere	0	67.2	67.2	2.82	7.32	1.37
2009	411	Br UAN+Nutra-Sphere	0	67.2	67.2	2.92	6.93	1.41
2009	109	SB UAN	0	67.2	67.2	2.80	7.06	1.46
2009	211	SB UAN	0	67.2	67.2	2.61	6.31	1.30
2009	301	SB UAN	0	67.2	67.2	2.81	6.94	1.35
2009	414	SB UAN	0	67.2	67.2	2.70	6.24	1.45
2009	113	SB UAN+SU	0	67.2	67.2	2.88	7.40	1.47
2009	214	SB UAN+SU	0	67.2	67.2	2.79	6.23	1.35
2009	304	SB UAN+SU	0	67.2	67.2	3.02	7.12	1.38
2009	405	SB UAN+SU	0	67.2	67.2	2.85	6.95	1.31
2009	111	SB UAN+N-Sphere	0	67.2	67.2	2.97	7.62	1.44
2009	205	SB UAN+N-Sphere	0	67.2	67.2	2.64	7.08	1.27
2009	310	SB UAN+N-Sphere	0	67.2	67.2	2.98	6.59	1.34
2009	410	SB UAN+N-Sphere	0	67.2	67.2	2.82	6.13	1.36
2009	114	Am. Nitrate	0	67.2	67.2	2.85	6.78	1.47
2009	213	Am. Nitrate	0	67.2	67.2	2.68	6.32	1.36
2009	303	Am. Nitrate	0	67.2	67.2	2.80	7.49	1.40
2009	408	Am. Nitrate	0	67.2	67.2	2.78	6.34	1.32

Table B.7 Continued

Year	Plot	Product	Starter N hg ha-1	N Rate kg ha-1	Total N Rate	Flag Leaf N %	Grain yield Mg ha-1	Grain N %
2009	103	33.6 Urea	0	33.6	33.6	2.81	7.08	1.46
2009	216	33.6 Urea	0	33.6	33.6	2.81	6.32	1.34
2009	308	33.6 Urea	0	33.6	33.6	2.82	6.80	1.33
2009	406	33.6 Urea	0	33.6	33.6	2.74	6.01	1.27
2009	102	100.8 Urea	0	100.8	100.8	2.88	7.12	1.45
2009	202	100.8 Urea	0	100.8	100.8	2.87	7.16	1.51
2009	313	100.8 Urea	0	100.8	100.8	2.94	7.13	1.54
2009	409	100.8 Urea	0	100.8	100.8	2.69	6.53	1.48
2009	108	134.4 Urea	0	134.4	134.4	2.96	7.14	1.58
2009	215	134.4 Urea	0	134.4	134.4	3.08	6.67	1.57
2009	309	134.4 Urea	0	134.4	134.4	3.19	7.19	1.50
2009	413	134.4 Urea	0	134.4	134.4	2.95	6.22	1.54

Appendix C - Green leaf ratings

Table C.1 Green leaf rating Manhattan 2008

Year	Plot	Product	Starter N kg ha^{-1}	N Rate kg ha^{-1}	Total N Rate kg ha^{-1}	Number of green leaves 5 plant average
2008	108	Control	22.4	0	22.4	1.8
2008	203	Control	22.4	0	22.4	1.6
2008	305	Control	22.4	0	22.4	1.6
2008	407	Control	22.4	0	22.4	2
2008	101	Urea	22.4	89.6	112	2.6
2008	206	Urea	22.4	89.6	112	3.4
2008	308	Urea	22.4	89.6	112	2.4
2008	406	Urea	22.4	89.6	112	2.4
2008	109	Agrotain	22.4	89.6	112	3
2008	205	Agrotain	22.4	89.6	112	2.6
2008	303	Agrotain	22.4	89.6	112	2.4
2008	412	Agrotain	22.4	89.6	112	3.2
2008	104	Super U	22.4	89.6	112	3.4
2008	212	Super U	22.4	89.6	112	3.2
2008	311	Super U	22.4	89.6	112	3.4
2008	411	Super U	22.4	89.6	112	3.8
2008	103	ESN	22.4	89.6	112	3.2
2008	202	ESN	22.4	89.6	112	2.8
2008	304	ESN	22.4	89.6	112	3
2008	410	ESN	22.4	89.6	112	3.4
2008	111	ESN/Urea blend	22.4	89.6	112	3.4
2008	201	ESN/Urea blend	22.4	89.6	112	2.8
2008	312	ESN/Urea blend	22.4	89.6	112	2.4
2008	402	ESN/Urea blend	22.4	89.6	112	3.2
2008	106	Br UAN	22.4	89.6	112	2.2
2008	208	Br UAN	22.4	89.6	112	2.4
2008	302	Br UAN	22.4	89.6	112	2.6

2008	409	Br UAN	22.4	89.6	112	1.6
2008	301	Br SU	22.4	89.6	112	2.6
2008	401	Br SU	22.4	89.6	112	2
2008	105	SB UAN	22.4	89.6	112	2.8
2008	211	SB UAN	22.4	89.6	112	2.8
2008	309	SB UAN	22.4	89.6	112	2.4
2008	404	SB UAN	22.4	89.6	112	2.4
2008	110	SB SU	22.4	89.6	112	3.2
2008	210	SB SU	22.4	89.6	112	4
2008	306	SB SU	22.4	89.6	112	3.2
2008	403	SB SU	22.4	89.6	112	3.4
2008	107	CB UAN	22.4	89.6	112	3.4
2008	207	CB UAN	22.4	89.6	112	4.2
2008	307	CB UAN	22.4	89.6	112	3
2008	408	CB UAN	22.4	89.6	112	2.2
2008	102	CB SU	22.4	89.6	112	3
2008	209	CB SU	22.4	89.6	112	2.8
2008	310	CB SU	22.4	89.6	112	3.2
2008	405	CB SU	22.4	89.6	112	3

Table C.2 Green leaf rating Manhattan, 2009

Year	Plot	Product	Starter N hg ha-1	N Rate kg ha-1	Total N Rate	Number of green leaves per plant
2009	106	Control	22.4	0	22.4	2.2
2009	210	Control	22.4	0	22.4	4
2009	309	Control	22.4	0	22.4	3.6
2009	401	Control	22.4	0	22.4	2.8
2009	103	Winter Urea	22.4	67.2	89.6	5.2
2009	206	Winter Urea	22.4	67.2	89.6	4.2
2009	301	Winter Urea	22.4	67.2	89.6	2.8
2009	406	Winter Urea	22.4	67.2	89.6	3.8
2009	105	Winter ESN	22.4	67.2	89.6	4
2009	213	Winter ESN	22.4	67.2	89.6	3
2009	312	Winter ESN	22.4	67.2	89.6	5
2009	414	Winter ESN	22.4	67.2	89.6	4.4
2009	111	Urea	22.4	67.2	89.6	4.2
2009	216	Urea	22.4	67.2	89.6	5
2009	314	Urea	22.4	67.2	89.6	5.4
2009	404	Urea	22.4	67.2	89.6	6
2009	108	Agrotain	22.4	67.2	89.6	5.4
2009	218	Agrotain	22.4	67.2	89.6	5.8
2009	310	Agrotain	22.4	67.2	89.6	6
2009	408	Agrotain	22.4	67.2	89.6	5.8
2009	115	Super U	22.4	67.2	89.6	5.2
2009	211	Super U	22.4	67.2	89.6	4.6
2009	307	Super U	22.4	67.2	89.6	4.4
2009	405	Super U	22.4	67.2	89.6	5
2009	101	ESN	22.4	67.2	89.6	5.6
2009	217	ESN	22.4	67.2	89.6	5.8

2009	318	ESN	22.4	67.2	89.6	5.6
2009	413	ESN	22.4	67.2	89.6	5.2
2009	102	ESN/Urea blend	22.4	67.2	89.6	5.4
2009	203	ESN/Urea blend	22.4	67.2	89.6	5.2
2009	302	ESN/Urea blend	22.4	67.2	89.6	4.8
2009	411	ESN/Urea blend	22.4	67.2	89.6	5.4
2009	118	Br UAN	22.4	67.2	89.6	4.6
2009	204	Br UAN	22.4	67.2	89.6	3.6
2009	315	Br UAN	22.4	67.2	89.6	4.4
2009	407	Br UAN	22.4	67.2	89.6	4.6
2009	112	Br SU	22.4	67.2	89.6	4.4
2009	208	Br SU	22.4	67.2	89.6	5.2
2009	313	Br SU	22.4	67.2	89.6	3.8
2009	417	Br SU	22.4	67.2	89.6	4.6
2009	113	BR Nutra-sphere	22.4	67.2	89.6	2
2009	202	BR Nutra-sphere	22.4	67.2	89.6	4
2009	305	BR Nutra-sphere	22.4	67.2	89.6	4.4
2009	412	BR Nutra-sphere	22.4	67.2	89.6	4.2
2009	107	SB UAN	22.4	67.2	89.6	3
2009	205	SB UAN	22.4	67.2	89.6	3.6
2009	316	SB UAN	22.4	67.2	89.6	5
2009	418	SB UAN	22.4	67.2	89.6	5.6
2009	110	SB SU	22.4	67.2	89.6	4.4
2009	209	SB SU	22.4	67.2	89.6	4.4
2009	317	SB SU	22.4	67.2	89.6	5.6
2009	416	SB SU	22.4	67.2	89.6	5.8

2009	109	SB Nutra-sphere	22.4	67.2	89.6	4.2
2009	212	SB Nutra-sphere	22.4	67.2	89.6	4.6
2009	308	SB Nutra-sphere	22.4	67.2	89.6	3.6
2009	409	SB Nutra-sphere	22.4	67.2	89.6	4.2
2009	117	CB UAN	22.4	67.2	89.6	5.4
2009	214	CB UAN	22.4	67.2	89.6	5.4
2009	304	CB UAN	22.4	67.2	89.6	5
2009	402	CB UAN	22.4	67.2	89.6	5.6
2009	114	100.8kg Urea	22.4	100.8	123.2	5
2009	207	100.8kg Urea	22.4	100.8	123.2	5.2
2009	303	100.8kg Urea	22.4	100.8	123.2	5.2
2009	410	100.8kg Urea	22.4	100.8	123.2	6.4
2009	104	134.4kg Urea	22.4	134.4	156.8	5.4
2009	201	134.4kg Urea	22.4	134.4	156.8	5.6
2009	306	134.4kg Urea	22.4	134.4	156.8	6.4
2009	403	134.4kg Urea	22.4	134.4	156.8	7
2009	116	168kg Urea	22.4	168	190.4	5.4
2009	215	168kg Urea	22.4	168	190.4	5.8
2009	311	168kg Urea	22.4	168	190.4	6.4
2009	415	168kg Urea	22.4	168	190.4	6.4

Table C.3 Green leaf ratings Ottawa, 2009

Year	Plot	Product	Starter N hg ha-1	N Rate kg ha-1	Total N Rate kg ha-1	Number of green leaves 5 plant average
2009	106	Control	22.4	0	22.4	3.2
2009	210	Control	22.4	0	22.4	4
2009	309	Control	22.4	0	22.4	3.4
2009	401	Control	22.4	0	22.4	2.8
2009	103	Winter Urea	22.4	67.2	89.6	4.6
2009	206	Winter Urea	22.4	67.2	89.6	4.6
2009	301	Winter Urea	22.4	67.2	89.6	4.4
2009	406	Winter Urea	22.4	67.2	89.6	3.4
2009	105	Winter ESN	22.4	67.2	89.6	5.4
2009	213	Winter ESN	22.4	67.2	89.6	4.8
2009	312	Winter ESN	22.4	67.2	89.6	4.6
2009	414	Winter ESN	22.4	67.2	89.6	6.2
2009	111	Urea	22.4	67.2	89.6	5.6
2009	216	Urea	22.4	67.2	89.6	5.2
2009	314	Urea	22.4	67.2	89.6	5.2
2009	404	Urea	22.4	67.2	89.6	5.2
2009	108	Agrotain	22.4	67.2	89.6	5.6
2009	218	Agrotain	22.4	67.2	89.6	5.2
2009	310	Agrotain	22.4	67.2	89.6	4
2009	408	Agrotain	22.4	67.2	89.6	5
2009	115	SU	22.4	67.2	89.6	6
2009	211	SU	22.4	67.2	89.6	5.2
2009	307	SU	22.4	67.2	89.6	5
2009	405	SU	22.4	67.2	89.6	5.4
2009	101	ESN	22.4	67.2	89.6	5.8

Year	Plot	Product	Starter N hg ha-1	N Rate kg ha-1	Total N Rate kg ha-1	Number of green leaves 5 plant average
2009	217	ESN	22.4	67.2	89.6	5.6
2009	318	ESN	22.4	67.2	89.6	6.6
2009	413	ESN	22.4	67.2	89.6	5.4
2009	102	ESN/Urea	22.4	67.2	89.6	5.2
2009	203	ESN/Urea	22.4	67.2	89.6	4.8
2009	302	ESN/Urea	22.4	67.2	89.6	5.8
2009	411	ESN/Urea	22.4	67.2	89.6	5.4
2009	118	Br UAN	22.4	67.2	89.6	3.2
2009	204	Br UAN	22.4	67.2	89.6	4.2
2009	315	Br UAN	22.4	67.2	89.6	3.8
2009	407	Br UAN	22.4	67.2	89.6	4
2009	112	Br SU	22.4	67.2	89.6	5.2
2009	208	Br SU	22.4	67.2	89.6	4.4
2009	313	Br SU	22.4	67.2	89.6	3.4
2009	417	Br SU	22.4	67.2	89.6	4.4
2009	113	BR Nutra-sphere	22.4	67.2	89.6	4.4
2009	202	BR Nutra-sphere	22.4	67.2	89.6	3.6
2009	305	BR Nutra-sphere	22.4	67.2	89.6	4.6
2009	412	BR Nutra-sphere	22.4	67.2	89.6	3.6
2009	107	SB UAN	22.4	67.2	89.6	3.4
2009	205	SB UAN	22.4	67.2	89.6	4.2
2009	316	SB UAN	22.4	67.2	89.6	4.6
2009	418	SB UAN	22.4	67.2	89.6	4.2
2009	110	SB SU	22.4	67.2	89.6	5
2009	209	SB SU	22.4	67.2	89.6	4.4
2009	317	SB SU	22.4	67.2	89.6	4
2009	416	SB SU	22.4	67.2	89.6	4.6

Year	Plot	Product	Starter N hg ha-1	N Rate kg ha-1	Total N Rate kg ha-1	Number of green leaves 5 plant average
2009	109	SB Nutra-sphere	22.4	67.2	89.6	5
2009	212	SB Nutra-sphere	22.4	67.2	89.6	4.4
2009	308	SB Nutra-sphere	22.4	67.2	89.6	4.4
2009	409	SB Nutra-sphere	22.4	67.2	89.6	3.4
2009	117	CB UAN	22.4	67.2	89.6	5.8
2009	214	CB UAN	22.4	67.2	89.6	6
2009	304	CB UAN	22.4	67.2	89.6	5.6
2009	402	CB UAN	22.4	67.2	89.6	5.8
2009	114	100.8kg Urea	22.4	100.8	123.2	6
2009	207	100.8kg Urea	22.4	100.8	123.2	5
2009	303	100.8kg Urea	22.4	100.8	123.2	5.4
2009	410	100.8kg Urea	22.4	100.8	123.2	4
2009	104	134.4kg Urea	22.4	134.4	156.8	6
2009	201	134.4kg Urea	22.4	134.4	156.8	5.8
2009	306	134.4kg Urea	22.4	134.4	156.8	6
2009	403	134.4kg Urea	22.4	134.4	156.8	5.4
2009	116	168kg Urea	22.4	168	190.4	6
2009	215	168kg Urea	22.4	168	190.4	6.2
2009	311	168kg Urea	22.4	168	190.4	6
2009	415	168kg Urea	22.4	168	190.4	6.6

Table C.4 Green leaf ratings Hutchinson, 2009

Year	Plot	Product	Starter N hg ha-1	N Rate kg ha-1	Total N Rate kg ha-1	Number of green leaves 5 plant average
2009	106	Control	22.4	0	22.4	3.2
2009	210	Control	22.4	0	22.4	2.4
2009	309	Control	22.4	0	22.4	3.4
2009	401	Control	22.4	0	22.4	3
2009	103	Winter Urea	22.4	67.2	89.6	2.8
2009	206	Winter Urea	22.4	67.2	89.6	4.2
2009	301	Winter Urea	22.4	67.2	89.6	2.8
2009	406	Winter Urea	22.4	67.2	89.6	3.2
2009	105	Winter ESN	22.4	67.2	89.6	2.8
2009	213	Winter ESN	22.4	67.2	89.6	3.4
2009	312	Winter ESN	22.4	67.2	89.6	4.8
2009	414	Winter ESN	22.4	67.2	89.6	4.2
2009	111	Urea	22.4	67.2	89.6	2.8
2009	216	Urea	22.4	67.2	89.6	4.6
2009	314	Urea	22.4	67.2	89.6	4
2009	404	Urea	22.4	67.2	89.6	3.8
2009	108	Agrotain	22.4	67.2	89.6	4.4
2009	218	Agrotain	22.4	67.2	89.6	5
2009	310	Agrotain	22.4	67.2	89.6	3.8
2009	408	Agrotain	22.4	67.2	89.6	4.2
2009	115	Super U	22.4	67.2	89.6	3.8
2009	211	Super U	22.4	67.2	89.6	3.4
2009	307	Super U	22.4	67.2	89.6	3.6
2009	405	Super U	22.4	67.2	89.6	2.8
2009	101	ESN	22.4	67.2	89.6	3
2009	217	ESN	22.4	67.2	89.6	4.6

Year	Plot	Product	Starter N hg ha-1	N Rate kg ha-1	Total N Rate kg ha-1	Number of green leaves 5 plant average
2009	318	ESN	22.4	67.2	89.6	5
2009	413	ESN	22.4	67.2	89.6	3.4
2009	102	ESN/Urea blend	22.4	67.2	89.6	3.2
2009	203	ESN/Urea blend	22.4	67.2	89.6	3.4
2009	302	ESN/Urea blend	22.4	67.2	89.6	3.8
2009	411	ESN/Urea blend	22.4	67.2	89.6	3.2
2009	118	Br UAN	22.4	67.2	89.6	4.6
2009	204	Br UAN	22.4	67.2	89.6	4.8
2009	315	Br UAN	22.4	67.2	89.6	4.4
2009	407	Br UAN	22.4	67.2	89.6	2.4
2009	112	Br SU	22.4	67.2	89.6	4.2
2009	208	Br SU	22.4	67.2	89.6	4
2009	313	Br SU	22.4	67.2	89.6	3.8
2009	417	Br SU	22.4	67.2	89.6	4.8
2009	113	BR Nutra-sphere	22.4	67.2	89.6	2.6
2009	202	BR Nutra-sphere	22.4	67.2	89.6	3.2
2009	305	BR Nutra-sphere	22.4	67.2	89.6	4.2
2009	412	BR Nutra-sphere	22.4	67.2	89.6	4.2
2009	107	SB UAN	22.4	67.2	89.6	3.2
2009	205	SB UAN	22.4	67.2	89.6	3.2
2009	316	SB UAN	22.4	67.2	89.6	4.4
2009	418	SB UAN	22.4	67.2	89.6	5
2009	110	SB SU	22.4	67.2	89.6	3.8
2009	209	SB SU	22.4	67.2	89.6	3.6
2009	317	SB SU	22.4	67.2	89.6	3.8
2009	416	SB SU	22.4	67.2	89.6	4.8

Year	Plot	Product	Starter N hg ha-1	N Rate kg ha-1	Total N Rate kg ha-1	Number of green leaves 5 plant average
2009	109	SB Nutra-sphere	22.4	67.2	89.6	2.8
2009	212	SB Nutra-sphere	22.4	67.2	89.6	4.6
2009	308	SB Nutra-sphere	22.4	67.2	89.6	3.8
2009	409	SB Nutra-sphere	22.4	67.2	89.6	2.6
2009	117	CB UAN	22.4	67.2	89.6	4.6
2009	214	CB UAN	22.4	67.2	89.6	5.2
2009	304	CB UAN	22.4	67.2	89.6	4.4
2009	402	CB UAN	22.4	67.2	89.6	4.4
2009	114	100.8kg Urea	22.4	100.8	123.2	4.8
2009	207	100.8kg Urea	22.4	100.8	123.2	4.2
2009	303	100.8kg Urea	22.4	100.8	123.2	4.8
2009	410	100.8kg Urea	22.4	100.8	123.2	4
2009	104	134.4kg Urea	22.4	134.4	156.8	4.6
2009	201	134.4kg Urea	22.4	134.4	156.8	4.6
2009	306	134.4kg Urea	22.4	134.4	156.8	3.8
2009	403	134.4kg Urea	22.4	134.4	156.8	3.8
2009	116	168kg Urea	22.4	168	190.4	4.8
2009	215	168kg Urea	22.4	168	190.4	5.2
2009	311	168kg Urea	22.4	168	190.4	4
2009	415	168kg Urea	22.4	168	190.4	4

Appendix D - SAS Example

The following SAS code is an example of proc GLM run on corn and grain sorghum trials and Pearson Correlation Coefficients run on corn trials.

```
DATA NFNPCYLD09;
INPUT PLOT BLOCK PROD$ YLD;
CARDS;

101   1     ESN   11599.22963
102   1     ESN/Urea    10904.87408
103   1     WinterUrea  9834.550085
104   1     120Urea     12379.06267
105   1     WinterESN   11563.31583
106   1     Control     7279.369379
107   1     SBUAN 8179.997358
108   1     Agrotain    10968.15393
109   1     SBNutrasphere     10081.83846
110   1     SBSU  9326.986052
111   1     Urea  9891.10438
112   1     BrSU  9393.181414
113   1     BRNutrasphere     6862.848817
114   1     90urea      11741.0295
115   1     SU    11356.71209
116   1     150Urea     13629.28697
117   1     CBUAN 10714.50444
118   1     BrUAN 10369.41391;


PROC GLM DATA=NFNPCYLD09;
CLASS BLOCK PROD;
MODEL YLD=PROD;
MEANS PROD/LSD ALPHA=.10;
RUN;
```

```
Data corn;
input plot block  gl eln;
cards;

101   1     5.6   2.40
102   1     5.4   2.33
103   1     5.2   2.47
104   1     5.4   2.57
105   1     4     2.47
106   1     2.2   2.24
107   1     3     2.33
108   1     5.4   2.56
109   1     4.2   2.39
110   1     4.4   2.52
111   1     4.2   2.52
112   1     4.4   2.54;

ods graphics on;
proc corr data= corn pearson;
var gl eln;
run;
```